Human health risks associated with contaminants in Southland waters

A review

Prepared for Environment Southland

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Prepared by:
Jennifer Gadd

For any information regarding this report please contact:

Jennifer Gadd
Aquatic Chemist
Urban Aquatic Environments
+64-9-375 2058
jennifer.gadd@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

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Executive summary

The National Policy Statement for Freshwater Management (NPS-FM, NZ Government 2017) directs regional councils to set objectives for freshwater bodies in their region and set limits on resource use to meet those objectives. Environment Southland will set objectives with the aim to 'maintain or improve' waterways for both ecological health and human health values. Human health is affected by pathogenic organisms and toxic contaminants: for the latter there is little information on potential human health risks. This report was commissioned by Environment Southland to assist in this limit-setting process with the following objectives:

- *To provide a high-level overview of the human health risk of toxic contaminants in waterways, estuaries and their potential sources in Southland that will be relevant in the objective setting process.*
- *To highlight key sources of toxic contaminants in Southland that should be considered in the objective setting process.*
- *To rank the risk of different toxic contaminant sources and activities.*
- *To identify key knowledge gaps with respect to toxic contaminants in Southland and human health risk.*

Methodology

This report was undertaken through desk-top review of information largely supplied by Environment Southland such as state of the environment monitoring data and reports, contaminated site investigation reports, and resource consent applications, monitoring data and reports. This information was used to identify key sources of contaminants to Southland waterways. The hazards associated with contaminants were collated from international toxicity databases.

Contaminant concentrations in three environmental media (groundwater, surface water and aquatic biota) were reviewed. The potential human health risks were assessed for three exposure routes: consumption of groundwater and surface water (as used for drinking water), and consumption of aquatic biota. Relative risks for each contaminant were assessed based on two factors:

1. comparing contaminant concentrations in water to drinking water standards (MoH 2018), and concentrations in aquatic biota to food standards (FSANZ 2017); and
2. the spatial extent of the concentrations above or approaching (>50%) these standards and the potential presence of individuals or groups of people that may be exposed to those contaminants.

Overview of human health risk of toxic contaminants

A wide variety of toxic contaminants were identified through the review as being potentially present in Southland waterways (groundwater, rivers, estuaries). These were inorganic contaminants, including nitrate; trace elements, including arsenic, cadmium, chromium, lead, nickel; pesticides, including triazine herbicides, phenoxy hormone pesticides, phosphonyls, and organophosphates; organochlorine pesticides (DDT, dieldrin, aldrin, endrin); hydrocarbons (BTEX and PAHs); and the vertebrate pest poisons 1080 and brodifacoum.

Health effects from toxic contaminants range from skin irritation and nausea, though to kidney or neurological damage, and cancer. Effects are specific to each contaminant and depend on concentrations people are exposed to, and the length of exposure (e.g., a one-off incident or lifetime exposure). Exposure may occur through use of the water for drinking, consumption of aquatic biota, or to a lesser extent, through recreational activities (via skin contact and accidental ingestion).

Key sources of toxic contaminants

There are multiple sources of potential toxic contaminants across the Southland region, including from agricultural, forestry, horticultural, industrial and municipal activities. Many of the identified contaminants are used or produced across multiple sectors, with few that are unique to single activities. In particular, pesticides are in widespread use across agricultural, forestry, horticultural and municipal activities. Pastoral farming is expected to be the largest source of pesticides as it covers nearly half of the land area in Southland. Legacy pesticides such as DDT and dieldrin were widely used in agriculture and horticulture and soils in these areas remain a possible source of these contaminants. Pastoral farming, and dairy farming in particular, is a key source of nitrate.

Many of the industries in Southland are associated with agricultural activities such as meatworks and dairy factories, which discharge organic matter including nitrogen. Timber processing plants are associated with discharges of copper, chromium and arsenic; the New Zealand Aluminium Smelter is associated with PAHs. Landfills throughout the region have potential to leach toxic contaminants, particularly older closed landfills. Stormwater discharges contribute copper and zinc and other metals used by specific industries. Vertebrate pest control operations use 1080 and at times, brodifacoum.

Ranking of toxic contaminant risks

Relative human health risks were assessed for 16 contaminants (or groups of contaminants) based on consumption of groundwater, surface water and aquatic biota (Table 1). The contaminant ranked with highest relative risk to human health in Southland is nitrate, due to its presence in groundwater (26% of wells tested) at concentrations at or approaching in the drinking water standards Maximum Acceptable Value (MAV) of 11.3 mg/L as nitrate-N. Groundwater is used as a drinking water source by nearly a third of the Southland population. Dieldrin/aldrin and BTEX in groundwater and arsenic in food (specifically cockles) have higher risk rankings than other contaminants, as they are also present at concentrations at or approaching drinking water standards or food standards in at least one location.

Lead and nickel were both ranked as having a medium human health risk compared to other contaminants, based on their presence in surface waters at or approaching drinking water standard MAVs. These rankings are conservative since they were based on total metal concentrations in untreated surface water. Cadmium and lead in aquatic biota were also ranked as medium risk based on concentrations measured in watercress from outside the Southland region. Data for watercress in Southland would provide more certainty around the risks posed by these contaminants.

Organochlorine pesticides and other legacy contaminants such as PCP were ranked with the lowest risk ranking, as were present-day pesticides and vertebrate poisons. For several contaminants there was insufficient information to assess risks – including nitrate, pesticides and BTEX in aquatic biota, and the pesticide glyphosate in surface waters.

Table 1: Summary of relative risks of contaminants through the consumption of groundwater, surface water and aquatic biota in the Southland region. Italicised entries are based on data from outside the Southland region.

Contaminant	Source [&] (L=localised, W=widespread)					Ingestion of groundwater	Ingestion of surface water	Consumption of aquatic biota
	A	F	H	I	M			
Arsenic	L	×	W	L	L	Lowest	Lowest	Higher
Cadmium	W	×	×	L	L	Lowest	Lowest	Medium
Lead	×	×	×	L	W	Lowest	Medium	Medium
Nickel	×	×	×	L	W	Lowest	Medium	Lowest
Nitrate	W	×	W	L	L	Highest	Lowest	Unknown
Dieldrin + aldrin	L	×	W	×	W	Higher	Lowest	Lowest
DDT	W	×	W	×	W	Lowest	Lowest	Lowest
Other POPs	×	L	×	L	L	Lowest	Lowest	Lowest
Organophosphates	W	W	W	×	L	Lowest	Lowest	Unknown
2,4-D & MCPA	W	W	W	×	W	Lowest	Lowest	Unknown
Triazine herbicides	W	W	W	×	W	Lowest	Lowest	Unknown
Glyphosate	W	W	W	×	W	*Lowest*	Unknown	Unknown
1080	W	×	×	×	×	Lowest	*Lowest*	Lowest
Brodifacoum	L	L	×	×	L	*Lowest*	*Lowest*	Lowest
BTEX	×	×	×	L	×	Higher	*Lowest*	Unknown
PAHs	×	×	×	L	×	Lowest	*Lowest*	*Lowest*

Notes: [&] A= agriculture, F = forestry, H = horticulture, I = industry, M = municipal.

Key knowledge gaps

There was limited information regarding the presence of toxic contaminants in groundwater and surface water, with the exception of nitrate. For groundwater there have been some studies that included metals in a large number of wells and pesticides in a small number of wells. In relation to surface waters, data were restricted to specific investigations or resource consent monitoring, with limited geographical coverage. There are few data on the presence of contaminants in aquatic biota, limited to only one study in the last 10 years, and no data relating to watercress or other aquatic plants. Analysis of contaminants in Southland watercress, and information on locations for gathering watercress, would provide more certainty regarding the potential human health risks from watercress consumption.

1 Introduction

1.1 Background

The National Policy Statement for Freshwater Management (NPS-FM, New Zealand Government (2017)) directs regional councils to set objectives for freshwater bodies in their region and set limits on resource use to meet those objectives. Environment Southland has included estuaries in the freshwater management units for the Southland region. Therefore, objectives will also be set for estuaries, with the aim to 'maintain or improve' both ecological health and the health of people and communities.

Human health is affected by pathogenic organisms and toxic contaminants. Toxic contaminants, such as heavy metals, pesticides and persistent organic pollutants, have been identified in sediment and biota within the New River Estuary, near Invercargill (Cavanagh & Ward 2014). Toxic contaminants have also been detected within soils, groundwater and streams throughout the Southland region (Cavanagh 2014, Close & Skinner 2012). Furthermore, there are many known sources of toxic contaminants in the region, such as closed landfills, pesticide dumps and other contaminated sites, as well as municipal and industrial discharges. However, there is little information on the potential human health risks of contaminants from these sources. This information is essential for the discussion around objective setting for Southland's waterways and estuaries.

1.2 Scope

The objectives of this report, as defined by Environment Southland in commissioning this report, are:

- To provide a high-level overview of the human health risk of toxic contaminants in waterways, estuaries and their potential sources in Southland that will be relevant in the objective setting process.
- To highlight key sources of toxic contaminants in Southland that should be considered in the objective setting process.
- To rank the risk of different toxic contaminant sources and activities.
- To identify key knowledge gaps with respect to toxic contaminants in Southland and human health risk.

The contaminants included in this review are inorganic contaminants including metals; organochlorine and other legacy pesticides; PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls) and other POPs; vertebrate pest poisons; and pesticides in current use. Emerging contaminants are not included in this review as they are the subject of an MBIE Endeavour research programme with a Southland focus (Cawthron 2019). Relevant information on the sources and risks of emerging contaminants may be found in Tremblay et al. (2011) and Stewart et al. (2016). Toxins – the toxic compounds produced by plants and algae such as microcystins produced during cyanobacteria blooms – are not included in this review. Microbial / pathogen risks are also outside the scope of this review.

This report is focussed on toxic contaminants associated with waterways – including both groundwater and surface water (lakes, streams, rivers, estuaries and coastal waters). It does not include contaminants associated with other environmental media, such as air or soil where uptake is through direct human ingestion or ingestion of plants grown in the soil. Toxic contaminants associated with soil are, however, considered where this is expected to lead to contamination of groundwater and/or surface waters. Exposure to toxic contaminants via air and soil could be considered in any future assessment of human health risks from contaminants in Southland to evaluate exposure routes of highest risk.

1.3 Sources of information

The information reviewed for this report was largely supplied by Environment Southland and includes state of the environment monitoring reports (groundwater and surface water), contaminated site investigation reports, and resource consent applications, monitoring data and reports. This information was supplemented by publicly available reports and journal articles related to the industries and activities operating in the Southland region.

1.4 Report outline

After this introductory section, Chapter 2 presents an overview of the risk assessment and the framework used in this report. Potential sources of toxic contaminants are reviewed and discussed in Chapter 3 drawing on information for the Southland region and including any data on toxic contaminant use or production. Chapter 4 describes the contaminants identified in the review, including the type of effects and any available standards or guidelines for contaminant intake to protect human health. Chapters 5 to 7 assess the risks associated with contaminants in groundwater, surface water and aquatic biota, respectively, based on major routes of exposure and contaminant concentrations either reported or expected to be present in each of those media. The gaps in knowledge as identified throughout this report are summarised in Chapter 8 and Chapter 9 provides an overall summary of the report.

2 Human health risk assessment

2.1 Risk assessment concepts

Human health risk assessment is "the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future" (US EPA 2019a). Risk assessments can be qualitative or quantitative (IPCS 2010). In relation to waterways, human health risk assessments can be used to answer questions like:

- What are the risks of drinking this water?
- Is it safe to eat these shellfish?
- How many shellfish is it safe to eat?

In the context of this report, risk is the probability of harmful effects to people exposed to a hazardous substance. Risk is a combination of:

- the inherent toxicity of the chemical (the *hazard*), and
- the level of exposure (the *likelihood*), which depends on how much of a chemical is present in an environmental medium (e.g., in the water), and how much contact a person has with that medium (e.g., how much water they drink) (IPCS 2010, US EPA 2019a).

2.2 Exposure media, pathways and routes

Exposure to contaminants occurs through a combination of different media (e.g., via air, soil or water) and different routes (e.g., ingestion or inhalation) (Table 2-1, (enHealth 2012, Environmental Protection Authority 2018b, US EPA 2019a)). This review considers only the media associated with water; and the exposure routes associated with these (shown in bold in Table 2-1, and in Figure 2-1). The media included are surface water, groundwater and food. The only food type included is aquatic biota; other food such as vegetables irrigated with contaminated groundwater or grown in contaminated soils are not included. The risks depend on the concentration of the contaminant in the relevant medium (e.g., in the surface water), the contact rate with that medium (e.g., amount of water consumed per event), the exposure frequency and duration (e.g., length of time and number of swims per year), and factors such as body weight and averaging times (e.g., averaged over a life-time).

Table 2-1: Exposure media and routes for contaminants. Only media and routes in bold are included in this review.

Media	Routes
Air	Inhalation
Surface water	**Ingestion (food and water, both dietary and non-dietary)**
Groundwater	Dermal (skin contact)
Soil	
Food	
Consumer products	

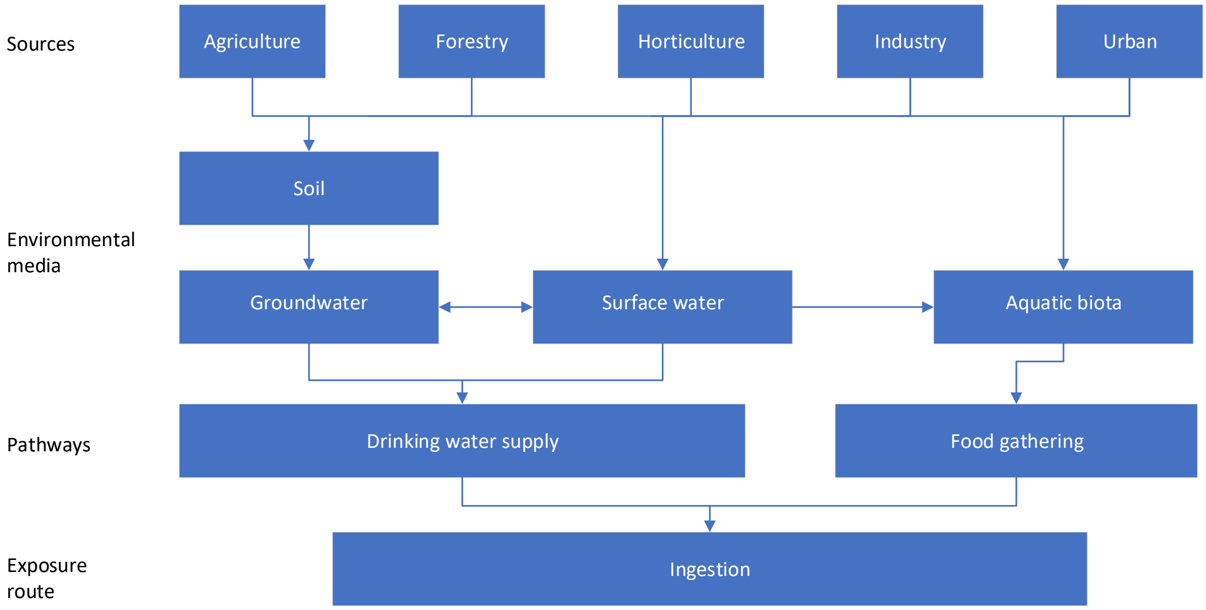

Figure 2-1: Conceptual model of exposure media, pathways and routes considered in this report. Adapted from enHealth (2012).

Ingestion is the primary route of exposure considered in this review. Ingestion occurs during multiple activities and for each of the three media included. Groundwater can be ingested where it is used as a potable water supply. Similarly, surface water can be ingested where it is used as a potable water supply and also ingested accidentally during contact recreation. In most cases, recreation is a route with lower risk compared to drinking water, as the amount of water ingested during recreation is significantly lower than total daily water intake, and the duration of exposure is lower (e.g., several days per year rather than every single day). Ingestion is the primary route of exposure for food collected from waterways and estuaries in Southland, such as watercress, shellfish and fish. This exposure route can be most important for contaminants that bioaccumulate – building up to higher concentrations in the biological organisms than in the surrounding water – such as organochlorine pesticides.

Inhalation is another potential route of exposure to contaminants in waterways, for example during recreational activities in waterways and estuaries; or inhalation of contaminants volatilised during showering. However, this exposure route is expected to have very low risk compared to ingestion, except for at specific locations, where contaminants are at much higher concentration. Such locations are expected to be subject to contaminated site investigations that include human health risk assessments of key exposure routes.

Dermal (skin) absorption of contaminants is also a potential route of exposure to contaminants in surface waters during recreation (such as swimming in rivers or estuaries), or in groundwater or surface water used as a water supply during showering/ bathing. However, risks associated with this exposure route are expected to be much lower due to the shorter duration of exposure.

2.3 Receptors for contaminants in waterways

When considering the risks of contaminants on human health, the receptors are any human individual or group that is or may be exposed to that contaminant (enHealth 2012, US EPA 2019a). For example, for risk associated with drinking groundwater at a contaminated location, the primary receptors are the people in the town or locality using that groundwater as their drinking water source. Populations upgradient of that location are not receptors and are not at risk. If there is no one using that groundwater as a drinking water source (e.g., groundwater adjacent to the coast), then there are no human receptors, and there is no risk to human health associated with the contaminated groundwater.

In addition to the general population, there may be individuals or sub-populations that may be at greater risk. This includes infants, toddlers, children, pregnant and nursing women, elderly people and those with chronic health issues (enHealth 2012). Health risks to infants, toddlers and children can differ from adults because of their lighter body weight; increased exposure (e.g., higher soil ingestion rate for toddlers than adults); and their different physiology and ability to metabolise contaminants (enHealth 2012). Furthermore, some contaminants have developmental effects that adversely affect a foetus or child but would not cause any (or only minor) adverse effects in an adult (e.g., children exposed to lead can suffer effects on brain development and learning (ATSDR 2019)).

There are also groups that may be at greater risk due to differences in behaviours and practices. Māori may have greater exposure than the general population to contaminants present in watercress, eels or other mahinga kai because of their higher dietary intake. For example, in a national nutrition survey (Russell et al. 1999), weekly watercress consumption was higher amongst Māori and Pacific Island respondents (14% and 13%, respectively, reported eating watercress at least once a week) than New Zealand European respondents (1%).

2.4 Risk assessment framework for this report

This report provides a qualitative assessment of the potential risks of exposure to different toxic contaminants in Southland. To rank potential risks from each contaminant, a system been developed broadly following the methodology for qualitative risk assessments set out by the NZ EPA (Environmental Protection Authority 2018b) based on two factors:

1) the magnitude of possible effects, in this case based on the concentration of contaminants in environmental media, compared to standards (the *hazard*); and

2) the *likelihood* for receptors to be exposed to those contaminants – based on the extent of the hazard and the presence of receptors.

The hazard is rated based on the comparison of the concentration of the contaminant in water to drinking water standards for New Zealand (Ministry of Health 2018) or the concentration of the contaminant in aquatic biota to food standards used in New Zealand (FSANZ 2017). Where a contaminant concentration exceeds the standard, the hazard is high. Where the contaminant concentration is above 50% of the standard, this is considered a moderate hazard and where the concentration is below the standard, the hazard is low. A threshold of 50% of the standard is considered suitable for a screening level assessment. This provides a degree of conservatism, and "early-warning" in some cases, and is consistent with the approach in drinking water standards (Ministry of Health 2018), where contaminants are to be monitored if within 50% of a maximum acceptable value (MAV).

The potential for receptors is considered in terms of both the location and the extent of contaminant presence: widespread presence throughout the region suggests a high likelihood for the source–media–receptors pathway being completed, and potential receptors probably exposed. Localised measurements suggest a lower likelihood for the source–media–receptors pathway being completed – and potential receptors only possibly exposed. In some locations, although contaminant concentrations may exceed drinking water standards, there are no receptors in that specific location (e.g., where concentrations are measured within a groundwater bore used purely for monitoring, and the water from the aquifer that bore draws from is not used for other purposes).

A matrix representing the level of risk can be constructed from these two factors: hazard and likelihood (Table 2-2). Four levels of risk are used in this ranking, from lowest (representing negligible risk) to highest (representing the highest hazard level and the highest likelihood of exposure). The risk rankings are relative rankings, rather than absolute ratings, and therefore the terminology is relative, rather than absolute (e.g., low, medium, high). This matrix is used to assign risk rankings in Chapters 5-7, for the three exposure pathways, namely consumption of groundwater, surface water and aquatic biota. Information gaps that could not be filled based on data and findings in other locations are noted in grey shading as “unknown”.

Table 2-2: Risk ranking based on contaminant concentrations and the number of possible receptors.

Concentration of contaminant in media, compared to drinking water standard or food standard *	Likelihood for people to be exposed		
	None	Possible	Probable
Conc. < 50% of standard	Lowest	Lowest	Lowest
Conc > 50% of standard, < 100% standard	Lowest	Medium	Higher
Conc. > standard	Lowest	Higher	Highest

* Drinking water standard, MAV = Maximum acceptable value; Food standard, ML = Maximum limit.

3 Sources of contaminants to Southland waterways and estuaries

3.1 Agriculture

Pastoral farming is the major agricultural activity in Southland and made up close to half of the total land area of the region in 2012 (LCDB V4.1, Figure 3-1). Dry stock farms (sheep, beef and deer) cover 700,000 ha and dairy farming 300,000 ha (Stats NZ 2018). Dairying has expanded considerably since the early 1990s, shown by dairy livestock numbers increasing from 38,000 in 1990 to a peak of 730,000 in 2017 (Stats NZ 2018). Land used for dairying has also increased, from 45,000 ha in 1994-95 (Moran et al. 2017) to 300,000 ha in 2017 (Stats NZ 2018).

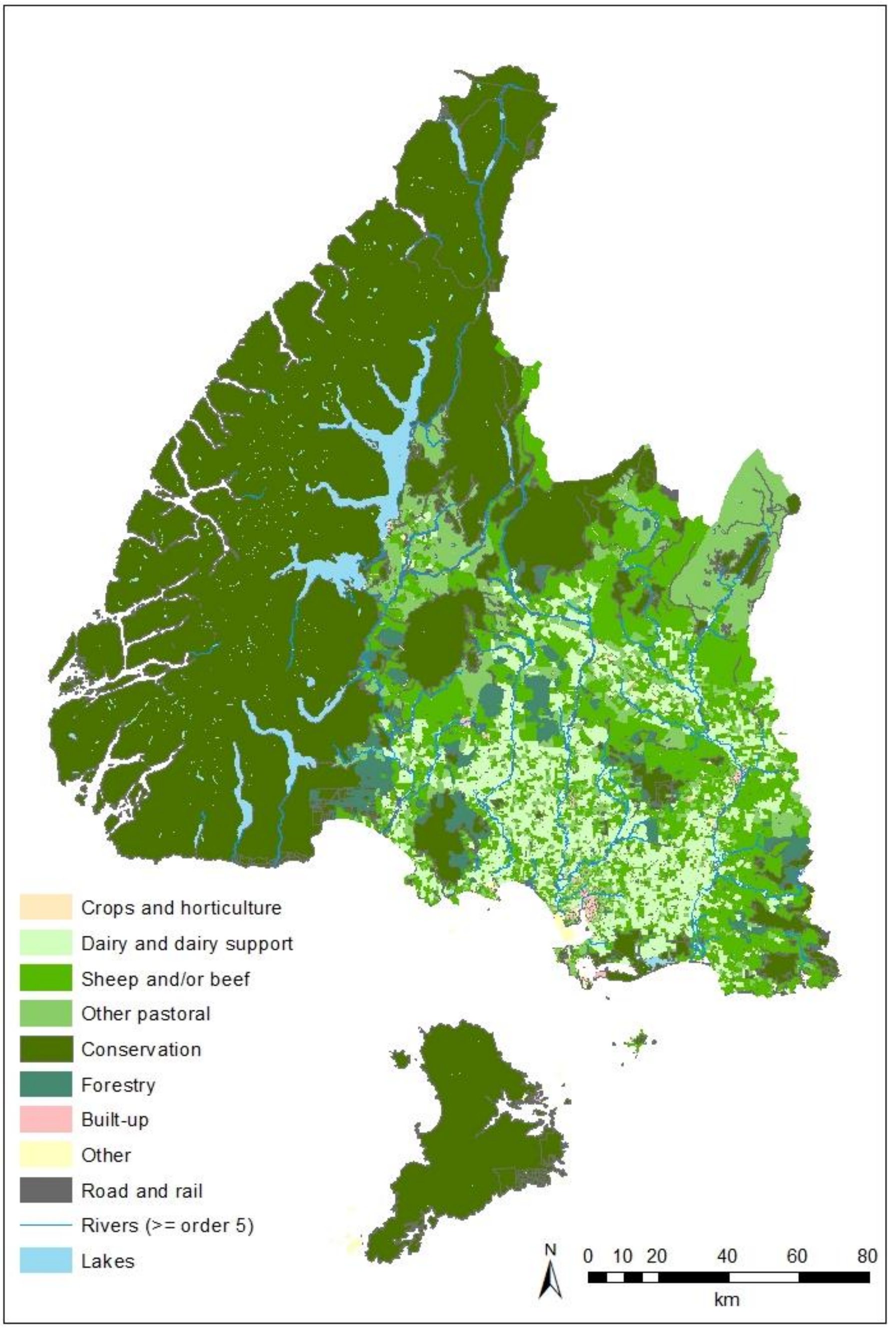

Figure 3-1: Land use in Southland region. Data supplied by Environment Southland, based on Pearson and Couldrey (2016).

Agriculture is a potential source of several contaminants, including products used intentionally, such as herbicides; or those either produced or released as a by-product of other products such as nitrate or cadmium.

Nitrate is used as a component of fertilisers applied to land to increase crop growth and is also derived from stock urine, particularly from dairy cattle. Nitrogen losses from dairy farms (predominantly in the form of nitrate) are higher than from other agricultural land uses. Risks of nitrogen loss to groundwater have been assessed by Environment Southland (Hughes et al. (2016), with the assessment finding large areas where there is moderate to high risk for groundwater contamination by nitrate (Figure 3-2).

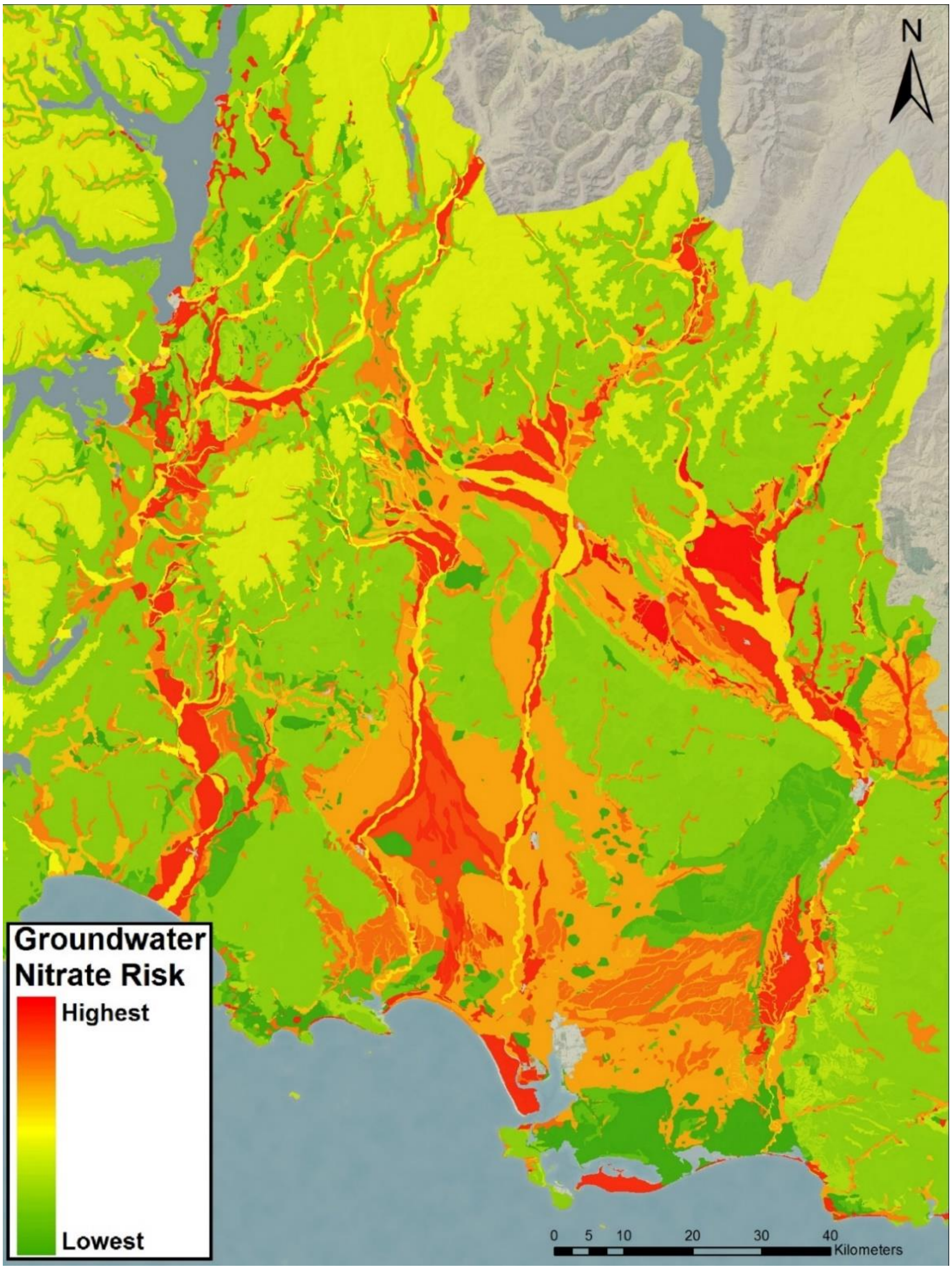

Figure 3-2: Assessment of groundwater nitrate contamination risk based on inherent landscape properties. Adapted from Hughes et al. (2016).

Cadmium can be present at high concentrations in phosphate fertilisers, particularly those sourced from Nauru rock phosphate (Cadmium Working Group 2011). Wide use of phosphate fertilisers around New Zealand has resulted in the accumulation of cadmium in the soil (Cadmium Working Group 2011). In a national survey of cadmium in soils, the median concentration in the 117 samples collected from Southland soils was 0.09 mg/kg and the maximum was 0.62 mg/kg (Cavanagh 2014, Taylor et al. 2007). These concentrations are much lower than in the Waikato, Taranaki and Bay of Plenty regions, where median concentrations were 0.74, 0.71 and 0.54 mg/kg, respectively (Cavanagh 2014).

Pesticides are used in agriculture, particularly herbicides for controlling weeds when establishing pasture. It is difficult to find information on the use of specific pesticides in agriculture in New Zealand, but there is information from 2004 that describes usage of pesticides by group. Pesticides used at the highest rates are in the groups phenoxy hormones, phosphonyls, and organophosphates, each at >20 tonnes of active ingredient per year (Manktelow et al. 2005). Information suggests that within each of these groups, the most frequently used pesticides are 2,4-D and MCPA (phenoxy hormones), glyphosate (phosphonyls), chlorpyrifos, diazinon and fenitrothion (organophosphates) (Chapman 2010, Manktelow et al. 2005). Insecticides are used primarily on dairy pastures with very little used in sheep, beef or deer farming (Manktelow et al. 2005).

Average application rates for pastoral farming are 0.17 kg/ha of total pesticides (Manktelow et al. 2005). Although this loading rate is not as high as other uses, pastoral farming covers a much larger area, leading to high total usage (Manktelow et al. 2005). Based on the national average application rate, the total loading over all pastoral land in the Southland region (1,000,000 ha) would be 170 tonnes. For the 2004 survey year, an estimate of 36% of total pesticides used in New Zealand was applied to pastoral land (Manktelow et al. 2005). There is no data specific to Southland available, however it is unlikely that pesticide use would be vastly different to the national picture as many of the plant and insect pests are located throughout New Zealand (Chapman 2010).

Historically, some of the pesticides used in agriculture included organochlorine pesticides (OCPs), which were then banned from use. For example, DDT was used extensively to control grass grub and porina caterpillars, often aerially sprayed mixed with fertiliser (Buckland et al. 1998a). Elevated concentrations of DDT and DDE remained in soils around New Zealand nearly 30 years after use was restricted in 1970 (DDT was completely banned from use in 1989 (Ministry for the Environment 1997)), though there is no available information on their presence in Southland pastoral soils. DDT and other OCPs are highly lipophilic (fat-loving), meaning that they do not tend to leach from soil but do accumulate in biota, especially grazing animals and this can pose a health risk for people consuming the meat or milk from those livestock. OCPs can be transported to surface waters along with soil, particularly when soil is exposed, such as due to stock disturbing the soil, or during earthworks. Although their use has been banned for over 30 years, there were still stockpiles of the insecticides on many Southland farms in 2008 (12.8 tonnes removed during a targeted programme in December 2007 (Environment Southland 2008)) and around New Zealand in 2018 (Fuller 2018). It is likely that sources of these compounds remain on farms, though it is difficult to predict whether there is any likelihood for OCPs from these stockpiles to enter waterways as this depends on where and how they are being stored, and whether such stockpiles are safely disposed of in the future (i.e., during pesticide collection programmes).

DDT, along with dieldrin, endrin, aldrin and lindane, were also used as sheep dipping chemicals. Use of these chemicals was restricted between the 1970s and 1980s, but due to their persistence, many may remain present in soils in the vicinity of historic sheep dip baths and troughs, and in some cases can contaminate groundwater and surface water. Arsenic was also used for sheep dipping from the 1840s up to 1980. There are approximately 30 livestock dip sites included in the Environment Southland Selected Land Use Register, but there are likely to be hundreds if not thousands more as sheep farming has been a major industry in the Southland region since 1850 (peaking in 1985 with 9 million sheep (Moran et al. 2017)).

3.2 Forestry

Plantation forestry covers the third largest area of Southland (Figure 3-3) after indigenous vegetation and exotic grasslands (Stats NZ 2018). Plantation forestry includes both commercial forestry (which makes up 75% of the area) and farm forestry – the growing of trees for additional income, shelter belts, riparian buffers or on retired pasture (which makes up 25% percent) (Moran et al. 2017). Commercial plantation forests include radiata pine, Douglas fir and eucalyptus species (Moran et al. 2017).

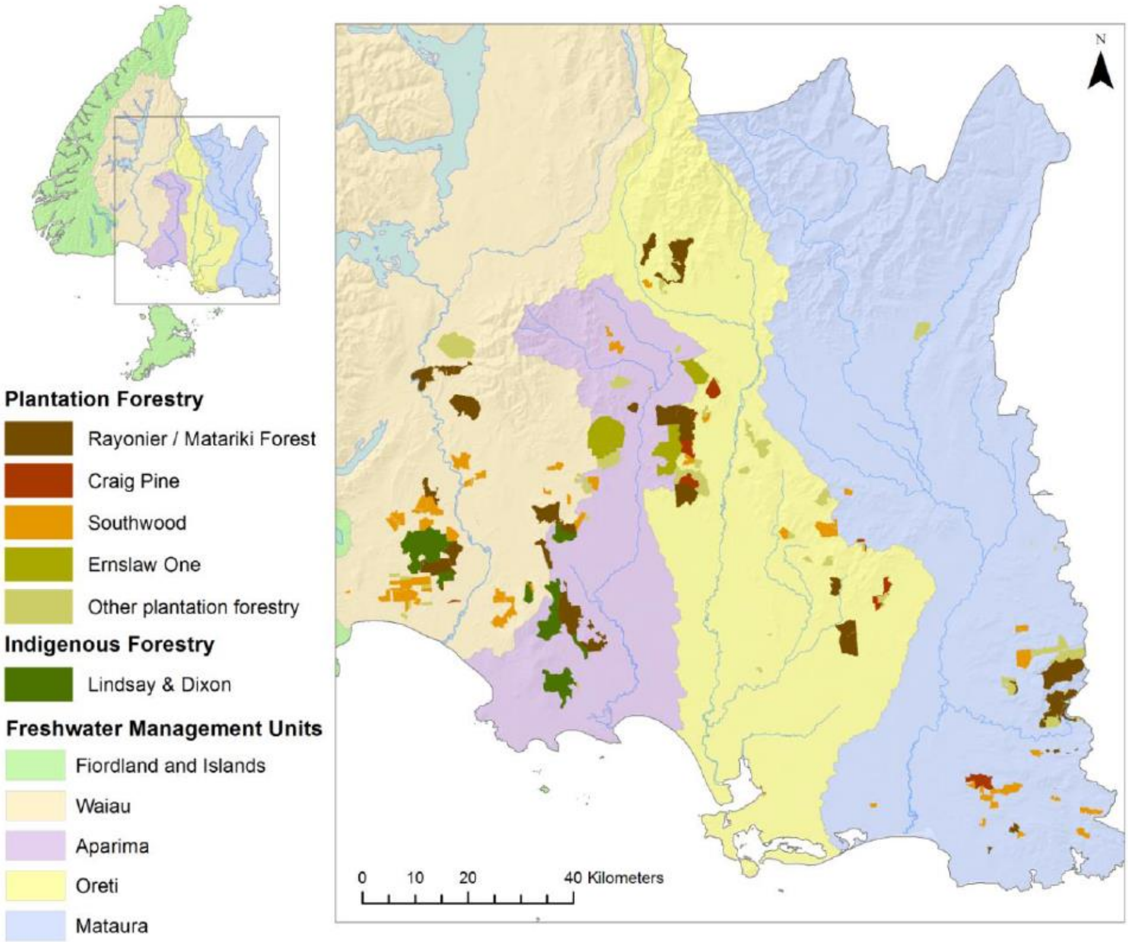

Figure 3-3: Southland forestry plantations. From Pearson and Couldrey (2016).

Toxic contaminants associated with forestry include pesticides used for weed and fungal control. Pesticides used in greatest quantity are the triazine herbicides, phosphonyls and inorganic fungicides and bacteriocides (Manktelow et al. 2005). Terbuthylazine, a triazine herbicide, is the herbicide used at highest quantity in forestry operations (8.0 kg/ha in the Southland region), applied aerially to control weeds after planting, along with hexazinone (2 kg/ha), another triazine herbicide (Rolando et al. 2013). Glyphosate (the active ingredient in Roundup®) is also frequently used, at applications of

3.3 kg/ha of active ingredient; along with metsulfuron (0.12 kg/ha active ingredient) prior to planting. Residues of terbuthylazine and hexazinone have been detected in stream water after herbicide application in plantation forests (Baillie 2016); concentrations were above drinking water standards on the day of treatment but declined within two days and remained below the standard thereafter (Baillie 2016).

Copper is used in large amounts to treat Dothistroma needle blight, as it is applied aerially to *Pinus radiata* plantations (Baillie et al. 2017). Copper is also used to treat fungal diseases affecting other tree species (Farm Forestry New Zealand 2019).

3.3 Horticulture

Compared to agriculture and forestry, a much smaller area of land (~ 52,000 ha in 2016 (Stats NZ 2018)) is used for horticultural purposes (including arable crops, Figure 3-1) in Southland. Important arable crops include barley, wheat and oats, much of which is grown for stock feed for dairy farming (Moran et al. 2017). Vegetable growing is relatively small (around 500-700 ha (Moran et al. 2017, Stats NZ 2018)) and consists primarily of root vegetables, including carrots, parsnips and potatoes (Moran et al. 2017). Southland is the only region of New Zealand with commercial tulip bulb and flower production; five companies grow bulbs for export (Moran et al. 2017).

The main contaminants associated with horticulture are pesticides and fertiliser (and associated contaminants). Nitrogen losses from horticultural crops are higher than for pastoral land use during the period of cropping (Moran et al. 2017). However, average annual losses are reduced as crops are harvested and rotated (Moran et al. 2017).

Nationally, pesticide usage is higher in the horticulture sector than in pastoral farming, arable cropping or forestry (Manktelow et al. 2005) at a loading of 13 kg active ingredient/ha/year (compared to 0.17 for pastoral farming and 0.27 for forestry). There is a much wider variety of pesticides used in horticulture compared to agriculture; and the type is related to the crops being grown (Manktelow et al. 2005). The main pesticide groups used for carrots and potatoes are dithiocarbamates, organophosphates and urea derivatives (Manktelow et al. 2005). There is no information on the pesticides used in tulip production. Overall, with the small area of horticultural land use in the region, the total amount of pesticides used in horticulture is expected to be much lower than in pastoral farming and forestry, at an estimate of 6,500 kg/year.

OCPs were also used in horticulture, particularly DDT and dieldrin. This has resulted in the presence of residues in soils that at times exceed guidelines for human health protection (Gaw et al. 2006).

3.4 Industries

The major industries in Southland are associated with the agricultural activities that dominate the region, including meat processing, milk processing, wood and timber processing, and fertiliser production. New Zealand's only aluminium smelter is also located in the region and there are several mines and quarries throughout the region. Each of these industries have different toxic contaminants potentially associated with them and many individual sites discharge their wastewater to waterways, particularly in the south and south-east of the region (Figure 3-4).

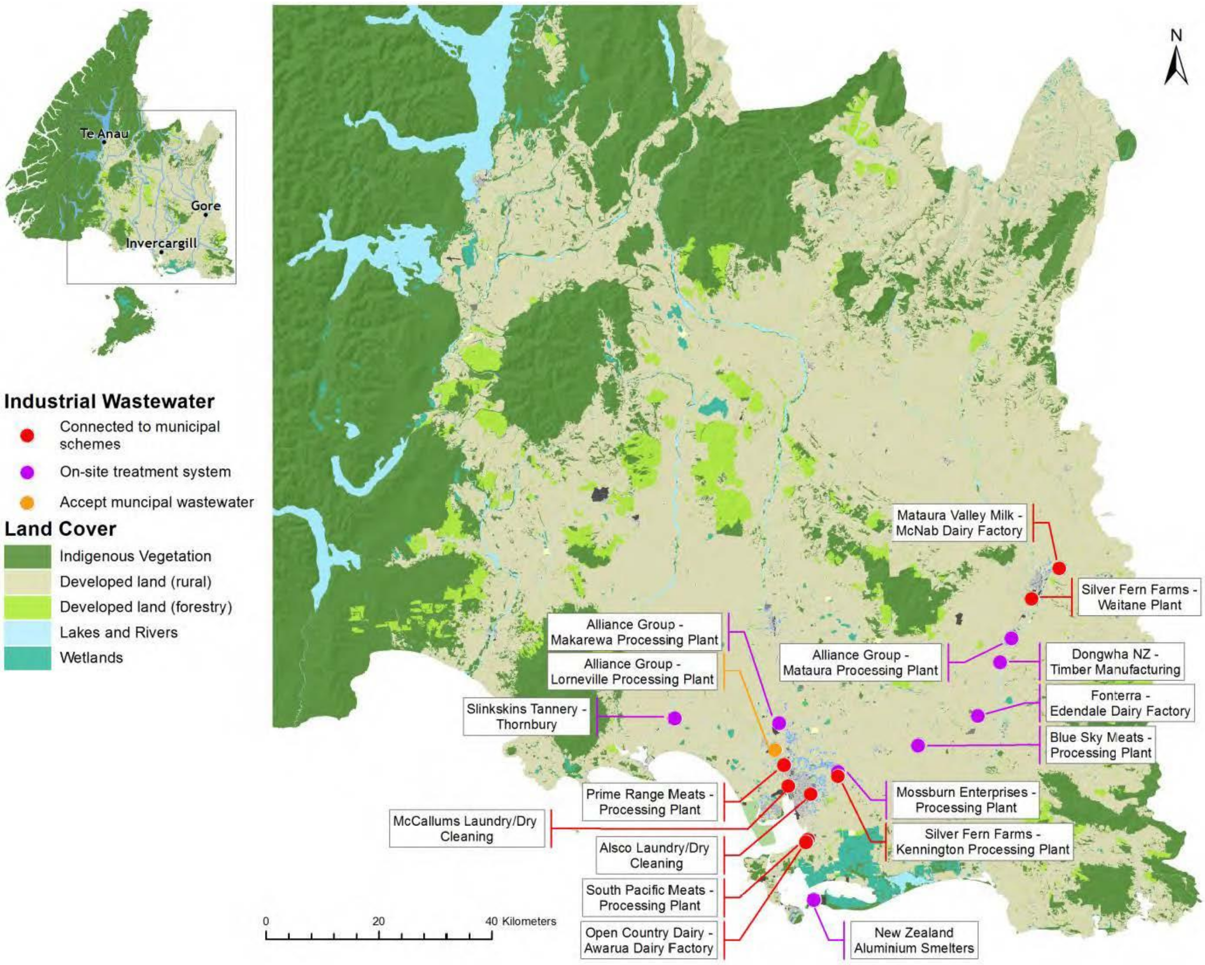

Figure 3-4: Location of key industrial wastewater discharges in Southland. From Moran et al. (2018).

The New Zealand Aluminium Smelter (NZAS) is the largest industrial plant in Southland and has consent to discharge contaminants to land, including circumstances where they may enter coastal waters. The primary contaminant associated with aluminium smelting is fluoride, which is produced and discharged to air at the smelter. The smelter also produces a waste product called dross, which contains aluminium oxide, magnesium, iron oxide, fluoride and ammonia and is traditionally disposed of via landfill. However, thousands of tonnes of this waste have been stockpiled around Southland in preparation for processing into fertiliser by a company which went into liquidation in 2016. Discharges from the site, including those of stormwater and cooling water, have historically been identified as a source of PAHs to the estuarine and coastal environment, including Bluff Harbour. Elevated PAH concentrations have been measured in sediments and shellfish, though the sources and concentrations in the environment have reduced over time (Depree 2001, New Zealand Aluminium Smelters Limited 2005).

Greenbriar Limited operate New Vale and Ohai Coal mines, two of the coal mines in the region. Both mines discharge wastewaters from the mines into surface waters but there is little information on the potential presence of toxic contaminants in those discharges (Greenbriar Limited 2018, Solid Energy Limited 2015).

Fonterra's Edendale site is one of the New Zealand's largest dairy processing plants, processing more than 15 million litres of milk per day (Moran et al. 2018). The site discharges wastewater onto land

and into the Mataura River. Open Country Dairy, the second largest dairy company in New Zealand, also operates a dairy processing plant in Southland, at Awarua, south of Invercargill and processes an average of 2.5 million litres of milk per year.

Alliance Group operate three meat processing plants in Southland at Lorneville, Makarewa and Mataura, each discharging treated wastewater into the adjacent river. Silver Fern Farms operates processing plants at Kennington and Waitane. There are also smaller processors including South Pacific Meats, Blue Sky Meats, Prime Range Meats and Mossburn Enterprises, each of which discharges wastewater to water, or to land where there is potential for leaching into groundwater and/or overland runoff to surface waters. The wastewaters from meat and milk processing comprise predominantly organic matter, are highly degradable and characterised by a high biochemical oxygen demand (BOD). The wastewaters can also contain high ammonia and other nitrogenous matter, and therefore contribute nitrate to surface water or groundwater (PDP 2015, PDP 2016). Trace element concentrations in the wastewaters are typically low (Freshwater Solutions Ltd 2015). In addition, wastewaters may contain chlorine and small amounts of chemicals such as biocides and detergents used in the processing and/or cleaning of process equipment, however these contaminants have rarely been tested in the wastewater.

The Slinkskins animal skin processing plant discharges to land via irrigation, wastewater that comprises factory washdown water containing chromium used in the tanning process. Chromium concentrations are monitored in the soil on the irrigated land and this monitoring suggests that the chromium is slowly accumulating and unlikely to be leaching into groundwater (Scandrett 2015).

There are five fertiliser related industries in Southland. One of these companies, Ballance Agri-Nutrients, manufacture phosphate fertiliser products at Awarua and have consent to discharge to both treated and untreated stormwater water from their site. The discharge, containing ammonia and fluoride, enters a tidal stream approximately 1 km from its outlet to the New River Estuary (Ballance Agrinutrients Limited 2006).

There are several wood and timber processing companies in operation in Southland, including Craigpine Timber, Niagara Sawmilling, Daiken Southland and Southwood Export. As well as milling wood, some of these companies treat the timber and process timber into medium-density fibreboard (MDF). Toxic contaminants are used in the timber treatment process, such as CCA (copper, chromium, arsenic, used to produce ‘tanalised’ timber), tributyltin (TBT), permethrin, and the triazole fungicides propiconazole and tebuconazole; and formaldehyde to produce MDF. Several of these companies have consents authorising discharges to water, including stormwater from the timber yards. Consent monitoring data for Craigpine Timber in Winton indicate that stormwater discharged into streams from this site contains copper, chromium and arsenic at concentrations above background (unpublished monitoring data, Environment Southland consents team).

Many timber treatment plants around New Zealand used pentachlorophenol (PCP), a persistent organic pollutant, as a timber preservative up to the 1980s. Dioxins and furans have also been associated with PCP contamination. There are around 60 timber treatment sites or yards in the Southland region and seven sites where PCP products are believed to have been formerly used (SPHERE 2008). Although dioxins have been measured in soils at such sites, Tonkin & Taylor and SPHERE reported that dioxin concentrations in surface water were likely to be very low (SPHERE 2008). Site investigation reports for some former timber sites in Southland show soil contamination with arsenic, cadmium, chromium, copper, lead and zinc (Davis Consulting Group Limited 2017) but there is no information that indicates PCP is present in soils of Southland timber sites.

The Invercargill Gasworks was in operation from 1876 to 1986 at Spey Street (Davis Consulting Group Limited 2013), close to the Waihopai River mouth. Wastes from the gas works were disposed of on this site, and at several other sites in the area, in the municipal landfill to the south of the site (see section 3.5.1), and used as a fill for the reclamation of the Waihopai Arm. Gasworks wastes such as slag, clinker, glass and building rubble associated with the gas works have been identified during site investigations (Davis Consulting Group Limited 2013, Davis Consulting Group Limited 2014, e3 Scientific 2018, Golder Associates 2011). Soil samples collected from test pits in the vicinity demonstrate contamination from PAHs (predominantly naphthalene and benzo[a]pyrene), metals, especially lead, nickel and zinc, cyanide, TPH and BTEX (Davis Consulting Group Limited 2013, Davis Consulting Group Limited 2014, e3 Scientific 2018, Golder Associates 2011). PAHs, benzene and cyanide have also been detected in the groundwater beneath the site and in locations to the west (Davis Consulting Group Limited 2013). These contaminants have the potential to migrate from the groundwater into the Waihopai River and New River Estuary and accumulate in sediments or biota.

There are many small industrial activities in operation with the urban areas of Southland, especially Invercargill, as the only city in the region. Many of the industries are associated with the agricultural sector, such as structural, sheet and fabricated metal product manufacturing; and machinery and equipment manufacturing, which both produce items used in the dairy industry (Moran et al. 2018, Nimmo-Bell 2013). Transport equipment manufacturing is also a key industry with boat building (and repair) the biggest subsector, primarily supporting the commercial fishing industry (Nimmo-Bell 2013).

A wide variety of toxic contaminants can be used or released in industrial activities. The most common of these are hydrocarbons, as found in oils and greases. These can be released to ground and to groundwater or surface waters through accidental spills, deliberate discharges, or leakage from storage tanks (either above ground or underground). Site investigations undertaken during removal of storage tanks (e.g., (PDP 2007)) have detected BTEX, TPH and/or PAHs within groundwater bores adjacent to or downgradient of storage tanks.

Many industrial activities use or release metals, including obvious sources such as metallurgical industries, engineering workshops and automotive dismantlers, which can release copper, lead, zinc and mercury into the stormwater system (Gadd et al. 2009, Gnecco et al. 2006, Hopley 2018). Plastic manufacturing and moulding can be a source of cadmium into stormwater networks (Gadd et al. 2009). Discharges into the stormwater network are likely to increase surface water concentrations of these metals.

3.5 Municipal activities

There are approximately 97,000 people living in Southland, over half of whom (54,000) live in Invercargill City (Stats NZ 2019). The remainder live in one of the six larger towns (Bluff, Gore, Matāura, Winton, Riverton/Aparima and Te Anau), or in one of >30 smaller towns and settlements (Moran et al. 2018). Many of these towns are located adjacent to waterways – both rivers and estuaries (Figure 3-5). The main municipal activities that can be sources of toxic contaminants include landfills; wastewater networks and their discharges; stormwater networks and discharges; construction and maintenance of transport networks; and maintenance of parks, gardens, playing fields and golf clubs.

Figure 3-5: Location of Southland towns and settlements in relation to rivers and coastal areas. From Moran et al. (2018).

3.5.1 Solid waste

There is only one operational landfill in Southland, the AB Lime owned and operated regional landfill in Winton. This landfill receives approximately 50,000 tonnes of waste under contracts with Invercargill City Council (ICC), Gore District Council (GDC) and Southland District Council (SDC). This Class A landfill has leachate collection systems, and the leachate is recirculated within the landfill with excess leachate transported to the Invercargill Wastewater Treatment Plant (WWTP) at Clifton. Typical landfill leachate contains a range of organic contaminants with potential to cause toxicity, such as PAHs, monoaromatic hydrocarbons, chlorinated aromatic compounds, plasticisers (bisphenol A and phthalates), phenols, aromatic acids and aromatic nitrogen compounds (Baun et al. 1999, Kjeldsen et al. 2002, Öman & Hynning 1993, PDP 2007). Monitoring of the leachate from the AB Lime landfill prior to disposal (AB Lime 2019) indicates relatively high concentrations of dissolved arsenic (0.2-1.2 mg/L), total phenols (< 0.2 – 8.2 mg/L) and volatile acids (<10 – 4100 mg/L). It is not clear from the analyses of the phenols or volatile acids (AB Lime 2019) whether there are compounds present that have potential to affect human health. Operation of this landfill began after the banning of persistent organic pollutants (POPs) such as PCBs (widely used in electrical equipment) and OCPs, therefore these contaminants are not expected to be present in the leachate.

There are also numerous closed landfills located throughout the Southland region, of varying age, fill and environmental risk. Southland District Council is responsible for 48 closed landfills, including monitoring of surface and groundwater to assess actual or potential contamination from leaching. One of the largest closed landfills in the region is the former West Invercargill landfill, adjacent to the Waihopai River and Waihopai arm of the New River Estuary. This landfill received municipal waste, building materials and dredging wastes, and is expected to have also received industrial wastes, sewage from night soil collection and the Invercargill sewage treatment plant, and construction and demolition wastes including that from the former gas works site (Davis Consulting Group Limited 2014, e3 Scientific 2018). Leachate from the landfill has elevated concentrations of arsenic, boron, copper, lead, nickel and zinc compared to groundwater and surface waters in the region (Table 3-1). Similarly, monitoring data for the closed landfill at Bluff shows total lead concentrations in the bore water beneath the landfill (measuring 0.037 mg/L) are above the MAV of 0.01 mg/L.

There have been many investigations of the former Invercargill landfill in the area delineated by the railway yards / Mersey Street, Tweed Street and the estuary, where the land has been used for a range of different industrial activities. These investigations have identified soil contaminated with arsenic, cadmium, chromium, copper, lead, nickel, zinc, TPH, PAHs, asbestos, cyanide (associated with the gasworks) and some OCPs; from both historic landfill and industrial activities (Davis Consulting Group Limited 2014, e3 Scientific 2017, e3 Scientific 2018, KPES Ltd 2015).

Table 3-1: Dissolved contaminants in leachate from the New River Estuary Landfill. Unpublished data from Environment Southland.

Site name	Arsenic	Copper	Lead	Nickel	Zinc
Walkway Leachate Site 1	0.015	0.0043	0.0017	0.03	0.029
Foreshore Leachate Site 1	<0.00530	<0.00270	0.0021	0.01	0.0084
Foreshore Leachate Site 2	<0.00530	<0.00270	0.0007	0.0077	0.0068
Foreshore Leachate Site 3	0.0038	0.0006	0.0003	0.0026	0.0077
Foreshore Leachate Site 4	0.005	<0.00300	<0.0005	0.008	0.017
Foreshore Leachate Site 5	0.0065	0.0027	0.0007	0.0064	0.0088

There are also a small number of sites in Southland where organochlorine pesticides were dumped in the 1960s (Woodward-Clyde 1993). The dumping included both surplus pesticides, in cardboard boxes, plastic containers, gallon tins and metal drums; and empty drums after pesticides were sprayed onto Department of Lands and Survey land (Woodward-Clyde 1993). Anecdotal information suggests that several truckloads of pesticides and/or empty containers were dumped at each of these locations (Woodward-Clyde 1993). OCPs (aldrin, dieldrin, endrin and endrin ketone) have been detected in soil samples surrounding the dump sites and at distances of up to 15 m in some cases (AECOM 2019a, AECOM 2019b, Woodward-Clyde 1993). OCPs (especially aldrin) have also been detected in the groundwater below these sites and at times, have exceeded drinking water guidelines (AECOM 2019a, AECOM 2019b, Woodward-Clyde 1993). Concentrations in the groundwater have varied over time but do not appear to be decreasing substantially (AECOM 2019a).

3.5.2 Discharges related wastewater, stormwater and drinking water

There are 24 (18 operated by SDC, 3 by GDC and 3 by ICC) reticulated wastewater networks and treatment plants throughout Southland (Moran et al. 2018). Many of the WWTPs discharge to surface waters, mainly rivers, due to their inland locations. The Invercargill, Bluff and Riverton/Aparima WWTPs discharge to estuaries and coastal waters (Moran et al. 2018). Treated wastewater from Te Anau is discharged to land (Moran et al. 2018). The treatment systems range from single oxidation ponds at Nightcaps, to the tertiary system of Edendale-Wyndham which includes UV disinfection prior to discharge into the Mataura River (Moran et al. 2018).

As well as domestic wastes, the municipal WWTPs receive trade waste, particularly the Invercargill, Bluff and Gore WWTPs. Trade wastes make up 15% of the input volume to the Invercargill WWTP, 25% to the Bluff WWTP and a considerable (but unquantified) proportion to the Gore WWTP (Moran et al. 2018). The Invercargill WWTP at Clifton also receives leachate from the regional landfill.

Monitoring at the Invercargill WWTP at Clifton includes measuring the potentially toxic metals lead, copper, nickel and zinc in the treated discharge. Average concentrations of these metals are shown in Table 3-2. In addition to metals, wastewater effluent and sewage sludge are known to contain a wide range of organic contaminants, including aliphatic and aromatic hydrocarbons, chlorobenzenes, phenols, surfactants and pesticides (Gadd et al. 2005, Hamilton City Council 1996, Ogilvie 1998, Paxéus 1996, Stubin et al. 1996). POPs such as PCBs, OCPs and dioxins have been measured in wastewater effluents or sludges (Hamilton City Council 1996, Ogilvie 1998, Paxéus 1996, Stubin et al. 1996) but are expected to be declining in concentration (Tremblay et al. 2014). Effluents also contain pharmaceuticals, personal care products, and steroids and related compounds (Gadd et al. 2005, Tremblay et al. 2014), which collectively are often referred to as emerging organic contaminants (EOCs) These compounds may enter surface water when treated effluent is discharged to waterways, and may enter groundwater where effluent or sewage sludge is applied to land.

Table 3-2: Contaminants in treated wastewater discharge from Invercargill City's Clifton WWTP. Unpublished consent monitoring data supplied to Environment Southland by ICC.

Contaminant	Mean concentration (mg/L)
Nitrate-N	3.8
Cadmium	< 0.001
Chromium	0.0042
Copper	0.025
Lead	0.0023
Nickel	0.0074
Zinc	0.031

Local authorities around the Southland region provide and maintain stormwater networks in the urban areas. Southland District Council provides infrastructure in 25 towns, most of which discharge into the stream or river network – although some discharge into the adjacent lakes (e.g., Te Anau) and a few (e.g., Edendale) use soakholes to discharge to land. Stormwater from Invercargill City discharges into the streams and directly to the New River Estuary. Some of the networks, including those in Invercargill City, have cross-connection issues, where raw wastewater enters the stormwater network. Inflow and infiltration can also be an issue.

Stormwater quality is monitored by Invercargill City Council at 18 locations prior to discharge into streams (MWH Stantec 2016). Southland District Council has also measured the quality of stormwater discharges from its networks. This information confirms that the stormwater in Southland is a source of nitrate, lead, nickel, copper and zinc to waterways (MWH Stantec 2016). Petroleum hydrocarbons are also a key contaminant in stormwater discharges, though these are less frequently monitored during to difficulties with sampling and analysis.

Drinking water treatment plants often use aluminium as a coagulant to flocculate sediments, and use chlorine as a disinfectant to reduce pathogens (Ministry of Health 2007). Water treatment plants intermittently purge their systems, resulting in a discharge of water that, if used in the treatment process, contains aluminium or chlorine. Discharges to water are permitted if volumes are less than 3 m^3/day and chlorine is < 2 mg/L. Many of the water treatment plants around Southland are thought to have such discharges, though there is little known about the nature of contaminants associated with them.

3.5.3 Roading, parks and other municipal services

In addition to providing a source of stormwater runoff, the construction and maintenance of roading and rail networks can be a source of toxic contaminants. Coal tar binders were widely used throughout New Zealand prior to the 1970s as primers and in chip-sealing (Depree & Fröbel 2009). Coal tar contains high concentrations of PAHs, including the carcinogenic PAH benzo[a]pyrene (Depree & Olsen 2005a). Although not used for 30-40 years in New Zealand, the layers remain, albeit covered by subsequent layers of bitumen chip seal or asphalt. Despite this capping layer, studies in Christchurch identified very high concentrations of PAHs in soils adjacent to roads and footpaths with coal tar layers (Depree 2006, Depree & Olsen 2005a, Depree & Olsen 2005b), and their use is also attributed to high concentrations of PAHs in both stream (Gadd 2015) and estuarine sediments (Depree & Ahrens 2007). As PAHs accumulate in biota, coal tar residues represent a source of PAHs to aquatic shellfish and fish.

Pesticides are commonly used to control weeds alongside roads, including traffic islands, median strips, shoulders and roadside drains. There is potential for these pesticides to enter waterways, via runoff to surface waters or leaching into groundwater. Pesticides are also used in municipal parks and gardens, and on sports fields to control plant weeds. Historically, large volumes of DDT were used in Queens Park, the botanic gardens of Invercargill (Leonie Grace, pers. comm. Environment Southland). DDT concentrations in soil samples collected from Queens Park, Otakaro Park, Elizabeth Park and Russell Square and combined prior to analysis, measured 0.24 mg/kg (sum of DDT isomers and 2 breakdown products) (Buckland et al. 1998a). This was higher than in soils from all other provincial centres in New Zealand, though similar to concentrations in soil samples collected from Christchurch parks (Buckland et al. 1998a).

Fertiliser use (e.g., in parks, sports fields and golf courses) is a further source of nitrate to surface and groundwater, however there is little available information on actual usage. In general, the area of parks in urban areas is small compared to other land uses where fertilisers are also used.

3.5.4 Pest control[1]

The Department of Conservation and Environment Southland use aerial drops of bait containing 1080 to control brushtail possums on conservation land around Southland. For the period 2014 to 2017, up to 113,000 ha of land in Southland was treated each year by aerial drops of 1080, predominantly conducted by the Department of Conservation (Environmental Protection Authority 2018a).

Brodifacoum is another pest poison used around New Zealand to reduce possum and rodent numbers. Because brodifacoum is known to accumulate in wildlife and be transferred up the food chain to non-target animals including birds and pigs (Eason et al. 2002, Eason & Spurr 1995, Fisher 2009), it is usually used in bait stations and not applied aerially. However, brodifacoum is used in

[1] Although the Department of Conservation is a central government agency, pest control is included within municipal activities for ease of reporting.

aerial drops for eradication purposes, such as on off-shore islands, including Ulva Island, within the Southland region.

3.6 Diffuse and unknown sources

PCBs and dioxins were measured in soils collected from parks in Invercargill City, in the Catlins and in both flat and rolling pasture soils during a national survey (Buckland et al. 1998a). Of these sites, PCBs were only detectable in the Invercargill City soils (sum PCBs 3.38 µg/kg); concentrations were higher than in soil samples from other provincial centres, but similar to those in soil samples from Auckland and Christchurch (measuring 0.70 to 7.7 µg/kg) (Buckland et al. 1998a). Dioxins/furans, another group of chlorinated compounds, were measured at all locations at concentrations similar to other sites sampled.

3.7 Summary

The review of activities in Southland has identified that the following contaminants may be present in waterways and estuaries in the region:

- Inorganic contaminants, including nitrate and cyanide;
- Trace elements, including arsenic, cadmium, copper, chromium, lead, nickel and zinc;
- Pesticides, including triazine herbicides (atrazine, hexazinone, simazine, terbuthylazine, trifluralin), phenoxy hormones (such as 2,4-D and MCPA), phosphonyls (glyphosate), and organophosphates (chlorpyrifos, diazinon and fenitrothion);
- Persistent organic pollutants (POPs), predominantly organochlorine pesticides (DDT, dieldrin, aldrin, endrin), with no clearly identified sources of PCBs or dioxins/furans;
- Hydrocarbons, including BTEX and PAHs; and
- Vertebrate poisons, including 1080 and brodifacoum.

These contaminants, their sources in Southland and the extent of their usage, are summarised in Table 3-3. The potential for each of these to cause adverse effects on human health is reviewed next in Chapter 4.

Table 3-3: Summary of sources of contaminants in the Southland region.

Contaminant	Source (L = localised, W = wide-spread, ✖ = not a source) Agriculture	Forestry	Horticulture	Industry	Municipal
Arsenic	L	✖	W	L	L
Cadmium	W	✖	✖	L	L
Lead	✖	✖	✖	L	W
Nickel	✖	✖	✖	L	W
Other metals	W	W	W	L	W
Nitrate	W	✖	W	L	L
Dieldrin + aldrin	L	✖	W	✖	W
DDT	W	✖	W	✖	W
Other POPs	✖	L	✖	L	L
Organophosphates	W	W	W	✖	L
2,4-D & MCPA	W	W	W	✖	W
Glyphosate	W	W	W	✖	W
Triazine herbicides	W	W	W	✖	W
BTEX	✖	✖	✖	L	✖
PAHs	✖	✖	✖	L	✖
1080	W	✖	✖	✖	✖
Brodifacoum	L	L	✖	✖	L

4 Hazards of contaminants of concern

As outlined in section 1.2, the contaminants included in this review are inorganic contaminants including metals, organochlorine pesticides, PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls) and other POPs, vertebrate pest poisons, and pesticides (herbicides for control of plant pests, fungicides for control of fungal pests and insecticides for control of insect pests). This chapter outlines the mobility of these contaminants, their persistence and ability to bioaccumulate, and the likelihood of their presence in groundwater, surface water (including estuaries) and aquatic biota. Their potential adverse effects are reviewed and where available, drinking water and food standards are collated.

4.1 Persistence, mobility, and bioaccumulation

In many cases, the risks from contaminants used in Southland depends on their potential to accumulate in soil and/or water, and to migrate from soil into waterways, or accumulate in biota. This depends on their persistence, mobility, and bioaccumulative potential. Data relating to these factors are collated in Table 4-1 and are used to assess their potential presence in waterways and aquatic biota.

Persistence relates to how long a contaminant lasts in the environment before being subject to biotic (mediated by bacteria) or abiotic degradation (through processes such as photolysis, hydrolysis, and oxidation/reduction reactions). Persistence is usually measured by the half-life in soil, water or sediment; those with a half-life of more than 60 days in water are usually considered to be persistent compounds (Boethling et al. 2009). For this assessment:

- contaminants with a half-life of months to years are considered to be highly persistent (shaded red in Table 4-1),
- those with a half-life of weeks to months are moderately persistent (shaded orange), and
- those with a half-life of days to weeks are not considered persistent (shaded green).

As metals are trace elements, they do not degrade and can be considered persistent.

Mobility of trace elements and inorganic or organic contaminants relates to their ability to move from one environmental media to another, usually from soil into groundwater or into surface water. This depends on properties of the contaminant such as polar/ionic characters, acid/base chemistry, oxidation state (for inorganic contaminants), all of which affect water solubility. Hydrogeological factors are also important, including soil type, rainfall, topography, redox state, hydraulic conductivity and depth to the water table (Close et al. 2008, USDA 2019); these factors result in some aquifers being more vulnerable to contamination than others. For this assessment soil-water partitioning coefficients have been used to assess mobility: the Kd for metals and Koc for organic compounds.

- Low Kd / Koc values (e.g., < 1000) indicate low binding to soil and high mobility (shaded red in Table 4-1), and
- High Kd / Koc values (e.g., > 10,000) indicate strong binding to soil and low mobility (shaded green in Table 4-1).

Contaminants will accumulate in the environment when they are produced and/or released at a rate faster than they degrade. Some of the identified contaminants are no longer authorised for use in New Zealand, including OCPs and PCBs (Ministry for the Environment 2006), however stocks may remain in storage, residues may remain in soil, and in the case of PCBs, they may still be present in old electrical equipment that is either in use or has been disposed of. Therefore, there remains potential for these contaminants to enter aquatic environments, and this can occur gradually or sporadically, such as when soil containing the residues is exposed, resulting in release into waterways.

The chemical properties of contaminants also determine whether they are likely to accumulate in biota. Contaminants that can be metabolised and excreted by plants and animals do not tend to bioaccumulate (Walker 2001); however many anthropogenic (man-made) chemicals cannot be easily metabolised. Lipophilic (fat-loving) contaminants are more likely to accumulate in biota as they are readily stored in fat and not metabolised. Accumulation from water is assessed by calculating a bioconcentration factor (BCF): the concentration in an aquatic organism exposed through water, divided by the concentration in the water. As indicated by coloured shading in Table 4-1:

- BCFs less than 1,000 indicate the contaminant is not significantly bioaccumulative,
- BCFs between 1,000 and 5,000 indicate bioaccumulative potential, and
- BCFs above 5,000 indicate the contaminant is highly bioaccumulative.

There are a few contaminants that are environmentally persistent (e.g., in sediments) but have low bioavailability and do not accumulate as predicted based on theory, such as PAHs (Depree & Ahrens 2007). Furthermore, although metals do not degrade, not all of them accumulate in biota as a large portion of the metal is not bioavailable and some biota have systems to detoxify and release or sequester metals that are taken up (i.e., self-regulation of internal metal burdens).

The potential for contaminants to be present in waterways is assessed based mainly on mobility, adjusted for their half-life. Contaminants that are highly mobile, but have a short half-life have moderate potential to be present in water (orange shading in Table 4-1) whereas those that are highly mobile with a long half-life have a high potential to be present in water (red shading in Table 4-1).

The potential for contaminants to be present in aquatic biota is assessed based mainly on bioconcentration factor, adjusted for half-life. Contaminants that have high bioconcentration factors but a shorter half-life have lower potential to be present in biota (orange-red shading in Table 4-1) than those with longer half-lives (red shading in Table 4-1). Contaminants with low or moderate bioconcentration factors have low to moderate potential to be present in aquatic biota (shaded green, yellow or orange).

Table 4-1: Persistence, mobility and likely fate of toxic contaminants in waterways. Data from ATSDR (2019), NIH (2019), Sturdevant (2011) and USDA (2019). Red shading indicates high persistence, mobility or bioaccumulative potential; orange shading indicates moderate persistence, mobility or bioaccumulative potential; green shading indicates low persistence, mobility or bioaccumulative potential. These values are used to provide the rating for likely contaminant presence in waterways and aquatic biota.

Contaminant	Half-life in water	Water solubility † (mg/L at 25°C)	Mobility (Kd (metals) or K_{OC} Organic carbon partitioning coefficient)	Bioconcentration factor (BCF, dimensionless)	Potential for presence in:	
					Waterways	Aquatic biota
Arsenic	NA *	NA ‡	2,500	4-350	Moderate	Low-moderate
Cadmium	NA *	NA	800	5-4190	Low	Moderate-high
Chromium	NA *	NA	10-8,000	<1-200	Low	Low-moderate
Lead	NA *	NA	15,000	<1-2500	Low	Moderate-high
Nickel	NA *	NA	1,300	< 20 – 40,000	Moderate	Moderate-high
Zinc	NA *	NA	1,300	500-100,000	Moderate	High
Nitrate	Days	NA	-2	<1	Moderate	Low
DDT	Years	0.003	110,000-350,000	600-84,500	Low	High
Dieldrin	Years	0.2	1,957-23,310	3,300-14,500	Low	High
Endrin	Years	0.2	11,420	4,860-14,500	Low	High
Atrazine	Months-years	33	26-1164	<0.27-96	Moderate	Low
Hexazinone	Weeks-months	30,000	10-54	1-7	Moderate-high	Low
Terbuthylazine	Months	5-9	151-514	25	Moderate-high	Low
Propazine	Months	5	84-500	17	Moderate-high	Low
Simazine	Weeks-months	4	78-3,559	<1-55	Moderate	Low
Chlorpyrifos	Weeks	1.2	995-31,000	100-5000	Low	Low-moderate

Contaminant	Half-life in water	Water solubility † (mg/L at 25°C)	Mobility (Kd (metals) or K_{OC} Organic carbon partitioning coefficient)	Bioconcentration factor (BCF, dimensionless)	Potential for presence in:	
					Waterways	Aquatic biota
Glyphosate	Days	1200	2600-4900	0.52	Low-Moderate	Low
2,4-D	Days-weeks	890	20-136	3	Moderate	Low
MCPA	Weeks	825	50-62	1	Moderate	Low
Metsulfuron	Weeks-months	2790	4-345	1-17	Moderate-high	Low
PCP	Weeks-months	5-14	1000 – 100,000	2 – 45,000	Low	Moderate-high
PCBs	Months – years	0.01 – 0.25	> 5000	1000 – >100,000	Low	High
Dioxins	Years	0.0002	>100,000	6000 – >100,000	Low	High
Benzo[a]pyrene	Months-years	0.0038	3,700 – >100,000	200-55,000	Low	High
Phenanthrene	Days-years	600	9,200-25,000	700-2,630	Low	Moderate-High
BTEX	Weeks	1790	85	1.1-20	Moderate	Low
Brodifacoum	Weeks-months	0.24	14,000	570	Low	Low
1080	Days	1110	High	<5#	Low-moderate	Low

Notes: † The amount of substance that can dissolve in water at a specific temperature. ‡ Not provided for metals as this depends on the form (i.e., some salts are highly soluble, some are insoluble and elemental forms have low solubility). * Elements do not degrade. # Estimated BCF (US EPA 2012); supported by laboratory studies (Champeau et al. 2014, Suren & Bonnett 2006).

4.2 Toxicity of identified contaminants

Toxicity is the capacity to cause adverse effects on health (human health in this context), may be acute or chronic and may include carcinogenicity or genotoxicity. Acute toxicity is that which occurs after a short period of exposure, for example hours or days. The health effects may be sub-lethal (e.g., dermatitis) or lethal. Chronic exposure occurs over the long-term, covering a significant portion of the life span (i.e., years of exposure). Health effects from chronic exposure may also be sub-lethal, such as cognitive impairment, or lethal. Health effects can also be immediate or delayed, for example in the case of lung cancer caused by occupational exposure to asbestos decades prior to diagnosis. There can be critical windows of exposure, for example, exposure to certain chemicals during pregnancy can affect development of the foetus (e.g., exposure to PCBs in the womb can affect motor skills and short-term memory in later life (ATSDR 2019, Buckland et al. 1998b)).

Carcinogenicity refers to the ability to cause cancer. The International Agency for Research on Cancer (IARC) classifies substances into four classes (Table 4-2) according to their carcinogenicity, based on laboratory tests and epidemiological studies. The US EPA also classify substances according to likelihood to cause cancer into five categories that are similar but not necessarily equivalent to the IARC categories. The latest guidelines (US EPA 2005) express the cancer categories separately by oral and inhalation routes.

Table 4-2: Carcinogenic classifications.

	IARC classification	US EPA classification
Group 1	Carcinogenic to humans	Carcinogenic to humans
Group 2A	Probably carcinogenic to humans	Likely to be carcinogenic to humans
Group 2B	Possibly carcinogenic to humans	Suggestive evidence of carcinogenic potential
Group 3	Not classifiable as to its carcinogenicity to humans	Inadequate information to assess carcinogenic potential
		Not likely to be carcinogenic to humans

The potential health effects from exposure to various contaminants that may be present in Southland waterways are summarised in Tables 4-3 to 4-5.

Table 4-3: Human health effects of inorganic contaminants potentially present in Southland waterways. Unless referenced otherwise, all information about potential human health effects is sourced from ATSDR (2019), and information on carcinogenicity is from IARC (2019) and US EPA (NIH 2019).

Contaminant	Potential human health effects
Arsenic	Arsenic is acutely toxic through ingestion causing multi-system organ failure. Chronic oral exposure causes skin discolouration and corns or warts (ATSDR 2019). Arsenic is classed as a known carcinogen by IARC and NIH (2019), causing skin, liver, bladder and lung cancers.
Cadmium	Cadmium is chronically toxic through ingestion causing kidney damage and bone demineralisation (ATSDR 2019). Cadmium is classed as a human carcinogen by IARC (2019) and is classified as a probable carcinogen by US EPA when inhaled.
Chromium	Chromium is chronically toxic when ingested with effects on the gastrointestinal system, blood and reproductive system. Chromium VI ingestion causes ulcers, and irritation of the stomach and small intestine. Chromium III exposure can cause allergic dermatitis. Chromium VI, when inhaled, is classed as a human carcinogen by both IARC and US EPA, but there is inadequate evidence for oral carcinogenicity.
Copper	Copper is an essential nutrient at low concentrations and adverse health effects can occur from copper deficiency. At high concentrations copper can cause gastrointestinal effects and liver failure.
Lead	High levels of exposure can cause brain and kidney damage. Chronic exposure to lead affects the nervous system and results in cognitive effects such as reduced attention, memory and learning. Lead is considered a probable carcinogen by IARC and US EPA(NIH 2019).
Nickel	Nickel is acutely toxic through dermal contact and ingestion. Exposure can cause skin rash and sensitization to future exposure. Nickel compounds are considered human carcinogens and metallic nickel is considered possibly a human carcinogen by IARC.
Zinc	Zinc is an essential nutrient at low concentrations and adverse health effects can occur from deficiency. Zinc is acutely toxic to people through ingestion causing gastrointestinal irritation such as cramps, nausea and vomiting. Chronic oral exposure causes effects on blood with reduction in red blood cells and copper deficiency symptoms due to interference with copper absorption from food. Zinc is not classified for carcinogenicity.
Nitrate	Nitrate is acutely toxic through ingestion and conversion to nitrite. The main acute effect is methaemoglobinaemia (oxygen deprivation) which can be fatal, although effects are reversible (IPCS 2010). Chronic exposure is associated with formation of carcinogenic nitroso compounds in the gastrointestinal tract. Chronic exposure through drinking water containing > 0.88 mg/L (as nitrate-N) has recently been linked to colorectal cancers (Schullehner et al. 2018). This concentration is much lower than the guideline level of 11.3 mg/L (as nitrate-N) used to prevent methaemoglobinaemia (WHO 2017).
Cyanide	Cyanide is fatal at high concentrations through inhalation, oral, or dermal exposures due to severe depression of the central nervous system. Low-level exposures have been linked to altered thyroid hormone levels, nerve damage, headache, dizziness, weakness, irritability, weight loss, decreased appetite, and gastrointestinal complaints. Not assessed for carcinogenic risks by IARC or US EPA.

Table 4-4: Human health effects of POPs potentially present in Southland waterways.

POPs	Potential human health effects
DDT	DDT is acutely toxic causing tremors and seizures. Chronic exposure causes central nervous system, developmental, and reproductive effects such as an increased risk of having a premature baby. DDT is classified as a possible human carcinogen (Class 2B) by IARC and a probable human carcinogen (Class B2) by the US EPA.
Dieldrin	Acute dieldrin exposure affects the central nervous system and can cause dizziness and seizures. Chronic exposure can cause liver damage and consequent immune suppression. Dieldrin is classed as a probable carcinogen by IARC (Group 2A) and by the US EPA (Class B2).
Endrin	Acute exposures cause convulsions and can be fatal. Lower concentrations can cause headache, dizziness, nausea, vomiting and sometimes confusion. There are no known long-term health effects. Some studies in animals suggest endrin may damage genetic material. Not classifiable as a carcinogen by IARC or the USEPA.
Lindane	Chronic exposure by inhalation is associated with effects on the liver, blood, and nervous, cardiovascular and immune systems. Oral exposure can affect blood, immune and nervous systems. Animal studies indicate that lindane causes reproductive effects. Oral animal studies have shown lindane to be a liver carcinogen. IARC has classified lindane as carcinogenic to humans (Group 1) and US EPA has classified lindane as a Group B2/C, possible human carcinogen.
PCP	Toxicity from chronic PCP exposure targets the skin, mucous membranes, kidney and liver. Some effects include irritation, neurasthenia, chloracne, headaches and porphyria (ATSDR 2019, MoH/ MfE 1997). PCP is classed as possibly carcinogenic by IARC and a probable human carcinogen by US EPA.
PCBs	Acute toxicity is relatively low, however chronic exposure to PCBs causes acne-like skin problems and liver damage. Also affected are the immune and nervous systems. Babies of exposed women had abnormal motor and short-term memory skills. PCBs are classed as probable human carcinogens by both IARC and US EPA.
PAHs, including Benzo[a]pyrene	PAHs can cause dermatitis and respiratory diseases, affect immune systems, decrease fertility and affect foetal development. Several PAHs, including benzo[a]pyrene, are classed as probable human carcinogens, resulting in lung and skin cancers exposed via inhalation.
BTEX	Acute toluene exposure can affect the nervous system causing fatigue, loss of memory, confusion, weakness, nausea and loss of appetite. Acute benzene toxicity affects the blood, nervous system and immune system. Exposure to high levels of ethylbenzene can irritate the eyes and throat and cause dizziness. Xylene toxicity targets the nervous system and can affect kidneys and liver. Benzene is a known human carcinogen and is associated with leukemia.

Table 4-5: Human health effects of pesticides potentially present in Southland waterways.

Pesticide	Potential human health effects
Atrazine	Exposure can cause irritation of eyes and skin, dermatitis, skin sensitisation, dyspnea, weakness, incoordination, salivation, hypothermia, and liver injury. There was a positive association between atrazine exposure in drinking water and premature birth. IARC list atrazine as not classifiable based on carcinogenicity, while the US EPA classify atrazine as “Not Likely to be carcinogenic”.
Hexazinone	Hexaninone has low acute toxicity, but may irritate eyes and affect the liver at high concentrations. There are no other notable effects in animal studies. IARC and USEPA list hexazinone carcinogenicity as ”Not classifiable”.
Terbuthylazine	There is little information regarding the human health effects of terbuthylazine and no evidence of carcinogenicity. Information on toxicity is available from studies with rats: in long-term dietary studies, effects are evident on red blood cell parameters in females, an increased incidence of non-neoplastic lesions in the liver, lung, thyroid and testis and a slight decrease in body weight gain were observed.
Propazine	Low acute toxicity. Neuroendocrine effects observed in animal studies. IARC list propazine carcinogenicity as “Not classifiable”.
Simazine	No acute health effects other than dermatitis and irritation to eyes and respiratory passages. There are no clear chronic health effects from simazine. IARC list simazine carcinogenicity as ”Not classifiable” while US EPA classify propazine as “Not Likely to be carcinogenic”.
Chlorpyrifos	At very high concentrations, chlorpyrifos inhibits the cholinesterase enzyme, leading to an overstimulated nervous system causing nausea, dizziness, confusion, and respiratory paralysis and death. No chronic effects have been clearly demonstrated, though there is some suggestion of neuro-behavioural or mental development effects. US EPA classify chlorpyrifos as “Evidence of non-carcinogenicity”. Chlorpyrifos has not been evaluated by IARC, though they note reports of increased risk of leukaemia and of non-Hodgkin lymphoma in people working with pesticides.
Glyphosate	Glyphosate appears to be of low toxicity, and most reports of adverse effects are from intentional or accidental ingestion of pesticide formulations. There are no confirmed adverse effects related to chronic exposure. In 2015 the IARC classified glyphosate as “Probably carcinogenic” based on associations with non-Hodgkin’s lymphoma, however US EPA state glyphosate carcinogenicity is “Not classifiable”.
2,4-D	2,4-D is one of the components used in Agent Orange, however the adverse health effects of that substance were due to 2,4,5-T (the other major component) and dioxins contaminating the solution. Chronic exposure to 2,4-D may result in weakness, fatigue, headache, vertigo, and possibly liver dysfunction based on studies of pesticide workers. Peripheral neuropathy has been reported along with contact dermatitis. 2,4-D is classed as possibly carcinogenic (Group 2B) by IARC and not classifiable as a human carcinogen by US EPA.
MCPA	MCPA has low acute toxicity. Chronic exposure in workers can result in reversible anaemia, muscular weakness, stomach problems and slight liver damage. US EPA report MCPA is not likely to be carcinogenic.

Pesticide	Potential human health effects
Metsulfuron	There is little information on toxicity, but it can cause skin irritation. It does not appear to have effects on the reproductive system or be mutagenic. It is not likely to be carcinogenic to humans (NIH 2019).
Brodifacoum	Brodifacoum prevents blood clotting and also increases the permeability of blood vessels, and ingestion of large amounts can result in internal bleeding, brain bleeds or hematoma.
1080	Acute toxicity causes vomiting, damage to the heart and kidneys, and can cause death. There are no effects described that are associated with chronic exposure to humans, but animal studies suggest potential effects on the heart. There are no studies available that assess whether 1080 is carcinogenic, but animal studies indicate it is unlikely.

4.3 Reference doses, slope factors, guidelines and standards

Risk assessment factors are provided in toxicological databases for non-cancer and cancer health effects (endpoints). Reference doses (RfDs) are used to assess risks for non-cancer endpoints, based on an assumption that thresholds exist, above which a toxic effect will occur, and below which there will be minimal risk (US EPA 2019a, US EPA 2019b). The RfD is an estimate of the maximum daily exposure that will not cause any appreciable risk. These values are developed and published for various exposure routes and durations (acute vs chronic). RfDs for chronic non-cancer oral exposure are presented in Table 4-6. Higher RfDs imply that more of the contaminants can be consumed before an effect occurs.

For cancer endpoints, it is assumed there is no theoretical safe level of exposure to the carcinogen and that any dose poses a small, but finite, probability of generating a carcinogenic response (US EPA 2019a, US EPA 2019b). For these endpoints, a cancer slope factor is used to estimate risks, based on the exposure (i.e., Cancer risk = Exposure x slope factor).

The drinking water standards for New Zealand specify the maximum concentrations of contaminants (maximum acceptable value, MAV) that may be present in drinking water, based on human health risks (Ministry of Health 2018). These MAVs are presented in Table 4-6 for contaminants of potential concern for Southland; they are based on minimising health risks, based on consumption of water for 70 years at 2 L per day, and for an adult with a body weight of 70 kg. In most cases the MAVs are based on World Health Organization (WHO) guideline values. In the absence of WHO values, a Provisional MAV (PMAV) may be derived and applied. MAVs for carcinogenic substances are typically based on an excess lifetime cancer risk of 10^{-5} (Ministry of Health 2018).

New Zealand Food Safety, under the Australia New Zealand Food Standards Code (FSANZ), provides maximum levels for contaminants and natural toxicants in food (Schedule 19 of the code). This includes metals and specifies maximum levels, depending on the type of food (Table 4-6). The Ministry for Primary Industries provides maximum residue limits for pesticides, although these are not directly related to health risks.

Although they are common stormwater contaminants, there is no guidance for safe consumption of copper and zinc in food. These are essential nutrients at low concentrations and have low toxicity to humans, relative to the other toxicants in this report.

Table 4-6: Reference doses, carcinogenic slope factors, national drinking water standard MAVs (MoH 2018) and FSANZ guidelines for food (MLs) for contaminants of potential interest in Southland waterways. Shading indicates relative toxicity, from yellow (lower toxicity) to red (higher toxicity) based on reference doses.

Contaminant	Reference dose (mg/kg/day) (oral exposure)	Carcinogenic slope factor (per mg/kg/day) (Oral exposure)	Maximum acceptable value in drinking water (MAV) (mg/L)	Maximum levels in foodstuffs	
				Maximum level (mg/kg)	Food type
Arsenic	0.0003	1.5	0.01	1 2	In seaweed and molluscs; in crustacea & fish
Cadmium	0.0005 (water) 0.001 (food)	NA *	0.004	0.1 2	Leafy vegetables (including watercress) Molluscs, excl bluff oysters & queen scallops
Chromium	1.5 (Cr III) 0.003 (Cr (VI))	NA	0.05	-	No relevant ML
Copper	Not assessed	NA	2†	- 30	No current ML NZ FS 1984
Lead	Not estimated	NA	0.01	0.5 2 0.1	Fish Molluscs Vegetables (including watercress)
Mercury	Not assessed	NA	0.002	1	In crustacea, molluscs and most fish species
Nickel	0.02	NA	0.02		No relevant ML
Zinc	0.3	NA	1.5	- 40	No current ML NZ FR 1984
Nitrate (as Nitrate-N)	1.6	NA	11.3	-	
POPs					
DDT	0.00005	0.34	0.001 (sum of all isomers)	- 5	No relevant ML Action level for fish (FDA 2002)
Dieldrin	0.00005	16	0.00004 (sum of aldrin + dieldrin)		
PCP	0.005	0.4	0.009		
PCBs	0.00002	2	No MAV	0.5	Fish
Dioxins	7×10^{-10}	NA	No MAV		

Contaminant	Reference dose (mg/kg/day) (oral exposure)	Carcinogenic slope factor (per mg/kg/day) (Oral exposure)	Maximum acceptable value in drinking water (MAV) (mg/L)	Maximum levels in foodstuffs	
				Maximum level (mg/kg)	Food type
Hydrocarbons					
Benzo[a]pyrene (PAH)	0.0003	1	0.0007		
Benzene	0.004	0.015	0.01		
Toluene	0.08	NA	0.8		
Xylenes	0.2	NA	0.6		
Pesticides					
Atrazine	0.035	NA	0.002		
Hexazinone	0.033	NA	0.4		
Propazine	0.02	NA			
Simazine	0.005	NA	0.002		
Terbuthylazine	No data	NA	0.008		
Chlorpyrifos	0.003	NA	0.04		
Glyphosate	0.1	NA			
2,4-D	0.010	NA			
MCPA	0.0005	NA			
Metsulfuron	0.25	NA			
Vertebrate poisons					
1080	0.00002	NA	0.0035		
Brodifacoum	No data	NA	No MAV		

Notes: * Not assessed. † For aesthetic reasons only (staining of laundry and sanitary ware; taste).

5 Risks associated with contaminants in groundwater

This section addresses human health risks from contaminants in Southland groundwater. Firstly, the potential exposure routes for groundwater are discussed then secondly, contaminant concentrations in Southland groundwater are reviewed. Contaminant concentrations are compared to drinking water standard Maximum Acceptable Values (MAVs) (MoH 2018). Data from other parts of New Zealand are used where Southland groundwater data are lacking. Thirdly, the human health risks from contaminants in Southland groundwater are assessed according to the method described in Section 2.4; i.e. based on their concentration relative to those standards, the spatial extent of their presence, and the potential presence of receptors (i.e., individual or groups of people that may be exposed).

5.1 Exposure routes for groundwater

As described in Section 2.2, the primary route of exposure to groundwater is through its use for drinking, with the potential for direct ingestion of contaminants. A secondary route of exposure is through its use for showering and bathing, with potential for dermal absorption of contaminants. Groundwater may also be used to irrigate vegetable or fruit produce and there may be exposure both through consumption of that produce and during irrigation.

There are nine reticulated water supplies in Southland that use groundwater as the sole potable water source and one that uses a mixture of groundwater and surface water (Table 5-1). Based on a population of 93,000 (Stats NZ) and reticulated supplies for 69,000 (ESR 2018), there are an additional 24,000 people in Southland sourcing their own drinking water, primarily from roof water or private groundwater bores (Environment Southland staff, pers. comm. 2019). There are no data on the number of people using each source, as groundwater takes for domestic use are a permitted activity.

Based on the populations of each locality with reticulated supplies, and an assumption (based on discussion with Environment Southland staff) that half of the residents sourcing their own water use groundwater, up to 27,600 people could be exposed to contaminants present in groundwater, if contaminants were widespread throughout all aquifers.

Table 5-1: Towns and localities in Southland using groundwater for reticulated drinking water supply. From ESR (2018).

Town / Locality	Population
Gore	7,480
Winton	2,436
Riverton *	1,506
Edendale/Wyndham	1,152
Lumsden/Balfour	1,061
Otautau	798
Tuatapere	561
Otama	300
Mossburn	201
Otikerama	96

Note: * Riverton sources water from groundwater and surface water.

Use of groundwater for drinking is the route that is expected to result in the most exposure. This is because, for most contaminants, the ingestion route is associated with higher uptake than dermal contact; or irrigation routes (Ministry for the Environment 1999). Groundwater may be treated in some way prior to use for drinking water which may remove or reduce the concentrations of some contaminants; however, the treatment systems most widely used in New Zealand are chlorination, coagulation and filtration, which are not expected to remove dissolved contaminants. For this risk assessment it is conservatively assumed that the concentrations measured in groundwater are also reflective of the concentrations in drinking water supplies.

5.2 Presence of contaminants in Southland groundwater

5.2.1 Trace elements

There are multiple sources of trace elements in the region and several metals have been detected at elevated concentrations in soils. Metals and metalloids (arsenic, copper, lead, nickel, zinc) have been monitored on multiple occasions in groundwater wells throughout the region by Environment Southland. This monitoring (Environment Southland, unpublished data, summarised in Table 5-2) has shown that dissolved copper, lead and nickel are well below their respective drinking water standard MAVs. Zinc was the only metal to exceed a MAV, with a maximum concentration of 2.8 mg/L; however, the MAV for zinc is based on aesthetics (taste), not health effects. All other sample concentrations were <1 mg/L, with most concentrations <0.001 mg/L. The maximum concentration of dissolved arsenic in the samples tested was 0.003 mg/L, less than 50% of the MAV of 0.01 mg/L. Arsenic has been further investigated in 49 groundwater wells throughout Southland during synoptic surveys in 2005/06 and 2018. No arsenic was detected in any of the 196 samples collected during these surveys, based mostly on analytical detection limits of 0.001 mg/L. Chromium has been assessed in only five samples from three bores, and was below detection in all samples (<0.011 mg/L). This is consistent with data from elsewhere in New Zealand that indicates chromium concentrations are rarely elevated above background and do not exceed the MAV (Daughney & Randall 2009).

Table 5-2: Metals detected in Southland groundwater through monitoring by Environment Southland. Values in bold are above the drinking water standard MAVs. Unpublished data from Environment Southland.

Metal (dissolved phase)	Maximum concentration (mg/L)	Percentage samples >50% of MAV	No. of samples	MAV (mg/L)
Arsenic	0.003	0%	345	0.01
Copper	0.021	0%	40	2†
Lead	0.00017	0%	40	0.01
Nickel	0.0015	0%	40	0.02
Zinc	**2.8**	1%	93	1.5†

Notes: † For aesthetic reasons only (staining of laundry and sanitary ware; taste).

A survey of dissolved cadmium in Southland groundwater samples was undertaken in 2012 and no cadmium was detected in any of the 64 samples, based on a detection limit of 0.05 to 0.3 µg/L – 10 times lower than the MAV (Nokes & Weaver 2014). Cadmium has been detected in groundwater samples in the Waikato Region at up to around half of the MAV of 4 µg/L, however, cadmium concentrations in the Waikato soils are much higher than in Southland soils.

Monitoring associated with contaminated site investigations (e.g., sheep dips, gasworks, closed landfills) have generally not identified elevated concentrations of metals in groundwater. An exception is lead in bore water from beneath the Bluff closed landfill, which was recorded at 0.037 mg/L (which exceeds the MAV of 0.01 mg/L).

5.2.2 Nitrate

As described in Chapter 0, there are multiple sources of nitrate-N in groundwater; including dairy farming, horticulture, land application of wastewater and use of fertiliser in parks, gardens and golf courses. The most significant of these sources is dairy land use, primarily because of the comparatively large area dairying occupies in Southland.

The most recent analyses of groundwater total oxidised nitrogen concentrations (as a surrogate for nitrate-N concentrations), based on all Environment Southland data collected at quarterly intervals up to 2017, suggest median concentrations (shown in Figure 5-1) exceed the MAV of 11.3 mg/L in 4% of wells, and a further 22% of wells exceed half of the MAV (5.7 mg/L). Nitrate-N concentrations in 57% of the monitored wells exceed the 0.88 mg/L threshold (Schullehner et al. 2018) linked with increased risk of colorectal cancer but it is not clear (without further investigation of data) how many of these wells are used for potable water supply. Around 25% of wells have nitrate-N concentrations less than 0.4 mg/L; these are typically deeper (and likely confined) wells.

The concentrations of nitrate-N in shallow (<10 m depth) groundwater throughout the region has also been modelled (Figure 5-2). The results indicate several hotspots where concentrations are predicted to be above 50% or more of the MAV, large areas where nitrate-N is expected to exceed 3.5 mg/L and widespread exceedance of 1 mg/L. The associated human health risks are unknown but shallow unconfined groundwater is not expected to be widely used for potable water supply.

Routine monitoring up to 2010 of approximately 50 groundwater wells across the region (quarterly, as total oxidised nitrogen) as part of Environment Southland’s state of the environment (SoE) monitoring programme showed that nitrate was increasing in 36% of monitored wells (Environment Southland 2010). Information on whether these trends have continued subsequently was not available for this review. Highest concentrations of nitrate-N in groundwater have been measured in lowland, riparian and terrace aquifers (Liquid Earth 2010).

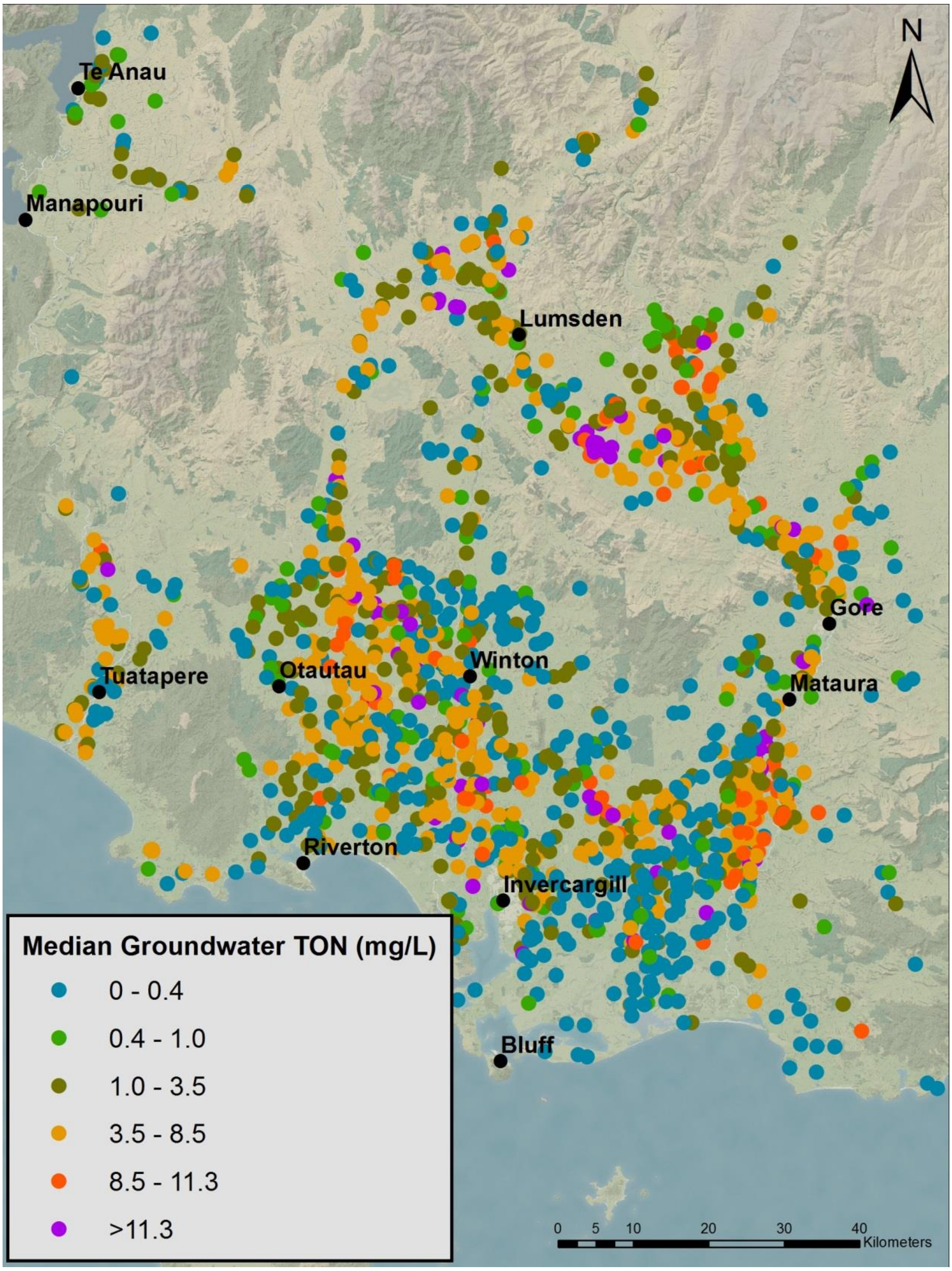

Figure 5-1: Total oxidised nitrogen (as a proxy for nitrate-nitrogen) concentrations in Southland groundwater. Medians are calculated for all sites using all available data up until 2017 (unpublished Environment Southland data).

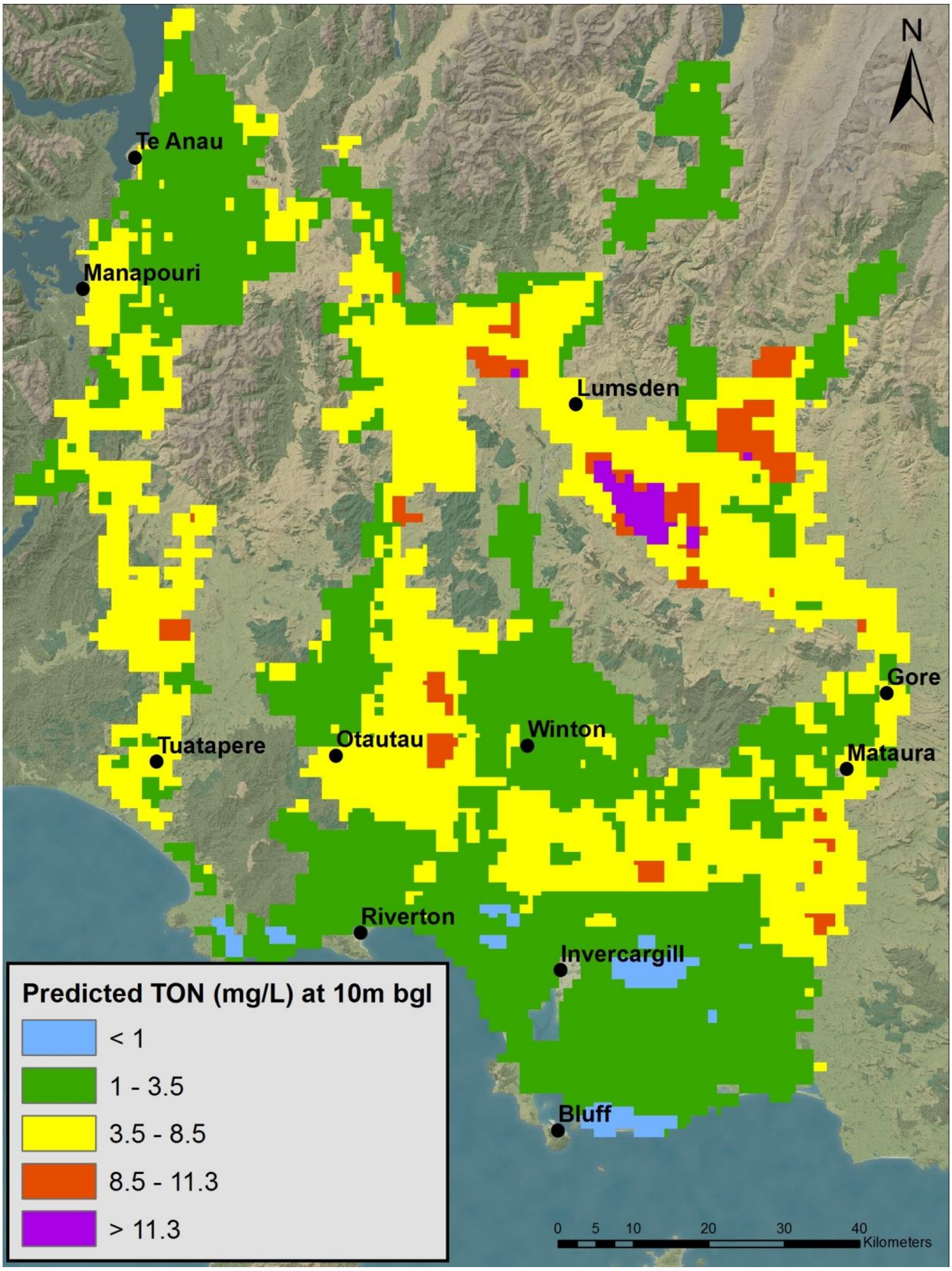

Figure 5-2: Predicted total oxidised nitrogen concentrations (as a proxy for nitrate-nitrogen) at a depth of 10 m below ground level (adapted from Snelder et al. 2019).

5.2.3 POPs

Although they were banned from use in the 1980s, there are numerous sources of organochlorine pesticides (OCPs) throughout Southland, including contaminated sites (sheep dips, pesticide dumps) and contaminated soils. Despite organochlorines being relatively immobile, dieldrin was measured at

0.13 µg/L in a groundwater well in the vicinity of a historical livestock dip or spray race operation during a national survey of pesticides (Close & Skinner 2012). OCPs have also been detected in groundwater collected adjacent to pesticide dumps, including at concentrations above the MAV (Table 5-3).

Although there was widespread use of DDT in Southland and it is measurable in soils, it has not been detected in groundwater in Southland, and has only been detected in one groundwater well in Otago during national pesticide surveys (e.g., Close & Skinner 2012), presumably due to its low mobility.

Table 5-3: Contaminant concentrations measured in groundwater near pesticide dumps in Southland. Values in bold indicate where a drinking water standard (MoH 2018) MAV is exceeded. Results from AECOM (2019a), AECOM (2019b) and Woodward-Clyde (1993).

Pesticide	Maximum concentration (µg/L)	MAV (µg/L)
Aldrin	**2.6**	0.04 (sum of aldrin + dieldrin)
Dieldrin	**11**	0.04 (sum of aldrin + dieldrin)
DDT	<0.3	1 (sum of all isomers)
Endrin	0.020	1
Endrin ketone	0.49	-

Although there are timber treatment sites in Southland where PCP was used, there is little information available regarding contamination of groundwater with PCP. Limited sampling around the West Invercargill landfill showed that PCP concentrations were below detection in groundwater (Golder Associates 2012). Investigations at sites that used PCP around New Zealand have generally shown that although PCP may be found in soils, concentrations in soil, surface water or groundwater are generally low, except for sites with very high PCP use, such as the Blue Mountain Lumber site in Central Otago, and the Waipa Mill site near Rotorua (SPHERE 2008).

While PCBs and dioxins may be present in soils around the region (Buckland et al. 1998a), and PAHs are also likely to be present from a range of different sources, there is no information on their presence in groundwater. The contaminants are unlikely to leach into groundwater, due to their low water solubility.

5.2.4 Present-day pesticides

There are multiple sources of pesticides in the region, including agriculture, forestry, horticulture, municipal uses and private use. As pesticides are applied to plants or soil, they have the potential to leach from soil into groundwater. In Southland pesticide leaching can be higher and degradation rates lower than predicted using literature values, possibly due to preferential flows and lower soil temperatures respectively (Close et al. 2008), increasing the likelihood of their presence in groundwater in the region.

Pesticides have been detected in groundwater wells in the Southland region during national surveys and during specific investigations (Table 5-4). The triazine herbicide terbuthylazine has been the most frequently detected pesticide, although never above the MAV (but within factor of 3). Most of the other pesticides detected were also triazine herbicides, which have low toxicity to humans relative to the concentrations found in the water samples. One organophosphate (chlorpyrifos) was measured during these national surveys, at 0.056 µg/L, well below the drinking water MAV of 40 µg/L standard (MoH 2018).

No other organophosphates or phenoxy hormones (also known as acidic herbicides) were detected in any groundwater samples in Southland, but they have been detected on occasion in other locations around New Zealand (Close 1996, Close & Flintoft 2004, Close et al. 2008, Close & Rosen 2001, Close & Skinner 2012).

Results for the 2018 survey have not yet been published but the data released to councils suggests that glyphosate, included in the survey for the first time, was detected in only one of the 139 samples collected throughout New Zealand (Cardwell 2019).

Table 5-4: Pesticides detected in Southland wells during national and specific surveys.

Pesticide	MAV (µg/L)	National surveys (Close 1996, Close & Flintoft 2004, Close et al. 2008, Close & Rosen 2001, Close & Skinner 2012)			Edendale pesticide investigation (Hughes 2008)	
		No. times detected	Maximum concentration (µg/L)	Percentage of MAV (%)	Maximum concentration (µg/L)	Percentage of MAV (%)
Atrazine	2	5	0.08	4	0.12	6
Bromacil	400	0	-	-	6.6	<2
DEA	2	5	0.15	8	-	-
DIA	2	2	0.17	9	-	-
Hexazinone	400	9	0.74	0	0.78	0.2
Metribuzin	70	1	0.14	0	0.14	0.2
Propazine	70	11	2.5	4	3.16	5
Simazine	2	9	0.31	16	0.64	32
Terbuthylazine	8	18	3.5	44	3.5	18
Chlorpyrifos	40	1	0.056	0	-	-

After initial detections in the 1994 national pesticides survey (Close 1996), the presence of triazine herbicides in the Edendale area was investigated further (Environment Southland 2000, Hughes 2008). Trace concentrations of up to eight different organonitrogen herbicide active ingredients were detected in six bores sampled (Table 5-4). The maximum concentrations of compounds measured were similar to those found during the national survey for hexazinone, terbuthylazine, and metribuzin, but somewhat higher for simazine, atrazine and propazine. Bromacil was not detected during national surveys but was detected (at low concentrations compared to the MAV) in these investigations (Hughes 2008). The presence of the herbicides was linked to spraying of herbicides in the Edendale Nursery (associated with the forestry industry), along with spot and roadside spraying, and concentrations appear to have decreased between 2000/01 and 2008.

5.2.5 Vertebrate poisons

To date, 1080 has only been detected in Southland groundwater during a specific trial, where 12,000 kg of 1080 pest bait was buried in a landfill at Winton, and shallow groundwater monitored for 13 months (Bowman 1999). Five of the 28 samples collected weekly from two bores downgradient of the site contained 1080, at concentrations between 0.0001 mg/L and 0.024 mg/L. Two samples collected had a concentration above the current provisional MAV of 0.0035 mg/L, indicating a potential risk at that time, however there was no 1080 detected after six months (Bowman 1999).

Nationally, water samples collected after aerial drops of 1080 pest bait showed traces of 1080 in 86 (3.4%) of the 2,537 samples tested by Landcare Research, collected from both drinking water supplies and natural waterways (Parliamentary Commissioner for the Environment 2011). It is not clear how many of these samples were collected from groundwater, however, the Parliamentary Commissioner for the Environment (2011) states none of the samples with detectable 1080 were taken from a drinking water supply. Field studies and monitoring during aerial operations indicate that 1080 is rapidly diluted and degraded (Eason et al. 2011, Parliamentary Commissioner for the Environment 2011, Suren 2006). Groundwater samples collected on the West Coast after a bait campaign did not contain any measurable 1080 residues, although some 1080 was detected within soil water samples (maximum 1.4 µg/L). The likelihood of 1080 entering drinking water supplies in Southland appears to be relatively low, and as concentrations are typically below the drinking water standard PMAV (Eason & Temple 2008, Parliamentary Commissioner for the Environment 2011, Srinivasan et al. 2012), the risks associated with its presence in groundwater are also low.

There are no data regarding the presence of brodifacoum in groundwater in Southland, however it is not expected to leach into groundwater due to its high soil sorption potential (ECHA 2010).

5.2.6 Hydrocarbons

BTEX compounds have been detected in groundwater affected by hydrocarbon storage tanks and the former Invercargill gasworks site, including both benzene and xylene at concentrations above their respective drinking water standards (Davis Consulting Group Limited 2013, PDP 2000). Total petroleum hydrocarbons (usually associated with the straight chain hydrocarbons, 0.5-2.8 mg/L) and naphthalene (0.1-153 mg/L) were also measured beneath the gas works site (Davis Consulting Group Limited 2013) but there are no drinking water standards for these.

Contamination of the groundwater in Invercargill poses little hazard to residents since they are on a reticulated water supply sourced from the Oreti River. However, storage tanks in other locations in Southland have potential to contaminate shallow groundwater. Potential risks from this need to be assessed on a case-by-case basis, if that groundwater is used as a drinking water source. There is no information on the presence of PAHs in groundwater, (other than that for naphthalene as described above), however due to their low water solubility and tendency to bind strongly to soil and sediment (Depree & Ahrens 2007) they are unlikely to be widespread.

5.3 Risk assessment for ingestion of groundwater

The risks related to ingestion of groundwater, as drinking water, are ranked in Table 5-5 based on their concentration in relation to their respective drinking water standards, the spatial extent of their presence above 50% of MAV, and the likelihood of potential receptors.

Nitrate (as nitrate-N) poses the highest risk. Nitrate has been measured above 50% of the MAV (and in some cases above the MAV) in many groundwater wells, some of which have potential to be used for drinking water, resulting in the “highest” risk rating in this assessment.

Dieldrin+aldrin and BTEX are ranked as "higher risk" than other contaminants, due to their detection above the MAV in groundwater and the possible presence of receptors. As the measurements were isolated and made adjacent to known contaminated sites rather than at multiple locations, the risk ranking is lower than it is for nitrate.

Although lead and 1080 have also been detected above their respective MAVs in groundwater, these again relate to isolated sampling cases: lead in groundwater beneath Bluff landfill and 1080 in a bore beneath a test landfill. As the groundwater downgradient of these known hotspots are not used for drinking water, there are no potential human receptors and therefore these both are ranked as "lowest" risk. All contaminants that were found below 50% of their associated MAV are also ranked as "lowest" risk.

Table 5-5: Summary of contaminant hazards and potential exposure in the Southland region through use of groundwater as a drinking water source. Italicised entries are based on data from outside the Southland region.

Contaminant	Conc. in groundwater	Extent of presence above 50% MAV	Potential receptors #	Potential risk ranking
Arsenic	<50% MAV †	None	NA	Lowest
Cadmium	<50% MAV	None	NA	Lowest
Lead	> MAV	Isolated	None	Lowest
Nickel	<50% MAV	None	NA	Lowest
Nitrate	> MAV	Widespread	Probable	Highest
Dieldrin + aldrin	> MAV	Isolated	Possible	Higher
DDT	< 50% MAV	None	NA	Lowest
Other POPs	< 50% MAV	None	NA	Lowest
Organophosphates	< 50% MAV	None	NA	Lowest
2,4-D & MCPA	< 50% MAV	None	NA	Lowest
Glyphosate	*< 50% MAV*	*None*	*NA*	*Lowest*
Triazine herbicides	< 50% MAV	None	NA	Lowest
1080	> MAV	Isolated	None	Lowest
Brodifacoum	*< 50% MAV*	*None*	*NA*	*Lowest*
BTEX	> MAV	Isolated	Possible	Higher
PAHs	< 50% MAV	*None*	NA	Lowest

Notes: # May be NA (not applicable), none, possible or probable. † MAV = Maximum Acceptable Value in drinking water (Ministry of Health 2018).

6 Risks associated with contaminants in surface water

This section addresses human health risks from contaminants in Southland surface waters. Firstly, the potential exposure routes for surface waters are discussed then secondly, contaminant concentrations in Southland rivers and lakes are reviewed. Contaminant concentrations in surface waters are compared to drinking water standard (MoH 2018) Maximum Acceptable Values (MAVs) where available. Thirdly, the human health risks from contaminants in Southland surface waters are assessed according to the method described in Section 2.4; i.e. based on their concentration relative to drinking water standards, their spatial extent, and the potential presence of receptors (i.e., individual or groups of people that may be exposed).

6.1 Exposure routes for surface waters

There are multiple routes of exposure to contaminants in surface waters, including from use for drinking (ingestion of contaminants), use for showering and bathing (dermal absorption), and contact recreation (potential for ingestion and dermal absorption).

There are eight reticulated water supplies in the region that use surface water (streams, rivers and lakes), as the sole potable water source while one uses a mixture of groundwater and surface water (ESR 2018). Although there are >20,000 people in Southland who are not connected to reticulated supplies, very few of these people are thought to use surface water intakes. The total population that is expected to use surface water for drinking water purposes is 56,600 (Table 6-1).

Table 6-1: Towns and localities in Southland using surface water for reticulated drinking water supply. From ESR (2018).

Town / Locality	Population	Source
Invercargill	48,700	Oreti River
Te Anau	2,628	Lake Te Anau, Upukerora River
Mataura	1,790	Mataura River, Pleura Stream, Waikana Stream
Riverton *	1,506	Aparima River
Milford Sound	850	Bowen River, Milford Village Creek
Manapouri	228	Lake Manapouri
Ohai/Nightcaps	667	Morley Stream
Eastern Bush / Otahu Flat RWS	180	Wairaki River
Kaiwera	50	Kaiwera Stream

Note: * Riverton sources water from surface water and groundwater.

Swimming, kayaking and other recreational activities may result in exposure to contaminants present in water. There are many river, lake and beach swimming spots across the Southland region. The top 25 recreational sites identified in a 2015 survey of residents (Ward 2015) included 12 coastal locations, 7 lakes / lagoons and 6 rivers. Swimming or diving was the most popular activity (undertaken by 30% of respondents), with other activities (such as surfing, water-skiing and paddle-based activities) collectively comprising up to 23%. Fishing (24%) and boating (15%) were other popular activities but exposure to water is lower for these activities. Most survey respondents (80%) reported spending upwards of 8 days per year participating in water-based recreation, with 47% spending more than 15 days. If the respondents were representative of the entire Southland population, then 30% of the population (28,000 people) could be potentially exposed to contaminants in surface waters.

Of all the potential routes of exposure, use of surface water for drinking is the route expected to result in the most exposure. For most contaminants ingestion is associated with higher uptake than dermal contact because exposure assessments estimate an average of 2 L of water consumed per day for drinking, compared to estimates of 0.025-0.05 L/hour for recreational activities (enHealth 2012, Ministry for the Environment 1999). Surface water is usually treated in some way prior to use for drinking water which may remove or reduce the concentrations of some contaminants; however, the treatment systems most widely used in New Zealand are chlorination, coagulation and filtration, which are not expected to remove dissolved contaminants. For this risk assessment it is conservatively assumed that the concentrations measured in surface waters are also reflective of the concentrations in drinking water supplies.

6.2 Presence of contaminants in Southland surface waters

6.2.1 Trace elements

The main sources of trace elements to surface waters are stormwater, wastewater, industrial wastewater discharges and forestry. Indirect routes via contaminated groundwater are likely to be minimal. Metals are not routinely monitored in Southland waterways through SoE monitoring (Wilson et al. 2012). However, metals are monitored in the streams of Invercargill by Invercargill City Council (ICC), as part of their global stormwater consent requirements (MWH Stantec 2016). ICC monitor arsenic, cadmium, chromium, copper, lead, nickel and zinc at 15 sites across Clifton Creek, Kingswell Creek, Otepuni Stream, Waikiwi Stream and Waihopai River. Although these streams are not expected to be used for drinking water, the metal concentrations in these streams serve as an indicator of potential concentrations in other waterways around the region that are affected by stormwater. This is a conservative comparison as Invercargill City is the largest urban area in Southland and the streams are relatively small in volume (compared to say Gore and its principal receiving environment for stormwater, the Mataura River).

The maximum metal concentrations measured in Invercargill streams between 2012 and 2015 (Table 6-2) show that only lead has a maximum concentration above a MAV. This comparison is highly conservative however, because total lead was measured; typically >90% of the total lead concentration is in particulate form, which would be removed during filtration or coagulation processes used during drinking water treatment. In addition, the drinking water standards are based on exposure over a lifetime whereas this concentration was measured only once and all other measurements (> 200 measurements) were below 0.01 mg/L.

Table 6-2: Total metals measured in stream water in Invercargill City. (MWH Stantec 2016).

Metal	Maximum concentration (mg/L)	MAV (mg/L)	Percentage of MAV (%)
Arsenic	0.0044	0.01	44
Cadmium	0.00015	0.004	3
Chromium	0.0081	0.05	16
Copper	0.034	-	-
Lead	0.015	0.01	150
Nickel	0.015	0.02	75
Zinc	0.27	-	-

6.2.2 Nitrate

Nitrate can be elevated in surface waters from the same sources as described in section 5.2.1, through overland runoff and – especially – through transport via subsurface and groundwater flows. Environment Southland routinely monitors nitrate-N in surface water at 55 sites across the region as part of state of its State of the Environment monitoring programme. This monitoring has shown that nitrate-N is somewhat lower in surface waters than in groundwater, with no sites having median concentrations above the drinking water standard of 11.3 mg/L. Most site median concentrations were less than 2.4 mg/L (shown as green or yellow in Figure 6-1) and many site medians were <1 mg/L (green in Figure 6-1).

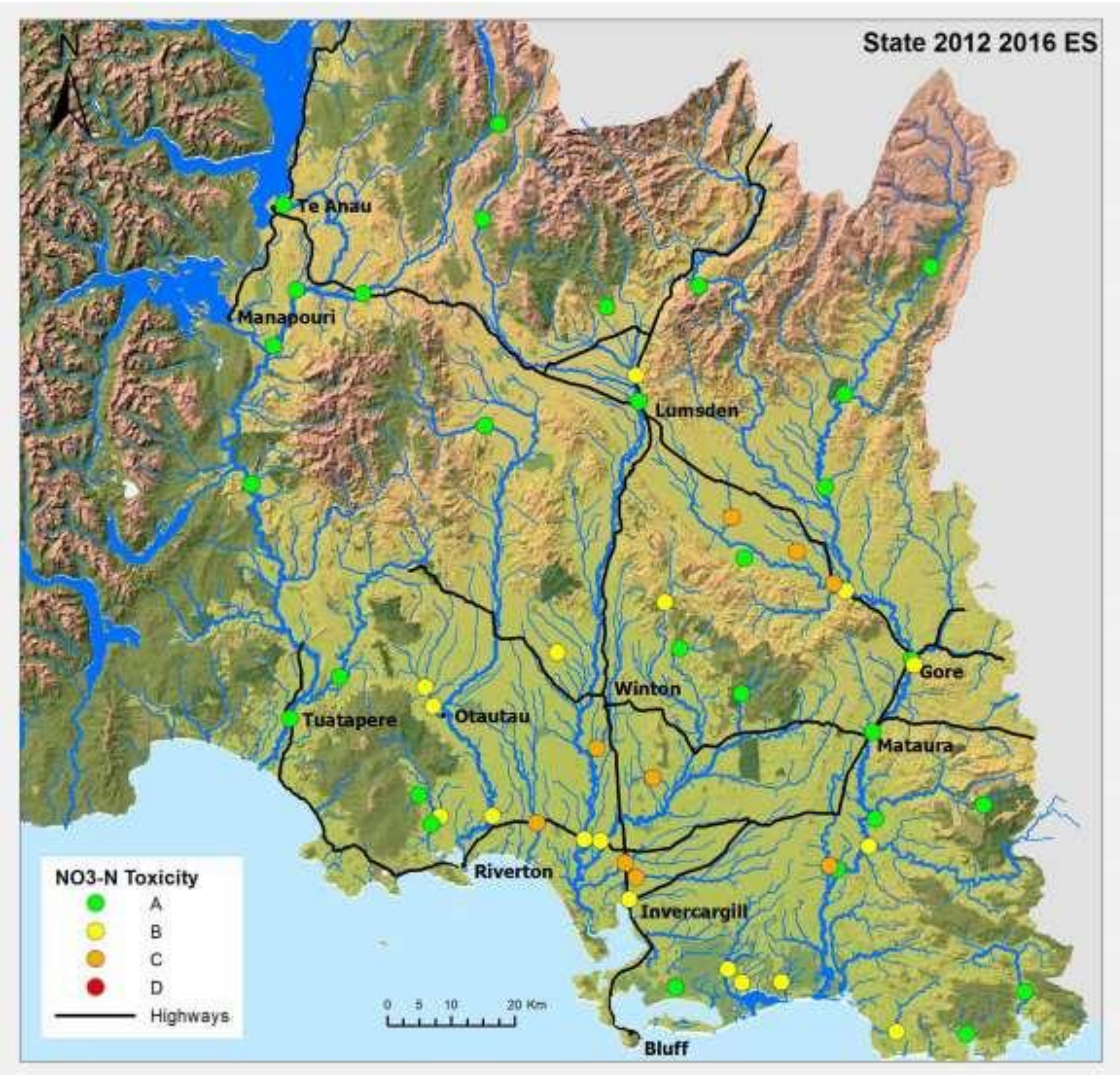

Figure 6-1: Nitrate-N in surface waters categorised according to the NPS-FM National Objectives Framework attribute states for toxicity to aquatic life. Annual median concentrations indicated by green (A) are ≤1 mg/L; yellow (B) are 1-2.4 mg/L; orange (C) are 2.4-6.9 mg/L ; and red (D) are >6.9 mg/L. Map from Hodson et al. (2008) and based on data from 2012-2016.

6.2.3 POPs

Pesticide dump sites represent a potential source of legacy pesticides into surface waters, potentially through groundwater. Monitoring of surface waters adjacent to the Caddon dieldrin dump site (Table

6-3) did not detect dieldrin in any water samples (AECOM 2019b). Organochlorine pesticides, PCP, PCBs and dioxins were also measured but not detected (Table 6-3) in any river water samples collected throughout New Zealand in a national survey of rivers in 1996, which included two sites on the Mataura River (Buckland et al. 1998b).

Table 6-3: POP concentrations in surface waters of Southland.

Pesticide	Maximum concentration (µg/L)	MAV (µg/L)	Reference
Aldrin	< 0.005	0.04 (sum of aldrin + dieldrin)	(AECOM 2019b)
Dieldrin	< 0.005	0.04 (sum of aldrin + dieldrin)	(AECOM 2019b)
DDT	< 0.06	1 (sum of all isomers)	(AECOM 2019b)
PCP	<0.003	9	(Buckland et al. 1998b)
PCDDs and PCDFs	Not detected	-	(Buckland et al. 1998b)
PCBs	Not detected	-	(Buckland et al. 1998b)

Pesticides have recently been detected in sediments collected from streams passing through sheep/beef farms (Shahpoury et al. 2013), nearly 50 years after use ceased. The pesticides included legacy pesticides such as DDT and dieldrin and those currently in use, such as chlorpyrifos, which was detected in 87% of sediment samples (Shahpoury et al. 2013). As pesticides are poorly water soluble, they are unlikely to present a risk for drinking of surface waters. However, their presence in sediment represents a potential route for uptake by aquatic biota.

6.2.4 Present day pesticides

There is very limited information regarding the presence or concentration of pesticides in surface waters in New Zealand (Matthaei 2018), however Hageman et al. (2019) recently assessed their presence in a number of streams, including six streams in Southland with predominantly pastoral land use in their upstream catchments. In each of the six streams three or four of the seven pesticides targeted were detected, including atrazine, chlorpyrifos, diazinon, 2,4-D, and imidacloprid. Estimated pesticide concentrations (Figure 6-2) based on the results from grab samples (chlorpyrifos) and passive samplers (all other pesticides) were low compared to respective drinking water standards. Additional pesticides (including MCPA, triclopyr, diuron, simazine and terbuthylazine) were assessed in Canterbury streams using a different passive sampling method and again concentrations were well below drinking water standards.

A study of a forestry pesticide application showed that pesticide concentrations in the second-order stream within the sprayed area were above drinking water standard MAVs on the day of treatment, declined within 2 days, and remained below MAVs thereafter (Baillie 2016). Concentrations were below drinking water standards at all times at the downstream sites, where the sprayed stream joined to larger streams with unsprayed forestry in their catchments (Baillie 2016). Although this study was not undertaken in Southland, the results indicate the occasional, but short-lived potential presence of herbicides in surface waters within forestry areas.

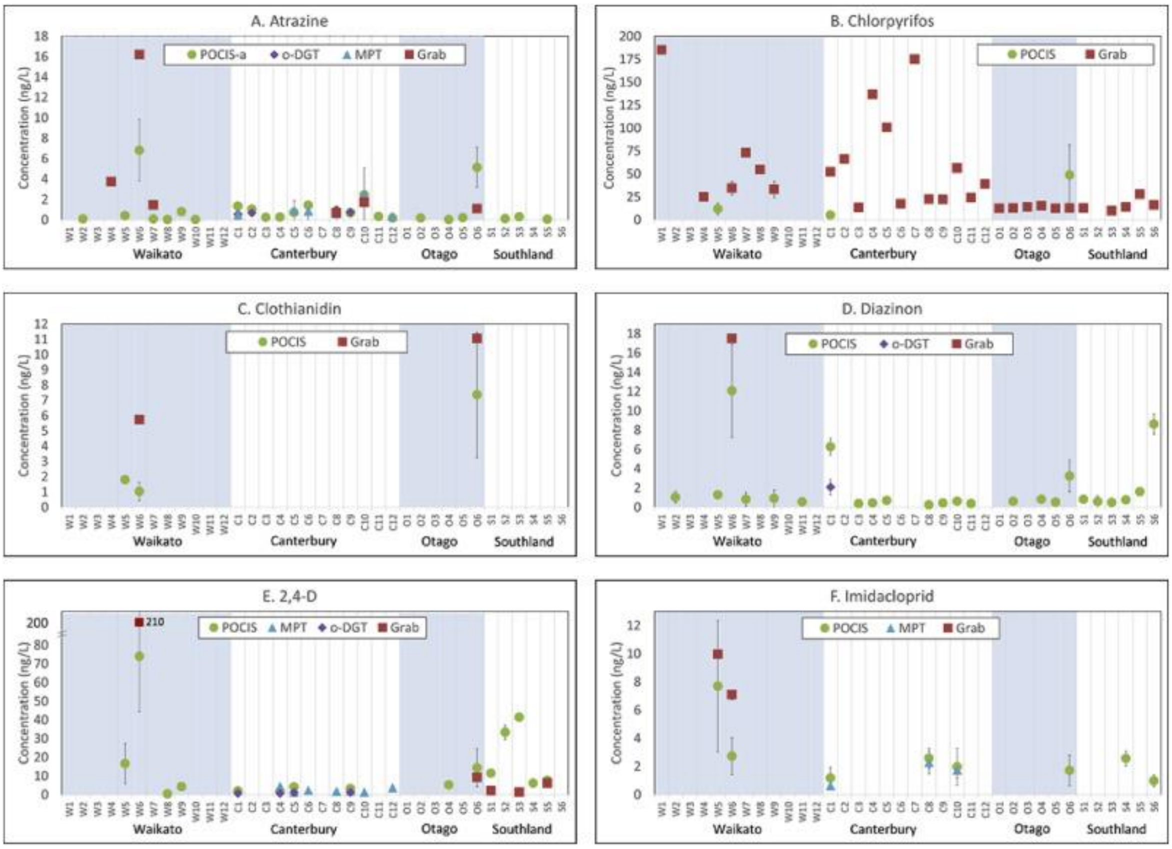

Figure 6-2: Pesticide concentrations in streams around New Zealand, including Southland, as measured using passive samplers. (Hageman et al. 2019).

6.2.5 Vertebrate poisons

There is no information specific to Southland regarding the presence of 1080 in streams. Traces of 1080 have been detected in around 3% of surface water samples collected throughout New Zealand by Landcare Research after aerial drops of 1080 pest bait (Parliamentary Commissioner for the Environment 2011). Specific investigations of 1080 fate have shown that 1080 can be rapidly leached into streams, but also rapidly degrades (Suren 2006). Measured 1080 concentrations are typically below the drinking water standard PMAV, though there have been occasional exceedances (Eason & Temple 2008, Parliamentary Commissioner for the Environment 2011).

There are no data available on the presence of brodifacoum in Southland surface waters, however there is information from other parts of New Zealand where monitoring was undertaken directly after aerial applications of brodifacoum bait (Fisher et al. 2011). Brodifacoum residues were below detection in over 200 water samples collected immediately after (1-48 hours) bait applications, at extended intervals following bait application (3-12 months), and after rainfall (Fisher et al. 2011). Based on these results, it is unlikely that brodifacoum would be detected in surface waters in Southland.

6.2.6 Hydrocarbons

There is no information on the presence of hydrocarbons (BTEX or PAHs) in surface waters in Southland. Based on information from other locations around New Zealand, it is unlikely that they would be found in surface waters as BTEX rapidly volatilise and PAHs have a strong tendency to bind to sediment (Depree & Ahrens 2007).

6.3 Risk assessment for ingestion of surface waters

In relation to using surface waters as a drinking water source, the contaminants of highest risk are lead and nickel, both ranked with medium risk compared to other contaminants (Table 6-4). This is due to their presence in surface waters near Invercargill City at concentrations above 50% of the MAV. However, these measurements are based on total metals and concentrations could be lower in treated drinking water, and these measurements are from a location where surface water is not used for drinking water.

All other contaminants were ranked with lowest risk as they have not been measured at concentrations above 50% of MAV. However, for many of these contaminants, no data exist for Southland. Glyphosate is categorised as unknown as no data are available for New Zealand.

Table 6-4: Summary of contaminant hazards and potential exposure in the Southland region through use of surface water as a drinking water source. Italicised entries are based on data from outside of the region.

Contaminant	Conc. in surface water	Extent of presence above 50% MAV	Potential receptors	Potential risk ranking
Arsenic	<50% MAV †	None	NA	Lowest
Cadmium	<50% MAV	None	NA	Lowest
Lead	>50% MAV	Isolated	Possible	Medium
Nickel	>50% MAV	Isolated	Possible	Medium
Nitrate	<50% MAV	None	NA	Lowest
Dieldrin + aldrin	<50% MAV	None	NA	Lowest
DDT	<50% MAV	None	NA	Lowest
Other POPs	<50% MAV	None	NA	Lowest
Organophosphates	<50% MAV	None	NA	Lowest
2,4-D & MCPA	<50% MAV	None	NA	Lowest
Triazine herbicides	<50% MAV	None	NA	Lowest
Glyphosate	Unknown	Unknown	Unknown	Unknown
1080	*<50% MAV **	*None*	*NA*	*Lowest*
Brodifacoum	*<50% MAV **	*None*	*NA*	*Lowest*
BTEX	*<50% MAV **	*None*	*NA*	*Lowest*
PAHs	*<50% MAV **	*None*	*NA*	*Lowest*

Notes: † MAV = Maximum Acceptable Value in drinking water (Ministry of Health 2018). * Based on data from locations outside of Southland.

7 Risks associated with contaminants in aquatic biota

This section addresses human health risks from contaminants in aquatic biota of Southland. Firstly, the potential exposure routes for aquatic biota are discussed. Secondly, contaminant concentrations in aquatic biota are reviewed and compared to food safety guidelines where available. Thirdly, the human health risks from consumption of aquatic biota containing contaminants are assessed according to the method described in Section 2.4; i.e. based on their concentration, their spatial extent, and the potential presence of receptors (i.e., individual or groups of people that may be exposed).

7.1 Consumption of fish, shellfish and other aquatic biota

Toxic contaminants that are taken up by fish, shellfish and other seafood can present a human health risk to those consuming the food. There are many fish and shellfish that are important food resources in Southland. Commercial fisheries in the region include that of the famous bluff oysters, blue cod, paua and crayfish (rock lobster) (Fisheries New Zealand). Shortfin and longfin eels are also commercially fished in Southland with about 80 tonnes of eels fished in Otago/Southland during 2006-07 (Fisheries New Zealand working group 2008).

Recreational fishing and shellfish gathering are popular activities in Southland and there are an estimated 17,000 recreational fishers (Fisheries New Zealand). In a survey of water users (Ward 2015), 64% of respondents reported collecting seafood (including freshwater food). The type of food most commonly gathered was fish (35% of total), followed by shellfish (29%) and whitebait (14%). Freshwater food sources include eel (5% of respondents) and watercress / puhai (4%) (Fish & Game Southland 2019).

Trout fishing is popular in Southland and the Mataura River is the most-fished river for brown trout in New Zealand (Fish & Game Southland 2019). Trout fishing is also popular in the Aparima, Oreti and Waiau Rivers, Southland lakes (Lake Te Anau, Manapouri, Monowai and Mavora Lakes) and in the Catlins.

7.2 Presence of contaminants in Southland fish, shellfish and other aquatic biota

7.2.1 Trace elements

Trace elements can accumulate in a variety of aquatic biota, including plants, shellfish, crustaceans and fish. Trace elements including arsenic have been assessed in cockles, eels and trout collected from Southland rivers and the New River Estuary (Table 7-1) (Cavanagh & Ward 2014). None of the samples contained trace elements at concentrations that exceed the current New Zealand food standards. Arsenic in cockles (mean concentration 1.7 mg/kg) was within 50% of the food standard (2 mg/L); however total arsenic was measured and the standard is based on inorganic arsenic, which is considered to comprise <10% of the total arsenic in fish flesh (Cavanagh & Ward 2014). There is no maximum level set for nickel in food. Based on the reference dose for this metal and for arsenic, and the relative concentrations measured in the eel and cockle flesh, nickel concentrations are not expected to result pose a health risk.

In addition to comparing the concentrations to food standards, Cavanagh and Ward (2014) assessed human health risks based on toxicological intake values and six different scenarios for consumption rates. That assessment indicated minimal risk to human health from consumption of eels, fish and cockles in most scenarios, but potential risks to high energy consumers (i.e., those with a much higher consumption rate) due to the presence of arsenic and/or mercury.

Table 7-1: Mean concentration of trace elements measured in biota in Southland. (Cavanagh & Ward 2014). The value in bold is above 50% of food standard (FSANZ 2017). ND = Not detected.

	Eel	Trout / mullet	Cockles	Food standard (FSANZ 2017)
Arsenic	0.06	0.46	**1.7**	2
Cadmium	0.024	0.002	0.01	-
Chromium	0.07	0.05	0.18	-
Lead	0.14	ND	0.006	0.5
Mercury	0.17	0.12	Not tested	0.5
Nickel	0.055	ND	1.3	-

Metals have not been measured in watercress in the Southland region, however there is information available from studies in Wellington and Canterbury (Edmonds 2001, Williams 2013). The mean or median concentrations reported in these studies indicate potential health risks from cadmium and lead (Table 7-2).

Table 7-2: Summary of trace elements measured in watercress in Wellington and Canterbury. Values in bold are above 50% of the maximum level recommended in food. Data from Edmonds (2001) and Williams (2013).

Element	Wellington (Minimum and maximum of reported mean [a])	Canterbury		Maximum level in food (FSANZ 2017)
		Stem (median) [b]	Leaf (median) [b]	
Arsenic	0.25	0.1	0.1	1.0
Cadmium	0.01	**0.1**	**0.1**	0.1
Chromium	0.25 – 0.38	Not measured		-
Lead	0.01 – **0.52**	**0.1**	**0.2**	0.1
Mercury	0.02	Not measured		0.5
Nickel	0.05 – 0.24	0.2	0.6	-

Notes: [a] Mean is used here as this is the most appropriate measure for consumption. [b] Mean concentrations not reported.

7.2.2 Nitrate

Nitrate does not accumulate in fish or shellfish so there is minimal risk from consumption of these food types, however nitrate does accumulate in plants, especially green leafy vegetables and plants in the family *Brassicaceae* (Hmelak Gorenjak 2013, Hord et al. 2009). This family includes the aquatic plant watercress. Nitrate concentrations of 870-2,790 mg/kg [2] have been measured in watercress purchased from retail outlets (Thomson et al. 2007), which is likely to be sourced from commercially grown crops. There is no information on the concentrations of nitrate in wild-collected watercress.

[2] Nitrate concentrations measured as sodium nitrate, $NaNO_3$, not as the nitrate-N form that is commonly reported for water.

Based on the nitrate concentrations measured to date, for most consumers the consumption of watercress poses little risk, as daily intake is low (Thomson et al. 2007). However, Thomson et al. (2007) indicated there are some populations that may have higher risk, which should be further assessed. These include a) those that are high consumers of watercress; b) moderate consumers that also consume drinking water from a source with elevated nitrate; and c) those that have a high rate of conversion of nitrate to nitrite. Thomson et al. (2007) state that there is currently no information on the population percentage of high rate converters.

7.2.3 POPs

Organochlorine pesticides were measured in eels, trout and mullet in eight sites in Southland waterways and estuaries by Cavanagh and Ward (2014). Eels and brown trout collected from the Mataura River, and cockles collected from the New River Estuary were also sampled as part of a national survey of organochlorines (Buckland et al. 1998b, Scobie et al. 1999). Comparison of the results from these two surveys (Table 7-3) suggests that, despite nearly 20 years between surveys, concentrations of these persistent organochlorines have not declined significantly over time. Despite this, all samples contained PCBs well below the New Zealand food residue limit of 500 µg/kg and DDT was below the FDA action level of 5000 µg/kg (ATSDR 2019). There is no maximum level in food for dieldrin, however the reference dose is very close to that of DDT (Table 4-6). As the concentrations of dieldrin in the aquatic biota were much lower than the concentrations of DDT, it is expected that the concentrations of dieldrin also have low health risk.

Table 7-3: Summary of organochlorine concentrations measured in biota in Southland. All data are in µg/kg wet weight (Cavanagh & Ward 2014, Scobie et al. 1999)

	2013 survey (Cavanagh & Ward 2014)				1996 survey (Buckland et al. 1998b, Scobie et al. 1999)		
	Eel		Trout / mullet		Eel	Trout	Cockles
	Median	Maximum	Median	Maximum	Results for 2 samples collected in Mataura River		
4,4'-DDD	4	37	1	3.2	0.94, 13.3	0.04, 0.09	0.22, 0.29
4,4'-DDE	33	128	10	16	24, 72	1.8, 13	0.49, 0.64
4,4'-DDT	3	22	1	1.6	2.8, 8.9	0.17, 0.48	0.079, 0.11
Dieldrin	1	3.4	Not detected		0.93, 4.6	0.15, 0.51	0.27, 0.32
PCP	Not measured				< 0.3	< 0.5, 0.8	< 0.2
Dioxins (sum) [1]	Not measured				0.65, 2.3	2.0, 13	4.15, 4.48
Dioxins, total TEQ [2]	Not measured				0.016, 0.059	0.032, 0.037	0.08, 0.039
PCBs (sum) [3]	Not measured				0.98, 7.5	0.16, 1.6	0.21, 0.23
PCBs, total I-TEQ [4]	Not measured				0.087, 0.33	0.065, 0.16	0.066, 0.067

Notes: [1] Sum of 25 PCDD/PCDF congeners, including half limit of detection for values below detection limits. [2] Toxic equivalents (TEQs) calculated based on International Toxic Equivalents Factors, including half limit of detection for values below detection limits. [3] Sum of 25 PCBs congeners, including half limit of detection for values below detection limits. [4] Toxic equivalents (TEQs) calculated based on Toxic Equivalents Factors provided by WHO, including half limit of detection for values below laboratory detection limits.

Organochlorines were also measured in sediment samples in both of these studies. The results indicated that the concentrations in sediment were not a good predictor for concentrations in biota; at some sites sediment samples did not contain OCs above detection limits, yet OCs were detected in biota (Cavanagh & Ward 2014, Scobie et al. 1999).

7.2.4 Present day pesticides

There is no information on the presence of currently used pesticides in aquatic biota in Southland. Most of the pesticides in high use in New Zealand are not bioaccumulative and so would not be expected to be present in aquatic biota (see Table 4-1, Section 4.1). Despite this, there are a few pesticides that can accumulate in biota (e.g., atrazine) and in overseas studies residues have been found in both freshwater (Gunkel & Streit 1980) and coastal biota (Reindl et al. 2015).

7.2.5 Vertebrate poisons

There does not appear to be any specific data regarding the residues of 1080 in aquatic biota in Southland, however information from studies around New Zealand suggests that the concentrations are likely to be low (Champeau et al. 2014, Lyver et al. 2005, Suren 2006, Suren & Bonnett 2006). In a controlled laboratory study by Landcare Research (Lyver et al. 2005), longfin eel in water tanks were exposed to 1080 in the water and through ingestion of baits or possum flesh containing 1080 residues. Eel tissues were found to contain measurable 1080, with a maximum of 0.06 mg/kg (Lyver et al. 2005). In a similar trial, 1080 was detected in koura at up to 5 mg/kg in the tail muscle and 3.3 mg/kg in the body tissue (Suren & Bonnett 2006). Rainbow trout force-fed 1080 capsules also contained 1080 in their tissue at a maximum of 4.7 mg/kg after 24-48 hours (Champeau et al. 2014). Concentrations decreased to close to 2 mg/kg after 84 hours, indicating that 1080 can be metabolised and eliminated by fish (Champeau et al. 2014). Although many of the concentrations are above the maximum residue limit (MRL) of 0.01 mg/kg set by Ministry for Primary Industries, that MRL is for pesticide surveillance and is not related to food safety. Health risk assessments based on the results described above (Champeau et al. 2014, ERMA 2007, Suren & Bonnett 2006) suggest negligible to very low likelihood of effects on people consuming any of the fish, even for high fish consumers.

Brodifacoum has been measured in freshwater and marine organisms around Southland. Cavanagh and Ward (2014) report on measurements of five different anticoagulants assessed in fish flesh and livers collected from rivers and streams feeding the New River Estuary: Waikiwi River, Kingswell Creek, Otepuni Creek, Waihopai River and Oreti River. Coumatetralyl and bromadiolone were detected in fish livers (Table 7-4), though not in flesh; whereas warfarin, brodifacoum and flocoumafen were not detected in any fish livers or flesh.

After an aerial bait drop of brodifacoum on Ulva Island to eradicate Norway rats, the tissues and liver of shellfish and coastal fish were assessed for the presence of residues. Brodifacoum residues were detected in three species (blue cod, limpets and blue mussels) out of the ten species sampled 43-176 days after the bait application (Table 7-4). Residues were also detected in pipis following bait application on Urupukapuka Island, in the Bay of Islands (Vestena & Walker (2010), cited in Masuda et al. 2015) and in mussels, limpets and paua after an accidental spill at Kaikoura (Primus et al. 2005).

Masuda et al. (2015) reported a very low risk of adverse effects for humans consuming the fish or shellfish based on the maximum concentration in the blue cod liver and a no observed effects level for humans of 0.001 mg/kg (the maximum concentration within a person). Because brodifacoum does accumulate in terrestrial animals, its use is restricted to one-off vertebrate pest eradication attempts rather than on-going pest control operations; therefore residues in marine biota are expected to decline over time (Masuda et al. 2015).

Table 7-4: Summary of anticoagulant residues (maximum concentrations in mg/kg wet weight) in Southland aquatic biota.

Species	Tissue tested	Brodifacoum	Bromadiolone	Coumatetralyl	Reference
Blue cod	Liver	0.092	Not tested	Not tested	Masuda et al. (2015)
Limpet	Whole body	0.016	Not tested	Not tested	Masuda et al. (2015)
Mussel	Whole body	0.022	Not tested	Not tested	Masuda et al. (2015)
Brown trout	Liver	< 0.005	0.034	0.024	Cavanagh and Ward (2014)
Yellow eye mullet	Liver	< 0.005	0.0088	<0.01	Cavanagh and Ward (2014)
Long fin eel	Liver	< 0.005	0.015	0.016	Cavanagh and Ward (2014)

7.2.6 Hydrocarbons

No information could be found regarding the presence of hydrocarbons in fish, shellfish or watercress in Southland. Data from other parts of New Zealand suggest that PAHs can be present within shellfish, but that concentrations are typically well below guidelines for consumption (e.g., average concentrations in Auckland shellfish < 10% of European Commission regulation (Stewart et al. 2013). Similar findings would be expected for shellfish in Southland as the region has less urban land use than the Auckland region and PAHs are expected to be lower in these aquatic environments, with the possible exception of the vicinity of Tiwai Point.

7.3 Risk assessment for consumption of biota

The risks related to consumption of aquatic biota are ranked in Table 7-5 based on their contaminant concentration in relation to food standards, the spatial extent of their presence above 50% of food standard, and the likelihood of people to consume that biota (potential receptors). Arsenic has the highest risk ranking based on its concentration in cockles at 50% of the food standard and the popularity of shellfish gathering in Southland. Cadmium and lead are ranked with medium risk despite the same hazard rating (concentrations exceed 50% ML) because these measurements were for watercress, which is consumed by far fewer people than shellfish. However, this does not decrease the risk to any individual who is a high consumer of watercress. Analysis of metals in Southland watercress would provide more certainty regarding the potential risks from watercress consumption.

The risks from nitrate in aquatic food, particularly plants, are unknown, as are risks posed by pesticides and BTEX. Risks from nickel, POPs, PAHs, 1080 and brodifacoum are ranked lowest.

Table 7-5: Summary of contaminant hazards and potential exposure in the Southland region based on consumption of aquatic biota. Italicised entries are based on data from outside the Southland region.

Contaminant	Conc. in biota	Extent of presence above 50% MAV	Potential receptors #	Potential risk ranking
Arsenic	>50% ML ‡	Unknown	Probable	Higher
Cadmium	>50% ML*	Unknown	Possible	Medium
Lead	>50% ML*	Unknown	Possible	Medium
Nickel	No ML	None	NA	Lowest
Nitrate	No ML	Unknown	Possible	Unknown
Dieldrin + aldrin	No ML	None	NA	Lowest
DDT	< ML	None	NA	Lowest
Other POPs	< ML	None	NA	Lowest
Organophosphates	Unknown	Unknown	Unknown	Unknown
2,4-D & MCPA	Unknown	Unknown	Unknown	Unknown
Glyphosate	Unknown	Unknown	Unknown	Unknown
Triazine herbicides	Unknown	Unknown	Unknown	Unknown
1080	< NOEL ^*	None	NA	Lowest
Brodifacoum	< NOEL ^*	None	NA	Lowest
BTEX	Unknown	Unknown	Unknown	Unknown
PAHs	*< ML*	*None*	*NA*	*Lowest*

Notes: # May be NA (not applicable), none, possible or probable. † MAV = maximum acceptable value in drinking water (Ministry of Health 2018). ‡ ML = Maximum limit in food (FSANZ 2017). * Based on data from locations outside Southland. ^ No observable effect level, risk was assessed within cited report.

8 Knowledge gaps

Human health risk assessments require information on the use or generation of contaminants of concern, concentrations in environmental media, pathways to susceptible populations and toxicity to humans. There are gaps in knowledge at all stages of this assessment, which are outlined below.

8.1 Sources of contaminants

There is inadequate information on the current use of pesticides in agriculture, forestry, horticulture or other uses, specific to the Southland region. The only information available is national data from 2004 (Manktelow et al. 2005). Pesticide usage rates specific to Southland would assist in identifying waterways with higher likelihood of pesticide presence, which could be targeted for sampling to assess potential health risks.

Data for the Invercargill City WWTP at Clifton does not include contaminants of potential health concern, except for some metals. As this WWTP receives trade wastes from a variety of sources, it would be useful if the effluent and sludge were periodically screened for a wide range of toxicants, focussing on those that have potential to bioaccumulate in marine biota.

Although the use of 1080 in Southland is recorded and reported on annually, the information describes the area of land treated and not the application rate. Given the high public interest in 1080 (and brodifacoum), compilation of this information could be useful to corroborate the low human health risks identified in this screening level assessment.

Environment Southland has many useful reports relating to investigations of contaminated sites and sites on the Hazardous Activities and Industries List, however information on the contaminants associated with each location is not readily accessible. It would be useful if the contaminant information was collated into the geographic database of site locations.

8.2 Hazards

In general, there is information available regarding the toxicity of all contaminants included in this review, particularly the legacy pesticides and other POPs. For some contaminants, including nitrate and glyphosate, there are conflicting assessments for carcinogenicity which add uncertainty to risk assessments. Where possible, risk assessments should take this uncertainty into account.

8.3 Groundwater

The national groundwater pesticide survey has demonstrated the presence of pesticides in several groundwater wells in Southland. It is not clear how many different wells have been sampled over the years of this programme, but the largest number of wells sampled in a single year was 11. Compilation of the pesticide data, along with maps of the aquifers sampled and locations of wells used for drinking water would be a useful resource for corroborating risks due to the triazine herbicides.

Human health risks in relation to nitrate in groundwater could be more accurately assessed through compiling the following information:

- measurements of nitrate-N concentrations in the reticulated drinking water supplies post-treatment, to assess risks to the population using this as a drinking water source; and

- mapping of the specific groundwater aquifers used for potable supply, the number of people using each aquifer and the nitrate-N concentrations in each aquifer.

8.4 Surface water

There is less information available regarding the presence of contaminants in surface waters: particularly for metals and for pesticides in present-day use. Analyses of surface waters have been limited to rivers and streams. No data were found for estuarine or coastal waters. Data are largely limited to the streams of Invercargill (for metals), consent-related investigations or monitoring downstream of discharges, or for specific studies adjacent to known contaminated sites.

8.5 Aquatic biota

Toxic contaminants have been assessed in biota in only two studies in Southland. The one recent study (Cavanagh & Ward 2014) that examined the presence of toxic contaminants in aquatic biota (including trout and eels in the streams and rivers, and cockles collected from estuaries) did not indicate any widespread risks but there was potential for health risks from arsenic and mercury for people that consume large amounts of fish. Further sampling from additional locations would be useful to validate the results of this study. The second study was a national survey of organochlorines undertaken more than 20 years ago; it included only two sites in the Southland region and avoided sites of potential contamination.

There is no information on the presence of contaminants, including metals and nitrate, in watercress collected from Southland, although watercress is known to accumulate these contaminants. A survey of hapū in the region and the general public could establish the locations most frequently used for collection of watercress and the amount consumed. This information could be used to target an investigation of contaminants in watercress, and a quantitative risk assessment based on those concentrations and local consumption rates.

There is no information on the presence of commonly used pesticides in aquatic biota.

9 Summary

There are multiple sources of potential toxic contaminants across the Southland region, including from agricultural, forestry, horticultural, industrial and municipal activities. There are many contaminants (e.g., metals, pesticides) that are used or produced across multiple sectors, with few that are unique to single activities. Sources may be localised, such as specific contaminated sites or industrial sites or point source discharges; or widespread such as where contaminants are applied across the land, which can result in diffuse transport (overland flow or leaching) into aquatic environments; and or where there are many point source discharges throughout the region. When discharged to water or applied to land, the likelihood of contaminant presence in water or aquatic biota depends on the rate of application, the concentrations discharged, their mobility and persistence, and bioaccumulation potential.

Many of the toxic contaminants identified as being used or generated in the Southland region have been investigated in groundwater, surface water and aquatic biota (Table 9-1); however, there are also many data gaps. This review indicates that groundwater and surface water concentrations of nitrate, lead, dieldrin, aldrin, BTEX and 1080 are at or approaching drinking water standards in at least one location and that arsenic, cadmium and lead are at or approaching food standards in at least one location (Table 9-1).

Table 9-1: Summary of contaminants present (or potentially present) in Southland groundwater, surface water and aquatic biota.

Media	Concentrations below 50% MAV / food standard	Concentrations above 50% MAV / food standard at one site	Concentrations above 50% MAV / food standard at multiple sites
Groundwater	Arsenic, cadmium, chromium, nickel DDT, PCP Atrazine, DEA, DIA, hexazinone, metribuzin, propazine, simazine, terbuthylazine, 2,4-D, MCPA, chlorpyrifos PAHs Brodifacoum* Glyphosate*	Lead BTEX 1080	Nitrate-N Dieldrin Aldrin
Surface water	Arsenic, cadmium, chromium Nitrate-N Atrazine, Hexazinone, 2,4-D, Chlorpyrifos Metribuzin*, Propazine*, DEA*, DIA*, MCPA*, Simazine*, terbuthylazine*, Glyphosate† DDT, aldrin, dieldrin, PCP 1080*, Brodifacoum*	Lead, nickel BTEX	None
Aquatic biota	Chromium, nickel, mercury DDT, dieldrin, PCP, dioxins, PCBs, PAHs* Brodifacoum*, 1080*	Arsenic, cadmium*, lead*	None

Notes: * Based on data for other regions.

Of the three environmental media included in this assessment, the contaminant with the highest risk ranking was nitrate in groundwater (Table 9-2). Although nitrate has relatively low toxicity, it is often found in Southland groundwater at concentrations exceeding the drinking water standard MAV of 11.3 mg/L, with more than 26% of sites recording median concentrations of at least half of the MAV and 57% exceeding the 0.88 mg/L threshold linked to increased colorectal cancer risk (Schullehner et al. 2018).

Dieldrin/aldrin and BTEX in groundwater and arsenic in food (specifically cockles) have higher risk rankings than other contaminants. Lead and nickel in surface waters and cadmium and lead in aquatic biota were ranked as medium risks compared to other contaminants. There are also a number of contaminants for which there is no information on which to assess health risks, particularly pesticides (i.e., 'unknown' risk).

Table 9-2: Summary of relative risks of contaminants through the consumption of groundwater, surface water and aquatic biota in the Southland region. Italicised entries are based on data from outside the Southland region.

Contaminant	Source [&] (L=localised, W=widespread)					Ingestion of groundwater	Ingestion of surface water	Consumption of aquatic biota
	A	F	H	I	M			
Arsenic	L	×	W	L	L	Lowest	Lowest	Higher
Cadmium	W	×	×	L	L	Lowest	Lowest	Medium
Lead	×	×	×	L	W	Lowest	Medium	Medium
Nickel	×	×	×	L	W	Lowest	Medium	Lowest
Nitrate	W	×	W	L	L	Highest	Lowest	Unknown
Dieldrin + aldrin	L	×	W	×	W	Higher	Lowest	Lowest
DDT	W	×	W	×	W	Lowest	Lowest	Lowest
Other POPs	×	L	×	L	L	Lowest	Lowest	Lowest
Organophosphates	W	W	W	×	L	Lowest	Lowest	Unknown
2,4-D & MCPA	W	W	W	×	W	Lowest	Lowest	Unknown
Triazine herbicides	W	W	W	×	W	Lowest	Lowest	Unknown
Glyphosate	W	W	W	×	W	*Lowest*	Unknown	Unknown
1080	W	×	×	×	×	Lowest	*Lowest*	Lowest
Brodifacoum	L	L	×	×	L	*Lowest*	*Lowest*	Lowest
BTEX	×	×	×	L	×	Higher	*Lowest*	Unknown
PAHs	×	×	×	L	×	Lowest	*Lowest*	*Lowest*

Notes: [&] A= agriculture, F = forestry, H = horticulture, I = industry, M = municipal.

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11 Glossary of abbreviations and terms

Acute	An exposure or response which operates over a short time. The effect does not have to be lethal
Anti-coagulant	A substance that prevents clotting of blood
Bioaccumulation	A general term for the process by which an organism stores a higher concentration of a substance within its body than is found in its environment
Biomagnify	The serial accumulation of a chemical by organisms in the food chain, with higher concentrations of the substance in each succeeding trophic level
Carcinogenic	Refers to the ability of a substance to cause cancer
Chronic	An exposure or response which operates over a long time. The effect can be lethal (e.g., cancer) or non-lethal (e.g., reduced brain function).
Dermal	Of, through or by the skin
Exposure	Contact with a chemical, physical or biological agent
Fungicide	Chemical substance used for the control of fungi
Genotoxic	Toxicants that affect perturb genetic material (i.e., DNA) to cause gene or chromosomal mutations
Hazard	The capacity to produce a particular type of adverse health or environmental effect, e.g. one hazard associated with benzene is leukemia (Ministry for the Environment 1999)
Herbicide	Chemical substance used for the control of plants (i.e., weeds)
Ingestion	Introduction of a substance to the body through the mouth
Inhalation	Introduction of a substance to the body through breathing
Insecticide	Chemical substance used for the control of insects
Lethal	Deadly; fatal; causing death
OCPs	Organochlorine pesticides, see definitions below
Organochlorine	In theory any chemicals that contain carbon and chlorine atoms joined together; in common usage this refers to a group of organochlorine POPs
Organophosphate	A class of insecticides, that disrupt the enzyme acetylcholinesterase. They are designed to control insects but can also affect other animals including humans.
PCP	Pentachlorophenol, a chlorinated hydrocarbon that was previously used in timber treatment and as a pesticide
Pesticide	Chemical substances used to kill pests, including herbicides, insecticides and fungicides.
Phenoxy hormone	A class of herbicides, chemically related to the plant growth hormone indoleacetic acid, that selectively kill broad-leaf weeds

Phosphonyl	A class of herbicides that includes glyphosate and glufosinate and closely related chemicals
POP	Persistent organic pollutants are organic compounds resistant to environmental degradation and controlled under the Stockholm Convention
Receptor	An organism, plant, human or physical structure which may be exposed to a chemical or other hazardous agent (Ministry for the Environment 1999)
Risk	The probability and consequence of an adverse outcome in a person, a species, a group or an ecosystem that is exposed to a hazardous agent. Risk depends on the level of toxicity of the hazardous agent, as well as the level and length of exposure
Sub-lethal	Having an adverse toxicological effect other than mortality
Toxicity	The quality or degree of being poisonous or harmful to plant, animal, human or other life
Triazine	A class of herbicides that share a similar structure of a triazine ring, composed of three carbon and three nitrogen atoms

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