THE IMPACTS OF CLIMATE CHANGE ON STORMWATER AND WASTEWATER SYSTEMS

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ABSTRACT

Much of New Zealand's stormwater and wastewater infrastructure is vulnerable to the risks associated with a changing climate, including sea-level rise or increasing extremes of rainfall and/or drought. The nature of existing stormwater and wastewater systems mean that they will be significantly impacted in a wide variety of ways including the increasing occurrence of compounding hazards. For example, many systems discharge to low lying areas, and it is these coastal and riverine locations that are most at risk from flooding associated with increasing rainfall intensity compounded with rising sea levels and changing groundwater levels.

This paper presents findings from Deep South Science Challenge research project into the economic, environmental, cultural and social impacts and implications of climate change on New Zealand's stormwater and wastewater systems. In addition to identifying impacts and implications, the study identifies regional priority areas, and develops a series of guiding principles for managers.

KEYWORDS

Climate change, impacts, implications, stormwater, wastewater, sea-level rise

PRESENTER PROFILE

James has an 18-year career in the infrastructure and environmental sectors, and works across asset management and infrastructure planning, as well as natural hazards, climate change resilience and risk management. He was part of MfE's Climate Change Adaptation Technical Working Group, and has been involved in a wide range of recent projects relating to climate and natural hazard risk - including Deep South Science Challenge, Otago Region's Climate Risk Assessment and various infrastructure risk & resilience assessments for clients.

1 INTRODUCTION

Hazards arising from climate change increase risks for many of New Zealand's settlements, both coastal and inland. These hazards include increasing temperatures, sea level rise (SLR), more frequent extreme rainfall events, more intense storms, more severe and frequent droughts, and more prolonged and intense westerly winds and more frequent and heavier swells. These hazards, and the associated compounding effects will increase the likelihood of flooding, coastal erosion, rain-induced landslides and higher groundwater levels.

A significant gap in knowledge has been identified regarding how climate change and related hazards will impact on stormwater and wastewater infrastructure, and what direct and indirect implications this will have on the economic, environmental, cultural and social domains.

This Deep South Science Challenge research project explored these impacts, and the resulting implications, via a range of processes including: local and international literature review, case study development, and an engagement process with key experts.

In addition to identifying impacts and implications, the study identified regional priority areas, and also developed a series of guiding principles for managers.

Note: This paper discusses the findings relating to key impacts only. Information regarding implications can be found in the main research report.

2 APPROACH

The project consisted of three key steps. Firstly, we identified the physical impacts of climate change on the stormwater and wastewater systems, and grouped these into common impact themes. Secondly, we investigated the resulting social, cultural, environmental and economic implications of the impacts. Finally, we identified regions/ towns/cities across New Zealand which may be particularly vulnerable from climate impacts on their stormwater and wastewater systems and developed a series of broad guiding principles for decision-makers.

The many and varied impacts of climate changes on the stormwater and wastewater networks were explored. Each type of asset that was investigated was exposed to a range of impacts that will potentially result from climate change. Many of these impacts are similar across various asset types.

3 CLIMATE HAZARDS, RISKS AND IMPACTS

MfE (2018) summarises projections for a range of climate variables for New Zealand These generally relate to 'hazards' as described within the introduction above. For this study, the primary climate variables considered to be of relevance to stormwater and wastewater infrastructure were as follows:

- Increased rainfall,
- Decreased rainfall,
- Increased temperature, and;
- Sea level rise.

Risk is defined as the potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as probability of occurrence of hazardous events (likelihood) multiplied by the impacts (or consequences) if these events occur. Risk *results* from the interaction of vulnerability, exposure, and a hazard (IPCC, 2014). See Figure 1.

For example, as sea level rises, the frequency of inundation (hazard) to a coastal township (exposed) would increase. If the building stock was of standard timber construction then the buildings would likely be 'vulnerable' to the hazard, and therefore present an overall risk.

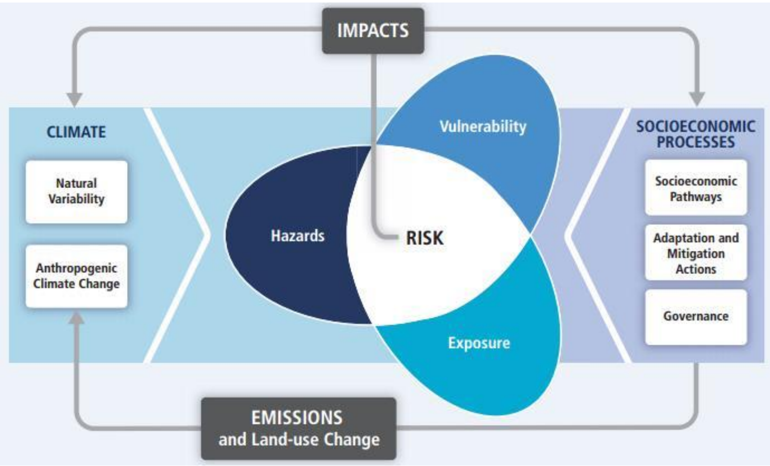

Figure 1: Concept of Climate Risk (IPCC, 2014)

In relation to the above diagram, it is important to note the following:

- Risk from climate related hazards, may lead to either acute impacts (e.g. disasters) or slow-onset (chronic) impacts (e.g. groundwater rise causing corrosion).
- Changes in both the climate system, as well as socioeconomic processes including adaptation and mitigation actions themselves can influence hazards, exposure and vulnerability.
- Socio-economic processes (which influence land use change and carbon emissions) create feedback loops, through changes in emissions. Actions to reduce emissions can reduce the future degree of climate change (over time) and therefore reduce risk.
- Risk is not static over time. All three elements of hazard, exposure and vulnerability can change. For example, a vulnerable community exposed to sea level rise may be at risk of more

frequent flooding. This risk may result in more frequent impacts (flooding) which in turn may increase vulnerability (reduce coping capacity) and further increase risk.

4 STORMWATER AND WASTEWATER SYSTEMS CONSIDERED

Figure 2 illustrates typical stormwater and wastewater systems and various elements of these. Of particular note are the presence of combined sewer systems, as well as separate stormwater and wastewater (sanitary sewer) systems. Tables 1 and 2 summarise the system components in more detail.

Figure 2: Typical stormwater and wastewater system schematic (EPA, 2015)

Table 1: Stormwater systems considered

Broad type	Included in study
Natural systems	• Streams (ephemeral, intermittent and permanent) • Overland flow paths
Built systems	• Overland flow paths (including roadside channels) • Piped network[1] (including catchpits/sumps, manholes, inlets and outlets) • Constructed channels • Stormwater quality devices (such as wetlands, ponds, rain gardens, swales) • Proprietary filter devices • Infiltration devices & soakage pits • Urban stopbanks.

Table 2: Wastewater systems considered

Broad type	**Included in study**
Reticulated systems	• Gravity pipeline conveyance • Pressure pipeline conveyance • Separated pipeline conveyance • Combined pipeline conveyance • Pump stations
Treatment systems	• Treatment plants (primary, secondary, tertiary) • Oxidation ponds • Sludge management • Disposal
On-site wastewater systems	• Primary on-site wastewater treatment • Secondary on-site wastewater treatment • Tertiary on-site wastewater treatment • Composting toilets.

5 MATAURANGA MAORI

Iwi and hapū have a kinship relationship with the natural environment, including fresh water, through shared whakapapa. Iwi and hapū recognise the importance of fresh water in supporting a healthy ecosystem, including human health, and have a reciprocal obligation as kaitiaki to protect freshwater quality (MfE, 2017b). The wealth of knowledge (matauranga Maori) that Maori communities and individuals have accumulated over time is uniquely place-focused and based on empirical observation. The holders of this knowledge are tangata whenua, and access to this knowledge may only be obtained through consultation and engagement with local iwi (Lewis, et al., 2015).

Pollution of waterways and harbours degrades the mauri (life force) of water, riparian zones and native flora and fauna, as well as affecting the ability for customary harvest of mahinga kai (Cunningham, et al., 2017). Maori values must be upheld by preventing the ingress of human or animal waste, contaminants or excessive sediment (MfE, 2014). This ties in to the management of stormwater and wastewater systems to ensure the protection of the mauri of land and water from damage, destruction or modification (Cunningham, et al., 2017). The significance of the environment to Maori as a cultural, social and economic resource, makes them particularly vulnerable to the impacts of climate change (MfE, 2017a).

6 CLIMATE CHANGE IMPACTS ON STORMWATER AND WASTEWATER

This section details the climate change impacts on the various stormwater and wastewater system components in relation to the primary climate drivers of interest, i.e. increased rainfall, reduced rainfall, temperature and sea level rise. A summary of impacts for each system component was developed through consultation with a panel of experts during a workshop in early May 2018. These impacts were then explored through further research, and are discussed below. For each climate impact we have categorised the severity of impact into three categories (low, medium and high).

High severity	Medium severity	Low severity

This was based on stakeholder views and allows focus on those areas where impacts are deemed to be most severe.

6.1 STORMWATER CONVEYANCE SYSTEM IMPACTS

Stormwater conveyance systems include pipelines, waterways (both natural and modified) and overland flow paths. In general, these systems are predicted to experience similar impacts from climate change.

Table 3 summarises the most significant impacts and severity of impact for each component of the system, based on literature review and stakeholder consultation. Increased rainfall /intensity and sea level rise were generally deemed to have a high severity of impact on stormwater conveyance systems. Reduced rainfall was deemed to have a medium or high severity and temperature extremes to have a high severity for waterways.

Table 3: Impact of climate change on stormwater conveyance systems

	Increased rainfall	Reduced rainfall	Sea level rise	Temperature
Pipelines	• Increased flooding • Damage to infrastructure • Increased inflow and infiltration	• Reduced baseflows • Ground settlement • Increased contaminant concentrations and sedimentation • Higher peak flows	• Increased flooding • Damage to infrastructure • Raised groundwater table	• Freezing
Waterways	• Increased flooding • Scour and erosion • Increased contaminant concentrations • Resuspension of historical sediment	• Reduced baseflows • Disconnected waterbodies • Increased contaminant concentrations and sedimentation	• Increased flooding • Raised groundwater table	• Reduced baseflow • Warmer water temperatures
Overland flow paths	• Increased flooding • Scour and erosion • Increased contaminant loading		• Increased flooding	
Pump stations	• Capacity reached, higher energy requirements		• Corrosion	• Overheating

The most significant impacts from increased rainfall are identified to be flooding as a result of system capacities being exceeded, damage to infrastructure from extreme events, increased inflow and infiltration into combined sewer systems (along with associated capacity and environmental issues), scour and erosion, and increased contaminant concentrations from higher velocities and increased mobilisation of urban contaminants into receiving environments.

The most significant impacts from decreased rainfall are identified to be higher peak flows (due to reduced water retention capacity within drier ground), reduced baseflow in waterways and pipelines resulting in ecological effects, sedimentation and blockages, increased contaminant loading (due to higher build up on contaminants and less flushing) and sedimentation and settlement, as a result of ground shrinkage (clay) and cracking.

The most significant impacts from sea level rise are identified to be increased flooding as a result of higher tailwater, damage to infrastructure through coastal erosion and saltwater impacts (corrosion), and a raised groundwater table where this is tidally influenced. Groundwater impacts can extend to damage to buried infrastructure, increased infiltration into pipe networks, and increased risk of both pipe flotation as well as liquefaction from earthquake shaking.

The most significant impacts from increased temperature *extremes* are identified to be reduced baseflow (as evaporation and evapotranspiration from increased plant water use increases), warmer water temperatures (especially from urban runoff) and freezing during extreme cold periods.

In addition to impacts on conveyance networks, there will also be impacts on stormwater treatment systems. These include including general impacts and those specific to raingardens, wetlands, detention ponds and infiltration devices. Table 4 summarises these impacts.

Table 4: Impact of climate change on stormwater treatment systems

	Increased rainfall	Reduced rainfall	Sea level rise	Temperature
Raingardens/Bio-retention cells		• Plant stress	• Reduced capacity • Salinity affecting plant health	• Increased evaporation • Plant stress
Wetlands	• Higher peak flows • Increased contaminant loading	• Plant and eco system stress	• Reduced capacity • Salinity affecting plant health	• Increased evaporation • Plant stress • Eutrophication
Detention ponds	• Higher peak flows		• Reduced capacity	• Increased evaporation • Eutrophication
Infiltration	• Higher peak flows • Increased contaminant loading		• Reduced capacity • Rising groundwater • Saline water ingress	

The significant impacts from increased rainfall on stormwater treatment systems are identified to be higher peak flows (impacting levels of service) and increased contaminant loading. Higher peak flows can also increase contaminant loading as influent concentrations of contaminants will be higher. Sediment/contaminant build up between events combined with higher flows during events may affect the efficiency of stormwater quality treatment systems, as they are required to deal with higher contaminant loads (Sharma, et al., 2016)

Impacts of increased rainfall on wetlands are identified by the New Zealand Department of Conservation (DOC) to be increased nutrient runoff (from surrounding catchments) and changing plant species as water level fluctuations change (Robertson, et al., 2016).

The impacts of reduced rainfall and higher temperatures on stormwater treatment devices are generally similar. Higher temperatures and changes in rainfall could result in a range of effects on lake and wetland systems (MfE, 2008b), including:

- An increased degree of eutrophication and greater frequency of algal blooms,
- Altering of lake margin habitats, including wetlands, with either increased or decreased rainfall,
- Negative impacts on aquatic macrophytes, particularly native species, if lake levels fall,
- A decrease in the habitat range of trout with increased water temperatures,
- Increased ranges of pest species (eg, carp), placing even more pressure on aquatic ecosystems.

The impact of climate change on proprietary stormwater filter devices was explored with a range of suppliers. This identified hydraulic performance, reduced capacity, salinity effects, durability and odour as the most significant impacts of concern, while recognising that the types, components and characteristics of devices varied greatly.

6.2 WASTEWATER CONVEYANCE SYSTEM IMPACTS

Based on stakeholder consultation, reduced rainfall and sea level rise were deemed to have a high severity of impact on wastewater pipeline conveyance systems. Increased rainfall was deemed to have a medium severity and temperature extremes to have a low severity. Refer summary in Table 5.

Table 5: Impact of climate change on wastewater conveyance

	Increased rainfall	Reduced rainfall	Sea level rise	Temperature
Separated	• Increased overflows	• Corrosion due to low flows resulting in increased concentration	• Pipes float causing cracking • Corrosion GW ingress leading to loss of functionality and capacity • Erosion/inundation causing loss of infrastructure	
Combined	• Increased overflows	• Corrosion	• Pipes float • GW ingress • Erosion/inundation causing loss of infrastructure	• Increased odours at outfalls
Pressure	• Increased overflows	• Corrosion	• Pipes float • GW ingress • Erosion/inundation causing loss of infrastructure	
Gravity	• Increased overflows • Increased blockages and breakages	• Corrosion	• Pipes float • GW ingress • Erosion/inundation causing loss of infrastructure	
Pump stations	• Increased overflows • Increased blockages	• Corrosion due to low flows resulting in increased concentration	• Corrosion • Flotation • Inundation • Flooding causing a reduction in the service zone of the pump station	• Blockages due to flushing of wet wipes as user behaviour changes in hot weather

The impacts of increased rainfall are identified to be increased overflows as a result of higher inflow and infiltration into piped networks, as well as increased instances of blockages and breakages/outages (as a result of extreme storm events).

Reduced rainfall and increased temperature are expected to have a range of impacts on wastewater systems. These include:

- Increased likelihood of blockages and related dry weather overflows (MfE, 2008b). This has been experienced and studied extensively in places such as Australia, South Africa and California that have experienced prolonged drought (Marleni, et al., 2012; Naidoo & Moolman, 2016; Yuan, 2010; Tran, et al., 2017; Budicin, 2016). Prolonged drought can result in water restrictions being put in place and the adoption of sustainable practices such as greywater reuse, low flush toilets. This implementation of both temporary and permanent demand/source management practices decreases wastewater flow. This reduction in flow is compounded by the reduction in I&I flows that enter the network from stormwater sources (Marleni, et al., 2012; ONeil, 2010).
- Reduced wastewater flow results in an increase in concentration as the solids content of wastewater remains the same. This results in increased likelihood of blockage, odour and corrosion of the reticulated wastewater network (Marleni, et al., 2012; Naidoo & Moolman, 2016; DeZellar & Maier, 1980).
- Increased wastewater concentration and increased temperature can increase the likelihood of malodorous emissions, and of particular concern is hydrogen sulfide, due to its odour nuisance, threat to public health and potential to enhance corrosion in sewer pipes (Yuan, 2010; Marleni, et al., 2012).

Case Study – Los Angeles 2015

Water conservation measures in Los Angeles instigated in 2015 following historically low rainfall since 2011 have been reported to have caused widespread corrosion and odours while water suppliers have suffered revenue shortfalls. Inadequate flushing flows caused build-up of solids resulting in pipe corrosion, and higher concentration flow caused faster wear in pumping stations. Heightened risk of blockage and corrosion prevention works have increased maintenance work in many drought affected cities, and water starved trees have been found to penetrate sewer systems more frequently in search of water (Stevens, 2015). Over the same period, wastewater treatment plants in California reportedly struggled with poor influent wastewater quality, due to elevated concentrations of total dissolved solids, nitrogen species and carbon (Tran, et al., 2017).

6.3 WASTEWATER TREATMENT PLANT (WWTP) IMPACTS

Based on stakeholder consultation, increased rainfall, reduced rainfall and sea level rise were deemed to have a high severity of impact on WWTPs and related processes. The range of impacts are summarised in Table 6.

Table 6: Impact of climate change on wastewater treatment plants / processes

	Increased rainfall	Reduced rainfall	Sea level rise	Temperature
WWTP – general	• Increased flows • Storm related power outages and road closures	• Increased strength of influent risking breach of toxicity levels	• Flooding and infrastructure decommission	• Performance varies with temperature • Odours (due to higher temperatures)
WWTP - Biological Systems (activated sludge / trickling filters)	• Increased flows	• Increased strength of influent risking breach of toxicity levels	• Outflows may be impacted	• Performance varies with temperature
WWTP - Oxidation Ponds				• Performance varies with temperature
WWTP - Sludge Management			• Raised groundwater table preventing dewatering	• Performance varies with temperature
Receiving environment	• Assimilation capacity reduced	• Assimilation capacity reduced	• Assimilation capacity reduced	• Assimilation capacity reduced

Key impacts are summarised in bullet points below:

- Increased rainfall will result in larger volumetric inflow into WWTPs. The volume or 'flow' of the wastewater increases, but the inflow's TSS (total suspended solids) remains the same resulting in a dilution of the influent to the WWTP. However the high stormwater flows can also carry large amounts of environmental debris associated with storm events. High inflows can affect the hydraulic performance of the system or overwhelm the infrastructure completely – causing untreated or partially treated discharges.
- Research indicates that WWTP performance decreases during increased wastewater inflows associated with rainfall events, and this was primarily attributed to decreased detention times in the treatment processes (Mines, et al., 2007).
- Decreased rainfall and drought conditions reduce the amount of water that flows into WWTPs. An increased occurrence of low flows will lead to decreased contaminant dilution capacity, and thus higher pollutant concentrations, including pathogens (Tolkou & Zouboulis, 2015). The volume or 'flow' of the water decreases, but the waste load remains the same, creating 'high-strength wastewater.' This is a result of reduced storm water ingress, but also implementation of water-conservation strategies, such as water restrictions for users.

- High-strength wastewater flow can cause problems for treatment plants. The increase in concentration of fats, oils, grease, organic and solid matter can result in blockages, early system corrosion and/or severe health and environmental risks (Pocock & Joubert, 2017).
- It is noted the lower flows and higher strength wastewater are likely to affect each plant differently, depending on the type and capacity of the individual plant. Treatment plants that rely on trickling filters, for example, are expected to be more affected by higher concentrations of pollutants, particularly in winter when efficiencies normally decrease due to slower biological reaction rates at lower temperatures.
- Rising sea levels presents the risk of flooding, damage to infrastructure, or even require decommission.
- Some wastewater treatment processes practice land based dewatering of wastewater sludge. Dewatering relies on a groundwater table at a sufficient depth below ground level to allow excess water to drain. A rising groundwater table may prevent adequate dewatering.
- Biological reactions naturally occur much faster in higher temperatures. Given the secondary treatment phase within WWTPs rely on these biological reactions, warmer temperatures would decrease land requirements, enhance conversion processes, increase removal efficiencies and make the utilisation of some treatment processes feasible (Tolkou & Zouboulis, 2015).
- Increased strength of wastewater, changes in the WWTP performance, and increased occurrence of overflows are all likely to increase odour, which increased during warmer temperatures.

7 REGIONAL ANALYSIS

Below we summarise a high-level analysis of New Zealand climate projections, stormwater/wastewater system characteristics and other factors to identify ‘hot spots’ where greatest physical climate impacts of a particular type are expected. This will help to identify which stormwater and wastewater impacts would be expected to be the focus of decision making in those areas, and where there may be consistent outcomes to be considered across similar geographic areas in New Zealand.

Research highlighted a number of factors that are likely to make certain towns and communities more vulnerable to a changing climate – in relation to stormwater and wastewater. The following factors have been identified which may combine with regional climate variability to increase climate risk to that community:

- Communities that rely on pumped stormwater systems.
- Communities with environmentally compromised waterways.
- Communities that are protected by levees / stopbanks.
- Areas of NZ that will be wetter e.g. West Coast.
- Communities with low-lying coastal WWTPs.
- Communities with WWTP which discharge to rivers.
- Communities with low-lying areas prone to flooding.
- Other factors that may mean they may have specific vulnerabilities. E.g. socio-economic.

Some examples of the above factors are discussed below.

7.1 COMMUNITIES WITH PUMPED STORMWATER SYSTEMS:

Communities that rely on pumped stormwater systems will be more vulnerable to increasing rainfall and extreme events due to the fact that these systems will have a finite design capacity, and no secondary system (or redundancy). Any failure or exceedance of capacity of this system will likely result in considerable community impact. In addition, these systems will be subject to increased wear and tear, and increased risk of blockages. In particular, areas of New Zealand that are projected to become wetter and also have a significant component of their stormwater system reliant on pumping include:

- Thames/Hauraki Plains
- Southland Otago (west Taieri)
- South Dunedin
- Tauranga (Papamoa)
- Blenheim
- Whakatane
- Palmerston North
- Christchurch

It is noted that areas with pumped stormwater systems such as Napier that are not expected to see a wetter climate may still have increased vulnerability due to increased extreme events (such as ex tropical cyclones) and through exposure to rising seas and coastal inundation.

7.2 COMMUNITIES WITH ENVIRONMENTALLY COMPROMISED WATERWAYS, LOW-LYING WWTPS, AND WWTPS DISCHARGING TO RIVERS

Communities that have environmentally compromised waterways will be more vulnerable to most aspects of a changing climate. Water quality deterioration is caused by a wide range of impacts, such as increased erosion, contaminants and wastewater overflows due to increasing rainfall, ecosystem stress and reduced flushing flows due to decreases in rainfall, and ecological impacts due to increasing temperatures. Of particular concern are waterways which receive WWTP effluent.

Figure 3 below provides a high level view of Macroinvertebrate Community Index (MCI) around NZ. Macroinvertebrates are considered a relatively good indicator of stream health as they are relatively long lived. They respond to stresses such as drought, pollution, floods and habitat removal, therefore provide a more long-term indicator than chemical sampling (MfE, 2016). The MCI data for New Zealand indicates that stream health in urban areas is generally poorer than stream health in pastoral, indigenous or exotic forest, with a median poor classification (MfE, 2016).

Communities with low-lying coastal WWTPs will be further exposed to rising groundwater, coastal erosion, inundation, and storm surge associated with sea level rise. Many of the country's largest treatment plants (by treatment volume) discharge to coastal or harbour environments, and are usually located at close proximity to the coastal zone (Figure 4). Additionally of concern will be treatment plants which discharge to river environments. This is due to the effects climate change will have on assimilative capacity of a rivers as receiving environments. Examples of locations which may be at risk include: Hamilton, Palmerston North, Queenstown, Stratford and Paraparaumu.

Communities that discharge to rivers in regions predicted to experience dryer conditions, such as Whangarei, will also face significant environmental problems as river flows decrease. Additionally, rising temperatures, which will be experienced across the country, are expected to limit the assimilative capacity of rivers in general.

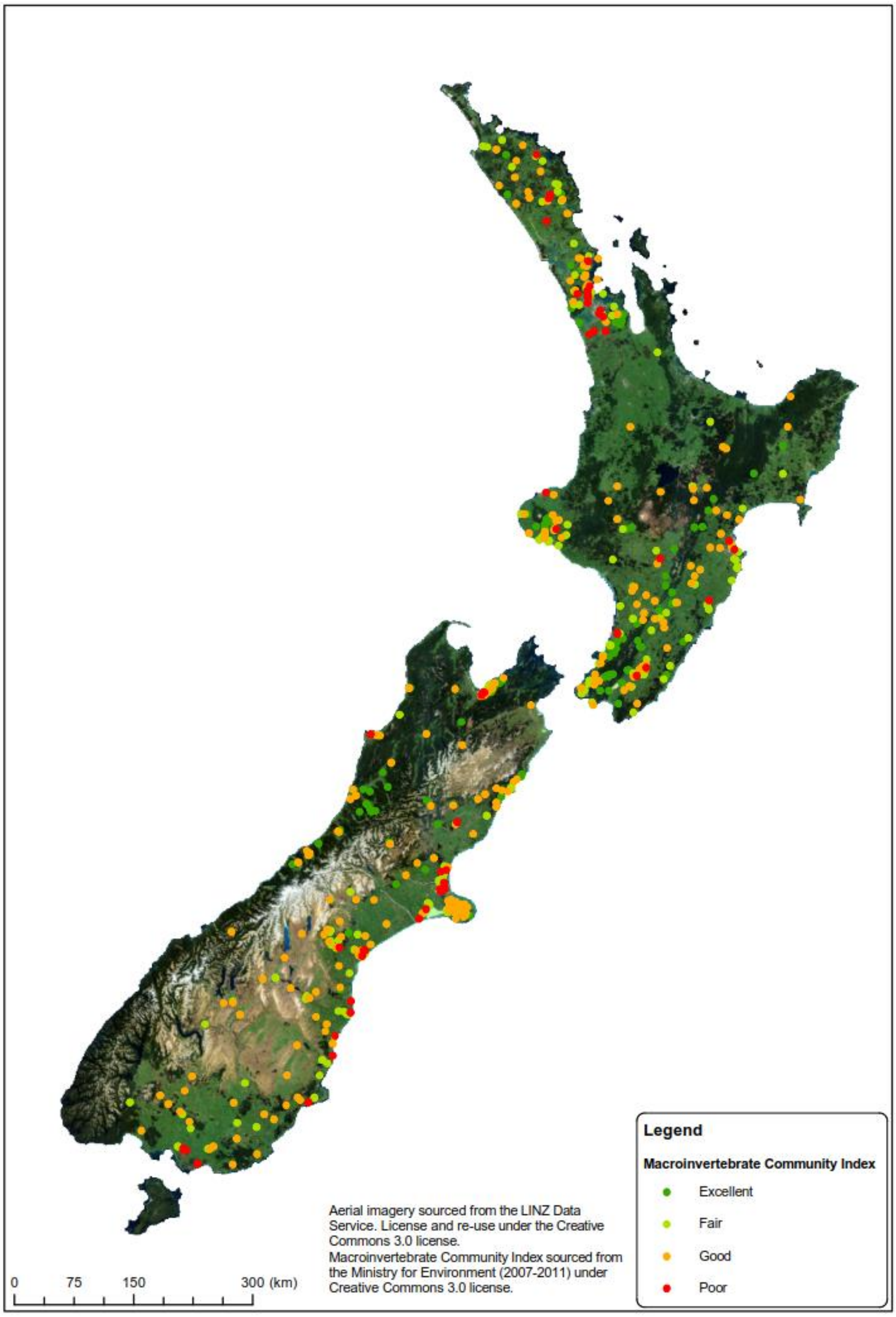

Figure 3 Stream health indicators (MCI)

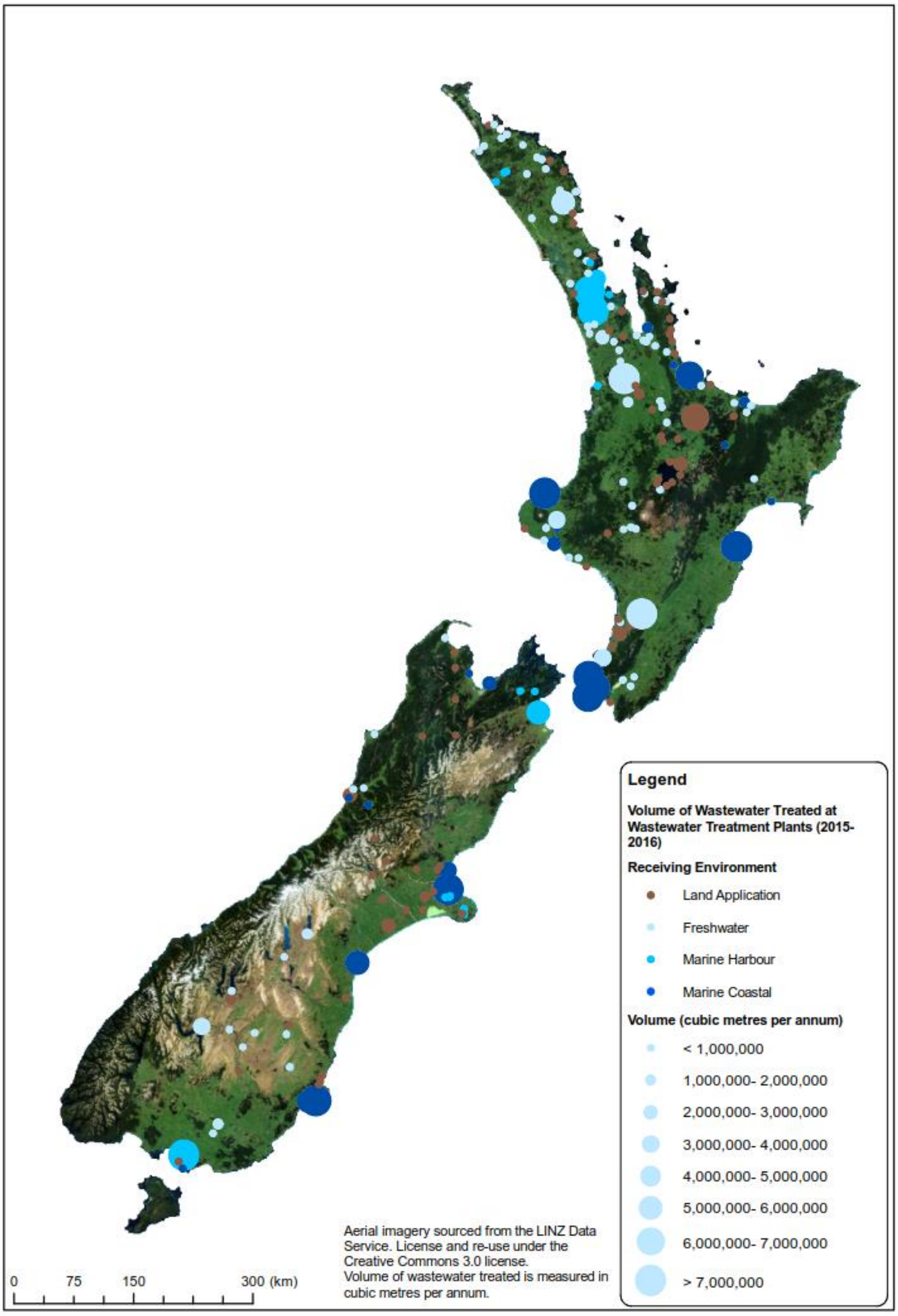

Figure 4 Wastewater treatment plants by discharge type and volume

7.3 LOW-LYING COMMUNITIES WITH INFRASTRUCTURE EXPOSED TO COASTAL INUNDATION

Communities that have low lying areas that are prone to flooding will experience increasing difficulty as the climate changes, and sea levels rise. Low-lying coastal communities will be subject to rising groundwater, coastal erosion, inundation and increasing storm surges due to sea level rise, and will also likely experience compounding surface water flooding during rainfall events.

A recent study funded by LGNZ (LGNZ, 2019) has identified the regional exposure of stormwater and wastewater systems to sea level rise (Figure 5). This work has identified the length of council-owned pipes located within each region that will be affected by various increments of coastal inundation above mean high water springs (MHWS). This work identified that the region with the highest exposure to sea level rise was the Hawkes Bay, with over 600 km of stormwater pipes and 100km of wastewater pipes exposed at 1.0m of elevation above MHWS. Other regions with significant exposure were identified to be Canterbury and Auckland, both with close to 100 km of stormwater pipes exposed (excluding Auckland Transport owned pipes in Auckland).

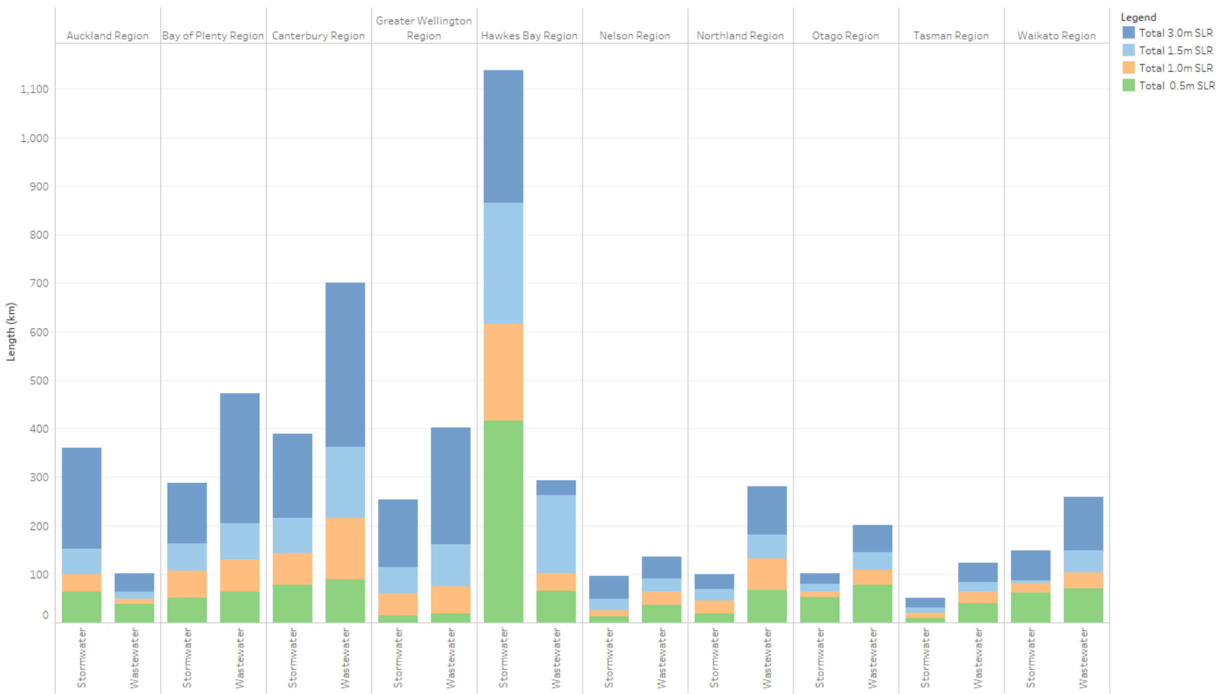

Figure 5: Stormwater and wastewater pipes exposed to various increments of coastal inundation (LGNZ, 2019).

8 SUMMARY AND RECOMMENDED GUIDING PRINCIPLES FOR DECISION-MAKERS

The impact of climate change on stormwater and wastewater systems both influences, and is influenced by, a range of broader issues within a national and sector-wide context.

These include issues with aging infrastructure, pressure for increased housing supply, an increased focus on water quality nationally, coupled with a higher awareness of Maori cultural concerns around the need to limit discharge to, and increase quality of our water bodies. Other issues/trends of relevance include the proposed institutional reform of the water and wastewater sector and the ongoing discussions around insurance availability in coastal environments. These pressures and concerns are mapped in Figure 6.

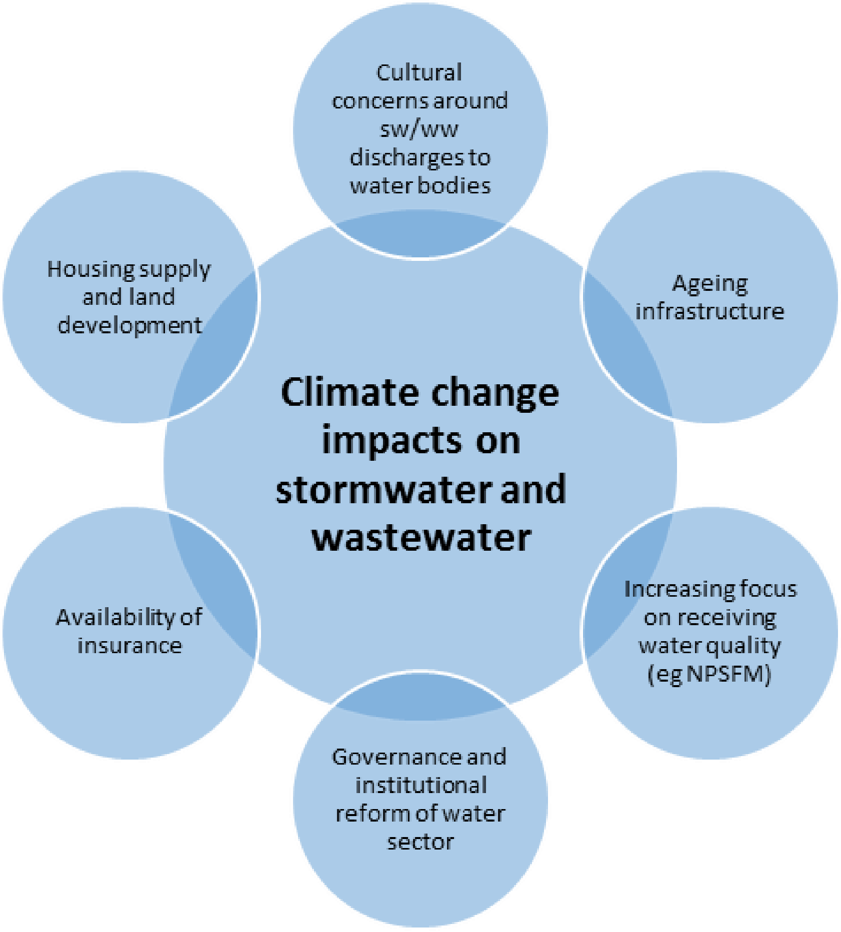

Figure 6: Summary of related national / sector trends and issues.

8.1 GUIDING PRINCIPLES

This research has highlighted a number of areas that require improved management of stormwater and wastewater systems to adapt to the impacts of climate change. A range of guiding principles and recommendations have been developed, and grouped into five themes – as shown in the figure below. These themes include: leadership and governance, monitoring and review, technical approaches to design, asset and risk management, funding and insurance, and cooperation / collaboration.

Table 7. Summary of guiding principles and actions

Guiding principles and actions				
Leadership and governance	**Monitoring and review**	**Technical approaches to design, asset and risk management**	**Funding and insurance**	**Cooperation and collaboration**
Shift asset manager focus from a response based action to preventative action.	Councils and government agencies should endeavour to better understand and monitor asset networks performance and climate hazards.	Councils and government agencies should understand the flood hazard risk to the community.	Councils and government should work to understand insurance risk and establish and safeguard funding pathways.	Opportunities for cooperation and collaboration between councils, government, lifeline services, Maori, researchers and others should be embraced.
• Agreement on the appropriate level of service public stormwater networks and acceptable water quality standards. • Introduce guidance for adaptive management of stormwater and wastewater assets. • Identify key critical assets that will require adaptive measures and agree adaptive management plans and timeframes. • Identify and prioritise the most vulnerable communities and sectors for climate adaptation measures.	• Ensure that asset databases are accurate and available • Monitoring of stormwater network performance • Monitoring of maintenance work • Consistent and ongoing monitoring of water quality, rainfall, runoff and groundwater levels • Monitoring of water quality treatment devices.	• Flood hazard mapping should be undertaken for all at risk population centres. • Government should demonstrate what actions are being taken to manage climate risk and convey what risks remain to the community. • Review of design standards to incorporate understanding on the impacts of climate change. • Climate adaptation plans should be developed and regularly updated for exposed communities. • Climate change risk assessment and registers for stormwater and wastewater assets should be developed, and regularly monitored. • Climate risk to stormwater and wastewater systems should be managed and prioritised consistently across organisations and aligned nationwide.	• Research undertaken to understand the implications of insurance and un-insurability due to climate change. • Secure funding source to ensure the risks of climate change are well understood • Ensure provision of funding is made for councils to invest in stormwater and wastewater systems so that the acceptable level of service can be met. • Consideration of intergenerational equity in funding decisions may be necessary to implement the necessary climate risk mitigation measures.	• Sharing of risk management strategies and mitigation approaches • Consideration of Matauranga Maori should be included in planning, design and decision making.

This study identifies that there are a wide range of impacts from climate change on stormwater and wastewater systems. Many of these impacts may be already be beginning to occur – and in many cases, action will be required now to mitigate worsening impacts. A range of recommendations are made, including: that a nationwide review of design standards should be undertaken to incorporate the impacts of climate change; that the ongoing research into the implications of climate change on insurance access and affordability be reviewed taking into consideration the findings of this study; and that planning and policy decisions for climate resilience be advanced by government and other regulatory bodies with urgency, in order to minimise the impacts and implications of climate change on the economy, environment, society, and the culture of New Zealand.

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