REPORT

Stormwater, wastewater and climate change: Impacts on our economy, environment, culture and society

Prepared for
Deep South National Science Challenge

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Executive summary

This Deep South Challenge funded project presents the findings from research focused on the following question:

What are the potential direct and indirect social, cultural, economic and environmental impacts of climate change on storm-water and wastewater systems?

In answering this question, the research considers: the significance of the impacts, how these impacts will be distributed across different groups, and how they will manifest in different contexts and locations (the implications). The research concludes by proposing a range of guiding principles for local government decision makers.

Climate change hazards/stressors which were relevant to stormwater and wastewater systems were categorised into the following five themes:

- Increased rainfall
- Decreased rainfall
- Sea-level rise
- Increased temperature
- Wind.

The stormwater and wastewater systems considered are summarised in Table1 E1.

Table E1 Stormwater and wastewater systems considered

Stormwater systems	Wastewater systems
• Piped network (including catchpits/sumps, manholes, inlets and outlets) • Stormwater quality devices (such as wetlands, ponds, rain gardens, swales) • Proprietary filter devices • Infiltration devices & soakage pits • Urban stopbanks. • Constructed channels • Overland flow paths (including roadside channels) • Streams (ephemeral, intermittent and permanent)	• Gravity pipeline conveyance • Pressure pipeline conveyance • Separated pipeline conveyance • Combined pipeline conveyance • Pump stations • Treatment plants (primary, secondary, tertiary) • Oxidation ponds • Sludge management • Primary on-site wastewater treatment • Secondary on-site wastewater treatment • Tertiary on-site wastewater treatment

Impacts of climate change on wastewater and stormwater systems

Impacts are defined as the direct or first order effect from a climate-related risk.

This research into the impacts climate change on stormwater and wastewater systems identified *three* main impact themes each for stormwater and wastewater systems.

Stormwater impact themes:

- Increased flooding of buildings and assets arising from higher peak flows, inundation from sea-level rise and raised groundwater levels

- Loss of land (including landslides) and damage to infrastructure arising from storm damage, temperature extremes, increased peak flows,asset failure, salinity exposure, groundwater level changes causing settlement and flotation and reduced flushing flows causing sedimentation.
- Deterioration of water quality arising from scour, bank/berm erosion resuspension of historical sediment, altered performance of water quality treatment devices, increased evaporation and dry out of vegetated systems, raised water temperatures and increased salinity exposure.

Wastewater impact themes:

- Nuisance flooding, spills and odour arising from increased temperatures, changing user behaviour resulting in higher concentration flows and blockages, and waterlogging of on-site wastewater treatment plants.
- Water quality deterioration arising from increased uncontrolled wastewater discharges, increased infiltration, increased salinity of wastewater affecting the performance of wastewater treatment plants (WWTPs), behaviour changes resulting in higher concentration flows which may result in a deterioration in the quality of treated wastewater discharges.
- Damage to infrastructure arising from storm damage, overheating and increased wear of pumping stations, waterlogging, soil structure and ecological changes affecting the performance of on-site systems, temporary or permanent inundation, groundwater fluctuation causing ground settlement or flotation, and changing user behaviour causing increased concentration wastewater leading to corrosion, blockages and increased maintenance at the WWTPs.

Implications of climate change on wastewater and stormwater systems

Implications relating to the primary impacts were identified - across the social, cultural, environmental and economic domains.

Implications are defined as the indirect (second/third order) effect, resulting from an initial impact. This relates primarily to changes to environmental, social, economic and cultural value following an impact.

Across the impact themes, the following recurring implications are evident:

- Physical disruptions (i.e. closed roads, stormwater and wastewater systems not working, evacuation of homes) and associated loss of income and increased costs for residents/ home owners, and business owners (discussed with broader economic implications).
- Reduction in mental health resulting from residents dealing with physical impacts such as injury and disease, chronic events, and loss of personal income, loss of sense of place and reduction in community cohesion
- Loss in cultural identity associated with potential loss of cultural values, damage or loss of cultural land, marae and taonga and a reduced mauri of waterways which may diminish the ability of Māori to participate in cultural practices such as gathering of food. Māori communities were identified to be particularly affected by loss and damage to their whenua, as many have a strong connection to their ancestral lands, to which a large aspect of their identity is tied.
- Reduced resilience of waterways resulting from increased wastewater overflows, increased discharge of stormwater contaminants, and stresses from sea-level rise and temperature changes, resulting in a multitude of effects on aquatic ecosystems. Changes in rainfall may also lead to increasing eutrophication (nutrient-enrichment) or more persistent low-flow

regimes that over time may reduce the assimilative capacity of receiving waters and hence constrain discharges to waterways (similarly for land discharges).

- Increased costs associated with replacing or repairing damaged assets, action taken to improve resilience (which at the coast could be managed retreat), and foregone production such as loss of income due to business disruption, and increasing insurance costs associated with these economic losses.

Regional analysis

Research into the impacts and implications of climate change on stormwater and wastewater systems in New Zealand highlighted a number of factors that are likely to make some towns and communities more vulnerable to a changing climate, including those communities:.

- that rely on pumped stormwater systems (or currently struggling with gravity systems)
- with environmentally compromised waterways (with diminishing assimilative capacity)
- that are protected by stopbanks
- are in areas expected to have increased rainfall and areas of New Zealand that will be wetter in combination with more intense extreme rainfall (which will be ubiquitous across New Zealand)
- with low-lying coastal wastewater treatment plants
- with WWTP which discharge to rivers
- with low-lying areas prone to flooding and/or where the groundwater exhibits a tidal signal
- Otherwhere other factors may mean they may have specific vulnerabilities, e.g. socio-economic conditions, small rating base.

Guiding principles for local government decision-makers

This research has identified a wide range of impacts and implications from climate change on stormwater and wastewater systems. This will require deliberate and planned management responses from all levels of local government in order to adapt.

A series of guiding principles for adaptive management are proposed for local government decision-makers.

1. Factor climate risk into decisions: Consider the current and future climate in all decisions for infrastructure – including asset management, renewals, planning etc.
2. Base decisions on evidence and current national guidance, supported by sound data and local knowledge. This is the basis of informed decision making and participatory democracy.
3. Cooperation and collaboration between councils, government, business, communities, lifeline services, Māori, researchers and other experts – incuding sharing of best practice in climate risk assessments, adaptation planning, stormwater and wastewater management and design.
4. Stewardship / kaitiakitanga and precaution – including shifting planning and asset management focus from response-based action to preventive action; embedding *water sensitive urban design* approaches within council standards and developing upskilling and education initiatives around this.
5. Prioritise the most vulnerable, and working with them to understand climate hazards that may affect them, and to develop response and adaptation strategies that are acceptable, effective and recognise the unique social/cultural/economic circumstances of each community
6. Long term, adaptive thinking and the development of adaptation pathways and plans; consideration of a range of 'typologies' of adaptation options; Consideration and awareness of

broader implications of insurance and un-insurability due to climate change; and securing funding sources to ensure appropriate levels of service can be maintained.

7 Prioritise actions with multiple benefits or which have ‘low-regrets’ - identifying actions which meet other national/sectoral challenges such as freshwater quality, aging infrastructure, biodiversity or GHG reduction; considering nature-based systems and water-sensitive urban design principles.

1 Introduction

This project is part of the ***National Science Challenge - Deep South*** research programme, which has an objective to help New Zealanders to adapt, manage risk and thrive in a changing environment. This research focuses on the following question, which was formulated after 'dialogue' workshops focussing on the impacts and implications of climate change on New Zealand (TRG, et al., 2018):

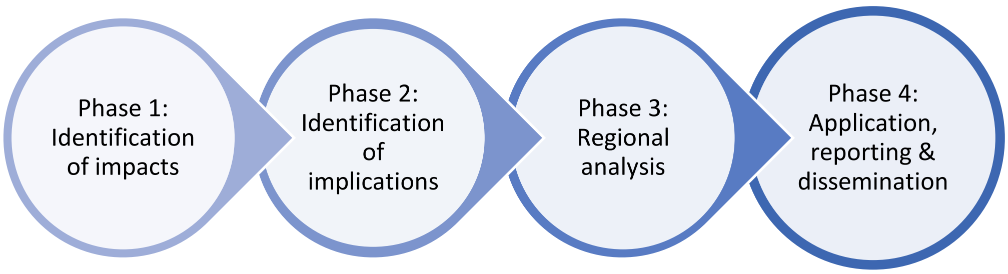
What are the potential direct and indirect social, cultural, economic and environmental impacts of climate change on stormwater and wastewater systems?

In answering this question, the research considers: the significance of the impacts, how these impacts will be distributed across different groups, and how they will manifest in different contexts and locations. The research concludes by proposing a range of guiding principles for local government decision makers.

In answering this question the research focuses on urban and peri-urban stormwater and wastewater systems and their various elements rather than the broader more complex systems approach on how society and the economy could be affected from the climate impacts on the these utility services. The focus ison reticulated systems/elements, but also includes on-site wastewater systems, as well as broader aspects of stormwater management such as overland flow paths and stopbanks that are fundamental to an urban stormwater management context.

1.1 Project phases and structure of this report

The phases of the research are outlined below. Our approach combined a number of tasks that were undertaken across each phase of work, with additional focus and detail being developed as the project progressed.



Phase 1: Identification of impacts

- Literature review
- Draft impacts list
- Expert panel briefing and workshop
- Revised impacts list based on workshop and completed literature review

Phase 2: Identification of implications

- Literature review
- Expert panel follow up
- Revised impacts and implications list based on expert panel engagement, literature review

Phase 3: Regional analysis

- Expert panel follow up
- Region specific review to identify regions, towns and cities that will be particularly vulnerable to climate change impacts
- Case studies

Phase 4: Application, reporting and dissemination

- Findings report
- Presentation
- Journal paper

As illustrated above, a key element of the project included convening an expert Technical Reference Group (TRG) and engaging with them during various phases of the project. The TRG included the following people:

Paula Blackett (NIWA)	Tumanako Faaui (Ngāti Whakahemo)
Mark Bishop (Watercare)	Rob Bell (NIWA)
Blair Dickie (Waikato Regional Council)	Adolf Stroombergen (Infometrics)
Iain White (Waikato University)	Sue Ellen Fenelon (MfE)
Gavin Palmer (Otago Regional Council)	Tom Cochrane (Canterbury University)
Stu Farrant (Morphum)	Liam Foster (Opus)
Troy Brockbank (Stormwater 360 / Opus).	

This report is structured as follows:

- Section 2 discusses climate change effects predicted for New Zealand.
- Section 3 discusses key elements of stormwater and wastewater systems.
- Section 4 explores impacts of climate change on these systems.
- Section 5 explores the implications stemming from the impacts of climate change on stormwater and wastewater systems.
- Section 6 outlines regions in New Zealand that may be particularly vulnerable to climate change impacts on their stormwater and wastewater systems.
- Section 7 presents conclusions and recommendations from this study and sets out some guiding principles for decision-makers.

1.2 Matauranga Māori

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 Māori) that Māori 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).

The Treaty of Waitangi establishes the platform for a partnership approach between Iwi/hapū and the Crown/Pākeha. This partnership approach is essential in enabling decision-making on climate change interventions and adaptation; and to ensure equity of outcomes across and within the social, cultural, environmental and economic domains. In addition, Iwi/hapū are the repositories of mātauranga Māori, traditional knowledge gathered and passed down relating to the natural environment. Incorporating an understanding of mātauranga Māori, as well as consideration of cultural and social differences will be important as we begin to understand the wider climate implications on stormwater and wastewater systems in New Zealand.

2 Climate change effects

2.1 Climate change risk and impacts

The recent ISO 14090 standard[1] on adaptation to climate change outlines three methods for assessing the impacts for climate change [Section 6.2]:

- Risk assessment (e.g. Fig 2.1)
- Vulnerability assessment, which can include the identification of the exposure and senstivity of the organization or agency, its activities and services to changes in climate and associated climate hazards, together with consideration of the ability of the organisation or agency yo manage the impact of these changes and hazards (i.e. adaptive capacity)
- Threshold analysis, which is an approach to prioritize where and when action will be needed by understanding the points at which the system is deemed to be no longer effective (in relation to objectives) as a result of the changing average or extreme climatic conditions. Note: These are called 'adapation thresholds' in the MfE coastal guidance (MfE, 2017).

This broad-scale report mainly focuses on a risk-based assessment of the impacts and implications. Howver, for specific adaptation planning at the local scale for specific utility services, the other two assessment methods would be useful adjuncts to a risk assessment e.g.what is the capacity of the system (physical, economic, governance) to continue delivering utility services and at what point are objectives or levels of service no longer tenable.

The ISO 31000 standard[2] on risk management sets out international best practice for generic risk management. It defines risk as "the effect of uncertainty on objectives". Note 1 to the definition highlights that effects may be positive or negative, presenting potential opportunities and/or threats. Note 3 explains that "risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood. This note provides flexibility. It anticipates and provides for risk to be described or characterised in different ways, depending on the phenomena being considered and the context, whilst maintaining the underlying focus on uncertainty and how that affects objectives (or levels of service). Climate change is a phenomena that exhibits widening uncertainty over time (mainly due to how global emissions will track) regarding the physical processes driving change; the consequences of climate change and timing of those consequences; and the effects of those consequences on the objectives of different communities and societies. Some changes will be irreversible such as sea-level rise, which will continue rising for centuries – with only the rate of rise constrained by the degree and speed of reductions in global emissions.

The IPCC (2014) describes hazard, exposure and vulnerability as separate factors which combine to create *risk* associated with climate change. This is illustrated in Figure 2.1, which was also used to define risk for the National Climate Change Risk Assessment (MfE, 2019) Risk can exhibit in impacts across social, cultural, environmental and economic domains. Those impacts can be mitigated through reducing emissions, and through adaptation, or building resilience to climate changes. *Resilience* can be defined as the capability to cope with, adapt to, recover from and develop/learn from an event (IPCC, 2014).

[1] ISO 14090:2019. Adaptation to climate change – Principles, requirements and guidelines. International Organization for Standardization
[2] ISO 31000:2018 Risk Management Guidelines. International Organisation for Standardisation

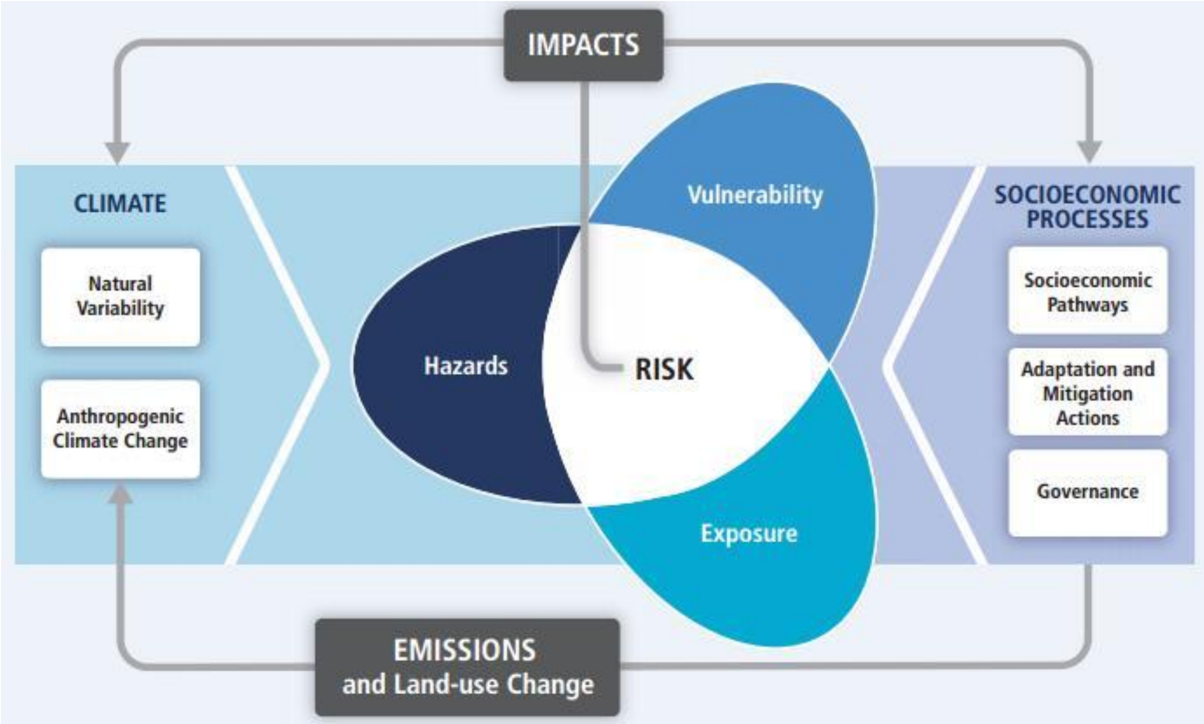


Figure 2.1: Schematic illustration of the concept of climate related risk as the interaction of climate related hazards with the vulnerability and exposure of human and natural systems (Oppenheimer, et al., 2014)

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

- Climate related hazards/stressors, may lead to either acute or sudden impacts (e.g. more floods or heatwaves) or gradualgradual-onset (chronic) impacts (e.g. groundwater rise, rising mean sea level), or increased variability (changes in seasonal rainfall or winds) [after ISO 14090].
- Changes in 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 greenhouse gas (GHG) emissions can create *feedback loops*, through changes in emissions. Actions to reduce emissions can reduce the future degree of climate change (over time) and therefore reduce potential adverse impacts.
- Risk is not static over time – with changing risk the "new norm". All three elements of hazard, exposure and vulnerability, and our understanding about them, can change. For example, a community exposed to ongoing sea-level rise will be more frequently exposed to coastal flooding. This will result in more frequent impacts (flooding, potentially compounded by coincident river flooding, intense rainfall and elevated groundwater levels), which in turn may increase vulnerability (reduce coping capacity) and further increase the potential for adverse impacts.

In particular relation to stormwater and wastewater systems, the three components of risk can be further detailed as follows:

- Hazards: Climate related hazards and gradual-onset stressors including precipitation (rainfall, hail, snow), temperature, evapotranspiration, sea-level rise, waves and wind [see Table B1-2 in MfE (2019)].
- Exposure: The degree of exposure of systems to climate hazards/stressors. Note the degree of exposure varies based on location, geography, topography, level etc.

- Vulnerability: This relates to the predisposition of stormwater and wastewater infrastructure to be adversely affected (based on (IPCC, 2014)) and relates to inherent properties e.g. design characteristics, material, age etc.

2.2 Defining risk sources, impacts and implications

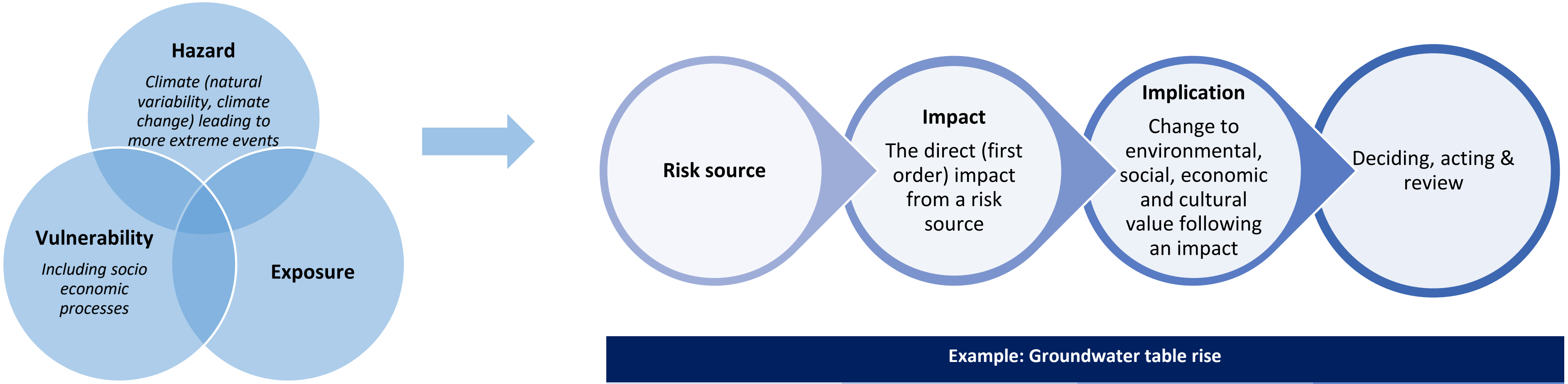
Risk results from the intersection of a climate hazard, with a 'risk receptor' that is exposed and vulnerable to the hazard impacts. Risk can manifest at various levels, and in the context of stormwater and wastewater systems this may be at the asset level, at the network level, at the system level, or across networks and systems (via interdependencies).

- Asset level risk: This is risk that applies to specific assets at an individual level.
- Network level risk: This is the risk to the whole network through network wide hazards or interconnectedness of asset types.
- Systemic / interdependency level risk: This is related to risk which results across and within systems. While this is outside the scope of this study, it is considered important to understand. Examples may include:
  - Climate impacts on power supplies which in turn, result in failure of pumping systems.
  - Climate impacts on stormwater/wastewater infrastructure where there are dense populations, and/or significant numbers of critical utilities, that result in more severe consequences. An example is the New Lynn stormwater failure (refer Case Study 6).

Risk sources can lead to *impacts* and downstream *implications*, which are the primary focus of this report. These terms are defined below and their interrelationship is illustrated in Figure 2.2.

Impacts are the "effects on natural and human systems" of extreme weather, climate events and climate change [ISO 14090:2019; Adaptation to climate change] and defined in this report as the direct or first order effect from a climate-related risk.

Implications are defined as the indirect (second/third order) effect, resulting from the primary impact. This relates mainly to changes to environmental, social, economic and cultural values following an impact.



Example: Groundwater table rise			
Risk source: • The potential for groundwater to rise, over time, affecting underground pipes	**Impact:** • Pipe corrosion, damage or failure • Increased infiltration into networks • Ground heave/flotation	**Implication:** • Increased service provider costs to repair damages, causing economic losses • Reduced levels of service • Deterioration of water quality from saline intrusion	**Deciding, acting, review** • Understanding impacts and implications can lead to prioritisation of interventions to mitigate risk.
Summary: Sea-level rise, can lead to rising groundwater (hazard) that can impact underground pipes (exposure), and depending on pipe material (vulnerability), this can lead to an impact (damage), as well as a range of implications.			

Figure 2.2: Process diagram showing risk and the resulting impacts and implications

2.3 Climate change hazards

Hazards (and stressors) arising from climate change increase risks for many of New Zealand's settlements, both coastal and inland. These include sea-level rise, more frequent extreme rainfall events in some regions, more intense storms, and more prolonged and intense westerly winds and thus more frequent and heavier swells. The compound effects of these hazards will increase the likelihood of flooding, coastal erosion, and higher groundwater levels (Stephens, 2015; Stephenson, 2018). Increases in temperature and drought conditions are also predicted, particularly in northern and eastern regions (MfE, 2018b).

2.3.1 Climate change effects already experienced

Both the New Zealand and global average surface temperatures have increased by around 1 degree since the early 1900s (e.g. NIWA's seven-station temperature series shows a 1.1°C rise from 1908–2018)[3], with most of this rise being attributed to increasing greenhouse gas (GHG) emissions due to human activity. Associated with that, heat expansion and melting snow and ice sheets globally have caused average mean sea level at the New Zealand coastline to have risen around 1818 cm since the start of the 20th century (MfE; Stats NZ;, 2019b) . Changes in extreme weather events are currently being observed, with decreasing frost days and cold temperature extremes and increasing high temperature extremes, increasing sea levels and increasingly intense heavy rainfall events due to warmer air having the capacity to hold more moisture. Average rainfall totals have increased in the southwest of the South Island and decreased in the north of the North Island (Reisinger, 2014; RSNZ, 2016).

2.3.2 Climate change projections

Projections of the future climate depend on the success of efforts to curb GHG emissions. A low or net-zero carbon emission scenario (Representative Concentration Pathway (RCP) 2.6 scenario in the IPCC Fifth Assessment Report - AR5 (Reisinger, 2014) is used to represent a world where global emissions are capped in the next decade and decline to net zero by the last quarter of this century. A continuing high carbon emission scenario (RCP 8.5) is used to represent a future where emissions continue at current levels for the rest of the century (Reisinger, 2014; RSNZ, 2016). These two scenarios capture the widely accepted range of likely future outcomes, however actual future outcomes may also exist outside of these scenarios, especially sea-level rise, where even for the range of RCP8.5 scenario forcings, may lead to multiple possible futures and rates of rise, depending on how instabilities in the polar ice sheets develop in response to the ongoing heat influx (MfE, 2017d) . Climate response lags behind GHG emissions, so that even if all emissions ceased immediately, sea levels are projected to rise over several centuries, albeit at a much slower rate than continuing emissions (MfE, 2017d). Food scarcity, fresh water availability, heatwaves, biodiversity losses and loss of useable land due to drought and coastal inundation are all expected to put pressure on global socio-political systems (RSNZ, 2016).

In a high GHG world in 2100, global mean temperatures are likely to be between 2.6 to 4.8^{o}C above 1986-2005 temperatures (IPCC, 2014). This would cause significant changes in rainfall patterns, causing dryout of sub-tropical regions and large increases in rainfall in higher latitudes. Existing climate patterns are likely to become more extreme, with droughts and rainfall events becoming more severe or frequent. River flows are likely to, on average, increase in the west and decrease in the east of New Zealand. More intense precipitation events would increase flooding. By 2070 this could range from no change, up to a fourfold increase in the frequency of heavy rainfall events

[3] NIWA 7-station series: https://niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data NIWA 7-station series: https://niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data

(RSNZ, 2016). Based on NIWA's High Intensity Rainfall Design System (MfE, 2018b), intense rainfall will increase substantially, particularly short-duration events e.g., a 10-year 1-hour duration rainfall event would increase by 11–18% per °C rise in temperature.[4]

Sea-level rise is expected to be in the range of 0.46–1.05 m by 2100 (MfE, 2017d; Table 10) , with further sea-level risesea-level rises up to 5-10 m possible in the next century and beyondif polar ice sheet instabilities reach a tipping point (RSNZ, 2016). As sea levels rise, increasing *frequency* and increasing *depth* of extreme sea level flooding reaching, and exceeding high thresholds relative to present day levels will occur (Stephens, 2015). The increasing frequency of extreme events will rise at an increasing rate, for example, the 0.01 annual exceedance probability (AEP) sea-level elevation which currently has a 1% chance of being reached on any given year will rise to being met annually (on average) after ~0.3 m of sea-level risesea-level rise (SLR) in Wellington (PCE, 2015)Table 3.2). This annual occurrence threshold is reached sooner for ssites with a small tidal range (such as Wellington) as any given SLR constitutes a greater percentage of the tidal range at these sites. Auckland, which has a larger tidal range, would see the 0.01 AEP sea level elevation occur annually (on average) after 0.45 m SLR (PCE, 2015). As sea-level rise occurs, the depth of inundation will also rise, which will cause damage and disruption to occur further inland (Stephens, 2015).

The main features of New Zealand climate change projections are summarised based on IPCC fifth Assessment in Table 2.1 (MfE, 2018b).

[4] https://niwa.co.nz/information-services/hirds/help https://niwa.co.nz/information-services/hirds/help

Table 2.1: New Zealand climate change projections[1] (MfE, 2018b)

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Mean temperature	Progressive increase with concentration. Only for RCP2.6 does warming trend peak and then decline.	By 2040, from +0.7°C [RCP2.6] to +1.0°C [RCP8.5]. By 2090, +0.7°C to +3.0°C. By 2110, +0.7°C to +3.7°C.	Warming greatest at higher elevations. Warming greatest summer/autumn and least winter/spring.
Minimum and maximum temperatures	As mean temperature.	Maximum increases faster than minimum. Diurnal range increases by up to 2°C by 2090 (RCP8.5).	Higher elevation warming particularly marked for maximum temperature.
Daily temperature extremes: frosts	Decrease in cold nights (minimum temperature of 0°C or lower).	By 2040, a 30% [2.6] to 50% [8.5] decrease. By 2090, 30% [2.6] to 90% [8.5] decrease.	Percentage changes similar in different locations, but number of days of frost decrease (hot day increase) greatest in the coldest (hottest) regions.
Daily temperature extremes: hot days	Increase in hot days (maximum temperature of 25°C or higher).	By 2040, a 40% [2.6] to 100% [8.5] increase. By 2090, a 40% [2.6] to 300% [8.5] increase.	
Mean precipitation	Varies around the country and with season. Annual pattern of increases in west and south of New Zealand, and decreases in north and east.	Substantial variation around the country (see section 3.6.1), increasing in magnitude with increasing emissions.	Winter decreases: Waikato, Gisborne, Hawke's Bay and Canterbury. Winter increases: Nelson, West Coast, Otago and Southland. Spring decreases: Auckland, Northland and Bay of Plenty.
Daily precipitation extremes: dry days	More dry days throughout North Island, and in inland South Island.	By 2090 [8.5], up to 10 or more dry days per year (~5% increase).	Increased dry days most marked in north and east of North Island, in winter and spring.
Daily precipitation extremes: very wet days	Increased extreme daily rainfalls, especially where mean rainfall increases.	More than 20% increase in 99th percentile of daily rainfall by 2090 [8.5] in South West of South Island. A few percentage decrease in north and east of North Island.	Increase in western regions, and in south of South Island. Decrease in extremes in parts of north and east of North Island.
Snow	Decrease.	Snow days per year reduce by 30 days or more by 2090 under RCP8.5.	Large decreases confined to high altitude or southern regions of the South Island.
Drought	Increase in severity and frequency.	By 2090 [8.5], up to 50mm or more increase per year, on average, in July–June PED.	Increases most marked in already dry areas.
Circulation	Varies with season.	Generally, the changes are only a few hectopascals, but the spatial pattern matters.	More northeast airflow in summer. Strengthened westerlies in winter.

1. This table is a reproduction from MfE (2016) and contains references to other sections within the MfE report.

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Extreme wind speeds	Increase.	Up to 10% or more in parts of the country.	Most robust increases occur in southern half of North Island, and throughout the South Island.
Storms	Likely poleward shift of mid-latitude cyclones and possibly also a small reduction in frequency.	More analysis needed.	See section 3.7.
Solar radiation	Varies around the country and with season.	Seasonal changes generally lie between -5% and +5%. (See section 3.9.1.)	By 2090 [8.5], West Coast shows the largest changes: summer increase (~5%) and winter decrease (5%).
Relative humidity	Decrease.	Up to 5% or more by 2090 [8.5], especially in the South Island. (See section 3.9.1.)	Largest decreases in South Island in spring and summer.

1. This table is a reproduction from MfE (2018b) and contains references to other sections within the MfE report.

2.3.3 Primary climate hazards of interest

Climate change hazards/stressors that have been considered relevant for this study are outlined in Table 2.2. These effects have been identified as likely to occur (MfE, 2008a; MfE, 2018b). The relevance to stormwater and wastewater systems was considered with high/medium/low scores being assigned to each (with input from the TRG). The climate change effects categorised as having a *high* and *medium* relevance to stormwater and wastewater systems have been simplified to five main 'themes' as shown. This simplification allowed for a structured approach to researching, discussing and presenting impacts and implications.

Table 2.2: Primary hazards/stressors of interest

Climate change hazards / stressor	Relevance to SW/WW systems	Simplified inclusion 'theme' in study
Increased frequency and intensity of rainfall events	High	Increased rainfall
Increased volume of rainfall events	High	
Drought followed by high intensity rain	High	
Increased frequency and intensity of droughts	High	Decreased rainfall
Increased numbers of dry days	High	
Sea-level rise and coastal flooding (waves, storm-tide)	High	Sea-level rise
Sea-level rise/high-tide inundation & rising groundwater	High	
Temperature increase (mean)	High	Increased temperature
Temperature increase (heatwaves)	High	
Changing seasons (earlier springs, fewer frost days, seasonal rainfall changes)	Medium	
Increase in severe winds	Medium	Wind
Accelerating coastal erosion	Medium	
Shorter duration of seasonal snow line	Low	
Reduction in glacier length and ice volume	Low	
Ocean currents change	Low	

Ocean temperatures increase	Low	

2.4 Current understanding of exposure, vulnerability and risk from climate change

Climate-related risks are not new to local government planners, resource managers and emergency managers. Climate change is not expected to create new hazards, but it may change the frequency and intensity of existing hazard events, as well as introduce some long-term shifts in climate patterns across the country (MfE, 2008a).

There are a number of studies which have been undertaken in recent years focusing on climate change projections and impacts on various sectors of the economy and society. In terms of specific stormwater and wastewater studies, most of the research to date has focused on exposure to sea-level rise and coastal inundation. Bell, et al., 2016) Bell et al. (2015) assessed exposure of a range of infrastructure types in low-lying coastal areas by counting affected normally-resident population, land-cover, land parcels and built assets (e.g., buildings, roads, railways, coastal structures) and estimated building replacement costs exposed in land-elevationelevation bands of 0.5 m up to 3 m above mean high water springs (MHWS).

A more recent study by Local Government New Zealand (Simonson, et al., 2019), using the GIS layers from the PCE study, analysed and summarised exposure of council-owned infrastructure for 62 coastal New Zealand councils in relation to four increments of coastal inundation. These included 0.5 m, 1.0 m, 1.5 m and 3 m increments of elevation above MHWS. The costs to replace three waters infrastructure for each of the increments of elevation above MHWS is shown in Figure 2.3. This reflects significantly higher costs to replace wastewater infrastructure than those for stormwater and drinking water (in decending order).

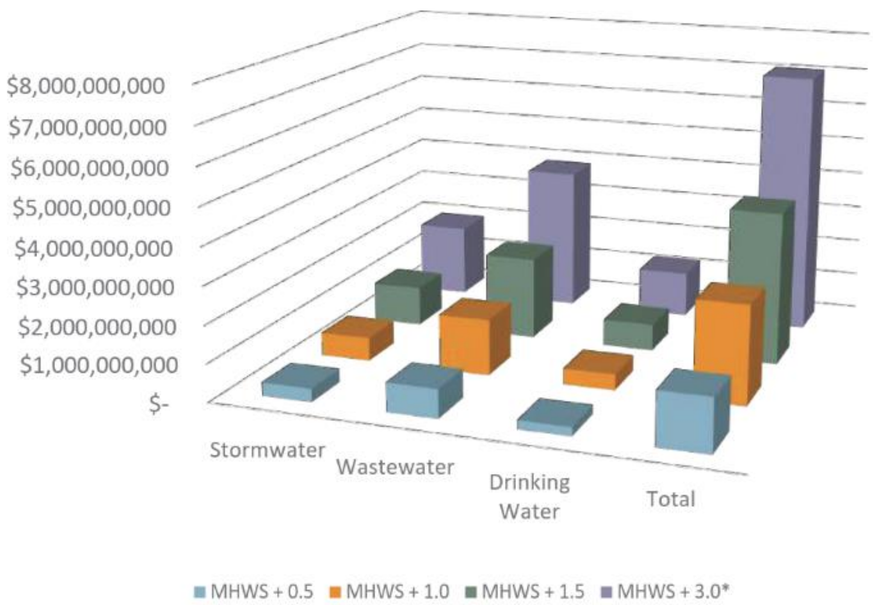


Figure 2.3: Total national replacement value for three waters infrastructure (Simonson, et al., 2019)

The above studies quantify potential exposure in coastal areas, suitable for understanding the quantum of future exposureat a national scale, however little work has been done to quantify risks (uncertainties), impacts or vulnerabilities.

It is noted that at the time of writing this report, the New Zealand Government is preparing for a national climate change risk assessment as recommended within MfE (2018a) using the risk framework prepared by an expert panel (MfE, 2019).

3 Stormwater and wastewater systems in New Zealand

Many of New Zealand's urban areas are located near the country's extensive coastline or clustered on flat river floodplains. Within these towns and cities, the most significant stormwater and wastewater infrastructure is often located where flows concentrate at the coastal or riverine edge. These low-lying assets are particularly vulnerable to sea-level rise and flooding associated with increased rainfall intensities.

A fundamental consideration in understanding issues relating to stormwater and wastewater is the *catchment* (sometimes termed 'watershed'). As stormwater systems are usually gravity-driven, all the excess rainwater that falls on land within the same catchment usually drains to the same place, unless it is intercepted above ground. Similarly, although wastewater is often pumped, the overall system usually drains in accordance with the local catchment (with interceptors and pump stations generally diverting wastewater to centralised treatment facilities outside catchments). It is noted that Māori place cultural importance on allowing water to remain in the catchment of its origin through principles such as kaitiakitanga (maintain resources for future generations), rangatiratanga (to allow iwi/hapū a meaningful role in managing resources in their rohe) and tikanga around connection with waterways, including the mixing of waters between areas or regions (see Section 3.3).

New Zealand's long and narrow topography means that catchment sizes are predominately small, however there are some sizeable catchments, particularly in the central North Island (Waikato, Whanganui), Canterbury/Otago (Waitaki)and Southland (Clutha). The size of a catchment can affect the response of stormwater runoff in that catchment, with small catchments being more likely to experience 'faster responses' and 'peaky' floods, with a short lead time to the peak of the flood, and a relatively high peak flow. Increasing coverage of the catchment with impervious areas (e.g. roads, pavements, roofs) exaggerates the fast runoff response of the catchment (termed 'time of concentration') as well as producing higher runoff volumes as the opportunity for infiltration and evapotranspiration are reduced (ARC, 1999).

Figure 3.1 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. The sections below discuss the system components in more detail.

Figure 3.1: Typical stormwater and wastewater system schematic (EPA, 2015). CSO = combined sewer overflow.

3.1 Stormwater systems

There are various ways in which stormwater systems and their various elements can be characterised. For example, there are conveyance systems and treatment systems, built ("grey") systems and natural ("green") systems. Within the conveyance systems, there are *primary* and *secondary* systems. *Primary* stormwater systems include open and closed conduits or channels, and are required to cater for flows generated by a specified 'design' rainfall event – typically the 10% AEP[5] flow (with an allowance for climate change). Generally, the local council or council-controlled organisation retains ownership of the primary system and is responsible for maintenance and performance (design level of service).

There are two additional sub-types of primary stormwater system – *separated* and *combined*. As portrayed in Figure 3.2, separated systems are intended and designed to convey stormwater only (and contain no wastewater[6]), whereas combined systems are designed to take both wastewater and stormwater and convey this to a treatment plant. During larger rainfall events, combined systems overflow, causing untreated effluent, diluted with rainwater, to discharge to receiving environments. Many separated systems are also subject to an influx of stormwater during rainfall events (due to combination of illegal connections and leaking pipes) which can also result in overflows and discharge to receiving environments.

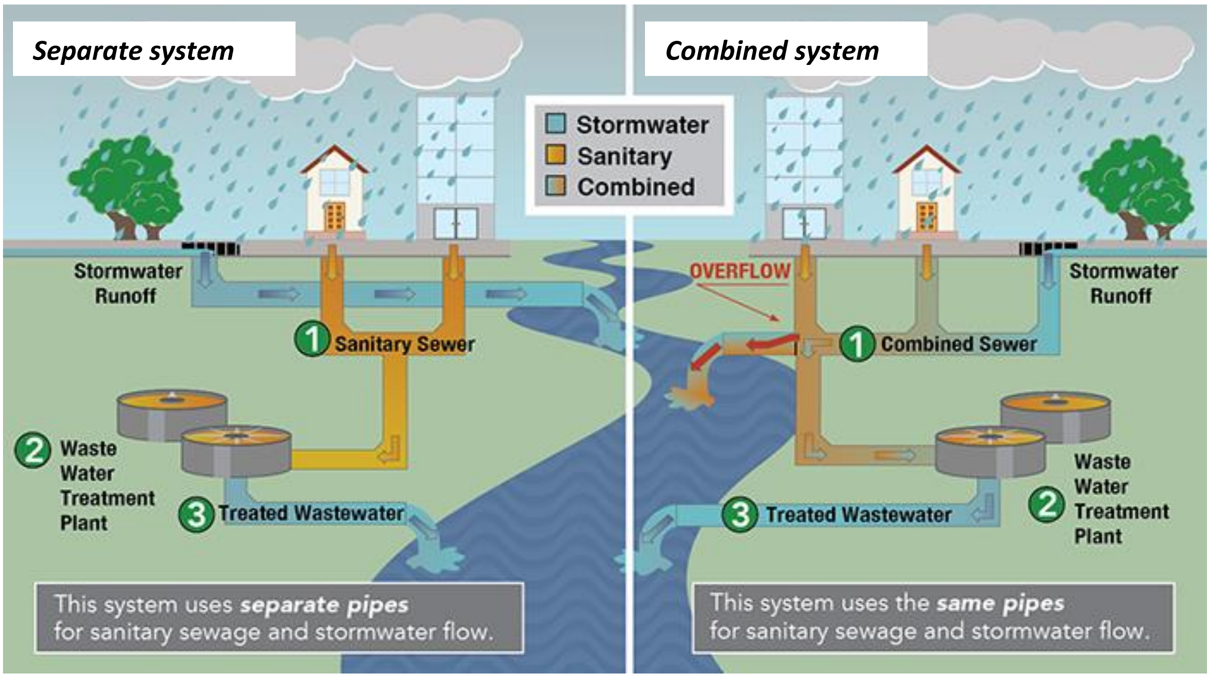


Figure 3.2: Separate and combined systems (Source: D.C. Department of Energy and Environment)

Secondary stormwater systems are designed to cater for flows in excess of primary system design capacity – and generally include overland flow paths and ponding/storage areas. These are typically aligned with natural flow paths. Ownership of secondary systems rely commonly on utilising either public or private land – which for the latter is usually registered as an easement on a land title.

[5] Annual Exceedance Probability
[6] It is acknowledged that in many separated stormwater systems it is common that illegal or unknown wastewater connections exist meaning that wastewater can enter the system and discharge untreated.

Overland flowpaths at a minimum must be capable of producing protection to the surrounding buildings from flooding for a 2% AEP rainfall or flood event (Building Code: Clause E1 Surface Water).

Stormwater infrastructure associated with government assets, such as state highways and rail corridors is owned and maintained by those state owned enterprises and designed to a level of service appropriate to the criticality of the infrastructure (NZTA 2016, NZTA 2010).

A key focus of this research project is to investigate elements of stormwater systems and networks in relation to climate change, and in this regard, we provide a list of these elements in Table 3.1 below (Auckland Council, 2015a)

Table 3.1:1 Types of stormwater systems / assets / elements included in this study

	Included in study	Not included in study
Natural systems	• Streams (ephemeral, intermittent and permanent) • Overland flow paths and ponding areas • Natural ponds and wetlands	• Ground aquifers
Built systems	• Conveyance: – Overland flow paths (including roadside channels) – Piped network[1] (including catchpits/sumps, manholes, inlets and outlets, pump stations) – Constructed channels – Stopbanks, control gates, tide flaps • Treatment: – Stormwater quality improvement devices (such as constructed wetlands, ponds, rain gardens, swales) – Proprietary filter devices • Construction stormwater management systems • Infiltration devices	• Diversion devices • Control structures • Living roofs • Rainwater tanks • Pervious pavements

[1] *Combined stormwater/wastewater systems are discussed as part of the reticulated wastewater system*

Within the sections below we describe the above systems and elements in further detail.

3.1.1 Stormwater conveyance

Stormwater conveyance systems exist to provide a route for stormwater to be conveyed safely through a catchment. These include primary and secondary networks, waterways and overland flow paths. A description of the components and design considerations for each of these are listed in Table 3.2 (Auckland Council, 2015a).

Table 3.2: Stormwater conveyance types and description

Stormwater asset type	Description
Stormwater conveyance	These are generally buried pipeline systems that convey stormwater with pipe diameters ranging from 100 mm up to over 1 m. Generally pipe depths are set at a minimum depth below ground level (0.6 – 1.0 m) to prevent stress loading from traffic. Flow is typically gravity driven. Pipe materials include reinforced concrete, polyvinyl chloride (PVC), polyethylene (PE), Polypropylene (PP). Additional system components include: Manholes, chambers, sumps/ catchpits, pumping stations (rare), soakage pits, tide gates or valves.
Urban waterways	These include either natural or engineered channels e.g. concrete lined channels (see Figure 3.3 for an example of an urban waterway). Associated system components include: bridges, culverts, inlets, outlets.
Overland flow paths	Secondary overland flow paths provide an alternative route which takes flow which is in excess of the capacity of the primary system. These often flow along roads or through private property (see Figure 3.4).
Pump stations	Pump stations are less common, and are required in instances where gravity conveyance is not possible. Pumping is generally avoided for stormwater conveyance due to the need for secondary flow path provision, increased running costs and maintenance requirements (see Figure 3.4 for an example of a pump station).

Figure 3.3: Kaiwharawhara Stream, a natural urban waterway in Wellington (Source: Maarten Holl/ Fairfax NZ)

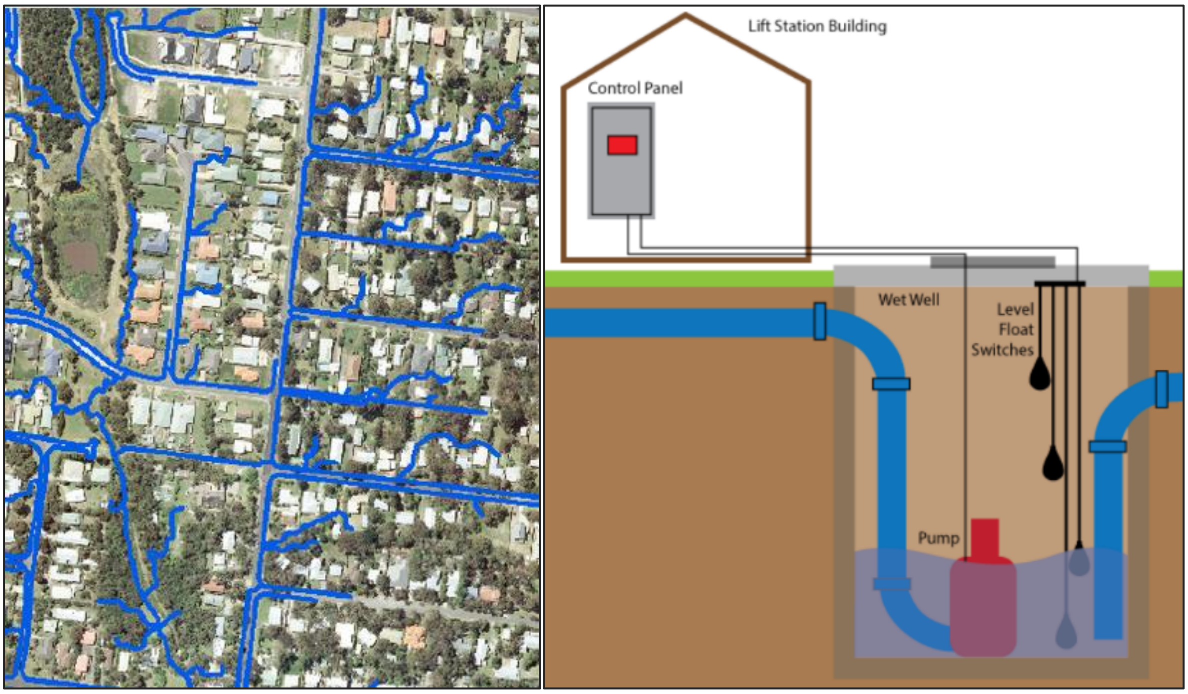


Figure 3.4: Overland flow paths (blue lines) (Source: ResearchGate.net), left, and Stormwater pump station (or lift station) (Source: Kevin Fiedler), right.

3.1.2 Stormwater treatment devices

Stormwater treatment devices are used to remove sediment and other contaminants from stormwater runoff. They can also be designed to detain/attenuate peak flows, retain flows for subsequent reuse, or to allow infiltration to groundwater. These devices are a requirement in many urban areas where water quality or quantity concerns exist and are sometimes used on upgraded state highways (noting NZTA have a protocol to treat stormwater runoff for any new project). A description of the purpose and design components of each device is listed in Table 3.3.

Table 3.3: Stormwater treatment devices and descriptions

Stormwater asset type	Description
Bio-retention cells/raingardens	Raingardens treat stormwater to improve water quality and retain small volumes of water depending on lining options and in-situ ground conditions. Raingardens, bio-retention swales and tree-pits are sunken gardens positioned to receive stormwater (see Figure 3.5). The combinations of plants and soil are designed to filter contaminants. These devices are intended to provide treatment to the 'first flush' of runoff and perform most effectively for smaller, more frequent rainfall events. Additional benefits include temperature reduction and moderating changes in frequent flow hydrology.
Proprietary filters	Proprietary filters typically comprise of a buried chamber with screens, filters, flow diversion and or chemical treatment to remove particulate contaminants from stormwater.
Constructed stormwater wetlands	Wetlands treat stormwater to improve water quality while providing detention of small and large volumes of water to

	reduce peak flows and changes in frequent flow hydrology. Constructed stormwater wetlands are ponded areas which are planted (generally with native species) and are designed to mimic the filtration and biological adsorption properties of natural wetlands (see Figure 3.6).
Detention ponds	Detention ponds provide capacity for detention of runoff from medium and large rainfall events to reduce peak flows.
Infiltration devices	Infiltration devices provide retention of stormwater, removing it from the stormwater system by discharging it to the groundwater table (Figure 3.7). Infiltration cannot be used in areas with impermeable soils such as clay.

Figure 3.5: Raingarden at Wynyard Quarter, Auckland (Source: MetroGreen)

Figure 3.6: Brylee Reserve stormwater treatment wetland. Papakura, Auckland (Source: Stu Farrant))

Figure 3.7: Stormwater detention and infiltration chamber system (Source: Humes, ChamberMaxx)

3.1.3 Urban stopbanks

Stopbanks are designed to confine floodwaters within channel banks, and historically have been constructed to enable land development for urban areas and farming. New Zealand has come to rely on the protection provided by over 350 flood protection schemes (both rural and urban), river control and land drainage systems (T+T, 2018).

Urban stopbanks are generally designed to a high level of service (e.g. greater than 1% AEP, or in some cases up to 0.2% AEP or higher) as specified by local authorities. Stopbanks are often earth bund structures that are formed parallel to a watercourse / river. When space is limited, these structures can be narrowed and steepened or even constructed from concrete. The construction of new stop banks is generally discouraged due to requiring ongoing maintenance for the prevention of settlement and possible piping failure (BOP 2014). They can also have an extremely high consequence of failure ("residual risk"), particularly in an urban context.

The effectiveness of stopbanks, combined with the low frequency of large flood events has led to a low public awareness of the significant risks faced by protected communities, until there is a failure (T+T, 2018). Flood risk is expected to increase as climate change leads to more extreme weather events and sea-level rise.

3.1.4 Construction stormwater management systems

Construction management systems provide treatment for stormwater runoff from sites where earthworks cause disturbance to land. These systems are designed to prevent erosion and the discharge of sediment, often referred to as 'erosion and sediment control'.

Construction management stormwater systems include diversion channels, sediment retention ponds, silt fences (see Figure 3.8), as well as coagulation and flocculation treatment.

Figure 3.8*: A silt fence used for erosion and sediment control*

3.2 Wastewater systems

A wastewater system is typically a network of pipes (reticulation) that collect and convey wastewater from urban centres or towns to a wastewater treatment facility. Wastewater systems can be of several types including combined, separate, pressurized, and vacuum. Though many sewer networks employ the use of pumping stations to create positive or negative pressure, gravity is used whenever possible. Wastewater treatment can involve a wide range of processes including screens, sedimentation tanks, filters, clarifiers and oxidation ponds. Figure 3.9 illustrates various wastewater system components and how they connect.

Treated wastewater is discharged either to the ocean, rivers or via land application or deep injection. The impact on the receiving environment is dependent on the quality of the effluent (i.e. level of treatment), the quantity of effluent, and the assimilative capacity[7] of the receiving environment (water or land).

In areas that are not connected to a reticulated network, on-site wastewater treatment is used.

Figure 3.9: Typical wastewater system components (CCC, 2018)

The sections below summarise the various components of wastewater systems in further detail.

3.2.1 Reticulated wastewater system

A reticulated wastewater system consists of pipe networks to convey domestic and industrial wastewater to a wastewater treatment plant. Pump stations are necessary where gravity cannot be used to drain wastewater. In urban wastewater networks these pump stations can include large chambers, with significant storage capacity. Pumped sections operate under pressurised conditions, which may be short connections within the network, or major conveyance routes termed 'rising

[7] Refer Section 4.2.2.5 for definition.

mains'. In catchments where stormwater runoff enters the wastewater system, this type of conveyance is referred to as 'combined' (Figure 2.1). This typically occurs in older infrastructure, and construction of new combined systems is no longer considered best practice. In combined systems, during large storm events, stormwater runoff can exceed the capacity of the conveyance system or treatment plant, causing discharge of untreated or partially treated effluent.

Descriptions of the various wastewater conveyance system components are provided in Table 3.4.

Table 3.4: Wastewater conveyance system components and description

Wastewater conveyance component	Description
Gravity pipeline conveyance	Pipeline that relies on gravity to convey wastewater flow. Gravity pipes are usually constructed with Vitrified clay (VC), PVC, Polyethylene (PE), Glass-fibre Reinforced Plastic (GRP) and Concrete (Watercare, 2015). Pipe sizes are generally no smaller than 100 mm and can be up to 4.5 m, such as the Auckland Central Interceptor.
Pressure pipeline conveyance	Pipeline that requires a pump or vacuum system to force flow uphill (see Figure 3.10). Materials for pressure pipes may include High Density Polyethylene (HDPE), Stainless Steel (SS), Polyvinyl Chloride (PVC) or Ductile Iron (DI) which are rated to a high pressure. Pipe sizes are typically smaller than gravity pipes. Private pressure connections (with a private pump station) are typically required to have 24 hours storage in the event of a power cut or pump failure (Watercare, 2015).
Separated pipeline conveyance	Pipeline that is designed to convey wastewater only and can be pressurised or gravity driven.
Combined pipeline conveyance	Pipeline that is designed to collect both stormwater and wastewater and is usually gravity-driven but can be pressurised (see Figure 3.11).
Pump stations	These are constructed where local topography means that gravity flow is unattainable. Typically pump stations consist of a wet well to collect effluent, along with pumps, valves, meters, electrical equipment and control systems (Laverack, et al., 2009), refer to Figure 3.12. Materials are generally designed for maximum corrosive resistance. This is because pump stations are susceptible to septicity[8] within the wet well and connected pipework, odour issues, and corrosion of equipment and pipes. (Watercare, 2015). Pump stations generally require minimum dry-weather storage capacity of 8 hours (Watercare, 2015).
Additional structures	Manholes, air vents, rodding eyes, overflow outfalls, ocean outfalls with diffusers.

[8] Septicity is the result of bacteria growing in sewage and on submerged surfaces, resulting in the formation of sulphides. These can cause wastewater to turn black and give off a foul odour.

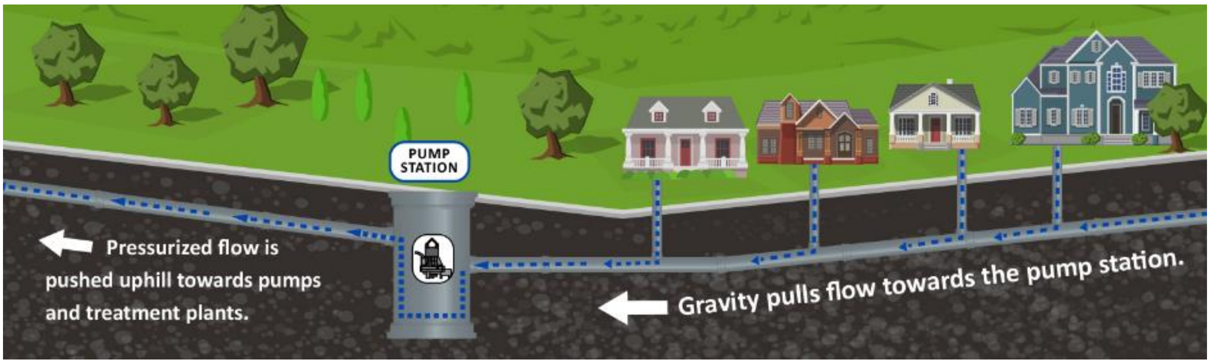


Figure 3.10: Example of pressure pipe conveyance, left, and gravity pipeline conveyance, right (Source: MSD Project Clear)

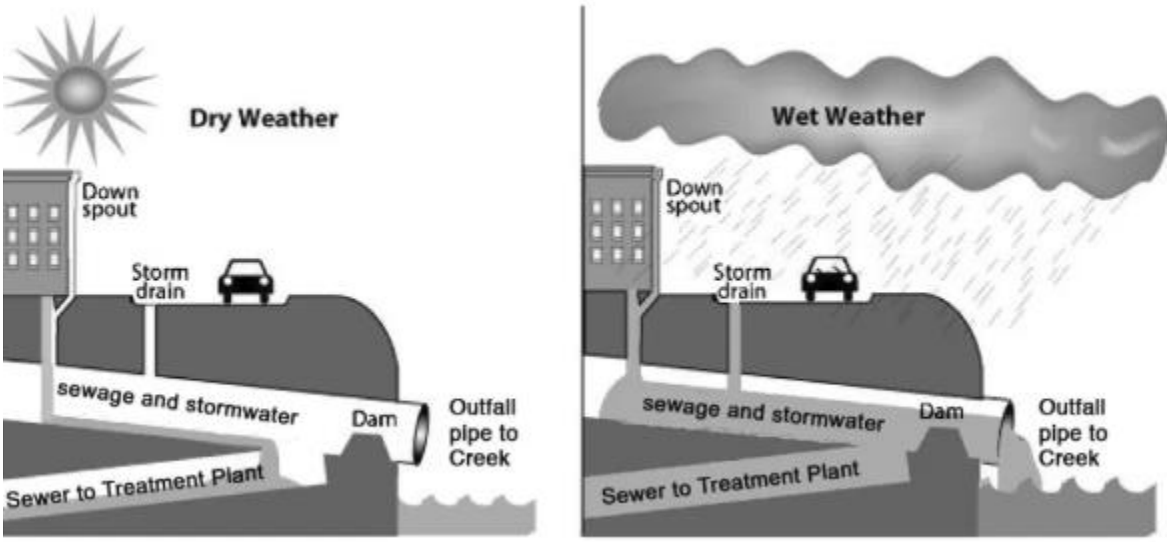


Figure 3.11: Combined stormwater & wastewater system - during dry / wet weather (Ashland Borough, 2018)

Figure 3.12: Project Hobson pump station, left (Fletcher Construction, 2010), and example pump station, right (Rebuild Christchurch, 2015)

3.2.2 Wastewater treatment plants

Wastewater treatment plants (WWTPs) vary widely across New Zealand and can include a wide range of processes including screening, sedimentation, filtration, clarifiers, oxidation ponds, etc. Of approximately 330 council-operated WWTPs, the smallest serves seven households (Cass and Lowe, 2016) and the largest, Mangere Wastewater Treatment Plant, serves a population of over 1,000,000 (Watercare 2015). Approximately 93% of all New Zealand's wastewater is treated within a WWTP, with the remainder treated by on-site wastewater systems.

Treated wastewater is discharged either to the ocean, rivers or via land application (WaterNZ, 2016). Refer to Figure 3.9 for a typical wastewater treatment plant layout. A description of the components of wastewater treatment plants is provided in Table 3.5.

Table 3.5: Wastewater treatment plant system components and description

WWTP component	System components and description
Treatment plants	Wastewater treatment plants range in size and complexity. Larger scale WWTPs have primary, secondary and tertiary treatment: **Primary:** Screening and grit removal **Secondary: Suspended Growth Systems:** These include systems such as activated sludge processes (reactors and, biological nutrient removal (BNR)), clarifiers, aeration systems, etc. **Fixed Growth Systems:** These include trickling filters for biological removal, often paired with aeration tanks and clarifiers. **Tertiary:** UV disinfection of secondary effluent.
Oxidation ponds	Oxidation ponds are often used as treatment for domestic wastewater from smaller communities and are considered primary and secondary treatment. They are shallow ponds for biological treatment of wastewater that utilise algae and wind action (New Zealand Water and Wastes Association, 2005).
Sludge management	Typically consists of digesters and sludge drying. Sludge is generally either sent to landfill or applied to land in New Zealand.
Effluent Disposal	Discharge to the ocean, rivers, or via land application or deep injection. Assets can include storage basins (for staged discharges), pumps, outfalls, spray irrigators etc

3.2.3 Onsite wastewater systems

Onsite wastewater systems treat wastewater and return it to the environment generally within the boundaries of a particular site. A typical arrangement for these systems is shown in Figure 3.13, where domestic effluent is treated to an acceptable level through a septic tank or proprietary treatment device, then discharged to a disposal field where soil processes treat effluent further (Auckland Council 2004, TP 58). The most basic of these systems, the septic tank, typically relies on gravity and biological processes. More sophisticated systems rely increasingly on pumps and regular servicing of filtration for sustained performance.

Table 3.6 describes septic tanks as well as other types of on site devices.

Table 3.6: On-site wastewater treatment devices

Asset type	System components
Primary on-site wastewater treatment	Septic tank and dispersal field (Figure 3.13). The septic tank requires regular (3-5 yearly) pump-out maintenance (MfE, 2008c).
Secondary on-site wastewater treatment	These systems are usually proprietary devices that use biological processes such as aerated wastewater treatment, vermicomposting, dosing and filtration. Treated effluent is discharged to a dispersal field (MfE, 2008c). Some systems are gravity fed, others require pumping and power supply for treatment. 24 hours of back up storage is often required.
Tertiary on-site wastewater treatment	This involves polishing of secondary treated effluent through filtration or disinfection - Chlorine, ultraviolet or ozone disinfection (MfE, 2008c).
Composting toilets	These are self-contained or split systems with a composting chamber located nearby the toilet. These systems use little or no water, and facilitate the aerobic breakdown of organic matter for reuse onsite.

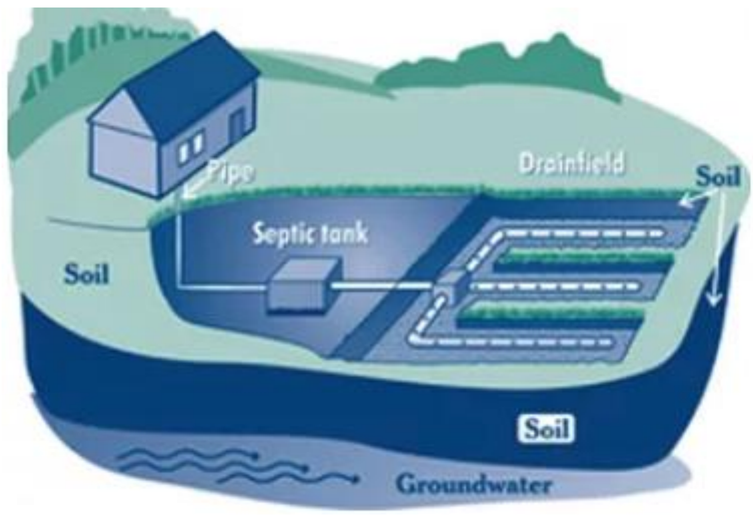


Figure 3.13: Primary on-site wastewater treatment (Source: US EPA)

3.3 Māori relationship with stormwater and wastewater

Māori have a unique relationship with the natural environmentand with water in particular (and by inference, stormwater and wastewater). There are a number of key concepts which are useful in describing this:

Kaitiakitanga (guardianship and protection)

As kaitiaki, Māori are guardians of the sky, sea and land of Aotearoa, New Zealand. 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).

Te mana o te Wai and Wai Tapu

Te Mana o te Wai is the integrated and holistic well-being of a freshwater body. Te Mana o te Wai is recognised as an integral part of the national freshwater management framework. Additionally, the concept of wai tapu relates to water bodies with special significance to Māori. These values must be upheld by preventing the ingress of human or animal waste, contaminants or excessive sediment (MfE, 2014). This relates closely 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 and water to Māori as a cultural, social and economic resource, makes them particularly vulnerable to the impacts of climate change (MfE, 2017a).

Integrated approaches for design

Te Aranga Design Principles are a cultural landscape strategy/approach to design which incorporates a series of Māori cultural values and principles. These include; Mana, Whakapapa, Taiao, Mauri Tu, Mahi toi, Tohu and Ahi Kā. The Te Aranga Design Principles address the processes of economic, social, environmental and spatial development changes. They are a set of outcome-based principles founded on Māori cultural values and formulated to provide practical guidance for enhancing outcomes for the design environment (Paul, 2017).

Te Aranga design principles have been adopted by Auckland Council to provide a clear process for Council engagement with mana whenua and how to enhance mana whenua presence, visibility and participation in the design of the physical realm (Auckland Council, 2019). These principles can be applied to help inform culturally appropriate stormwater and wastewater management / design (Cunningham, et al., 2017).

3.3.1 Māori view of wastewater and wastewater treatment

Māori (as tangata whenua) have a traditional relationship with their ancestral lands, waters, sacred places and other "taonga" or things important to them (Bradley, 2016). Within a traditional Māori world-view, places or activities related to human waste were deemed to be tapu or spiritually dangerous (Bradley, 2016). Anything deemed tapu was avoided and people understood that the consequences of violating this could range from misfortune to serious illness, even death (Bradley, 2016).

Māori have a cultural aversion to the discharge of raw or treated human wastewater to natural waterways, as well as the transportation of wastewater past marae, urupā and other sacred areas, often regardless of the level of treatment of the wastewater (Bradley, 2016).

In considering wastewater management and disposal, tangata whenua view wastewater in a holistic manner, generally irrespective of the methods of treatment (MfE, 2003).

3.4 New Zealand legislation and guidance for climate change relevant to "2-waters"

The section summarises existing legislation and guidance for climate change generally, and for stormwater and wastewater systems specifically.

The New Zealand Resource Management Act 1991 (RMA) gives legislative mandate to have particular regard to the effects of climate change [s7(i)]. Effects include potential effects of high probability, or low probability (which have high potential impact), cumulative effects over time, or in combination with other effects whether positive or adverse, temporary or permanent and whether past, present or future [s3]. The RMA also establishes a hierarchy of planning documents. This includes the mandatory New Zealand Coastal Policy Statement and other national policy statements, national environmental standards, national planning standards, regional policy statements, regional plans, and district plans. Through this hierarchy, councils are empowered to manage new and existing development, including where such development may be exposed to avoidable natural hazard and climate change effects.

Recent changes to the Section 106 of the RMA empower consent authorities to refuse to grant subdivision consents, or impose conditions on these consents, where there is significant risk from natural hazards. It requires an assessment of the proposal of the risk from natural hazards and is reinforced in Section 6(h) by the management of significant risks from natural hazards being a matter of national importance.

The purpose of the New Zealand Coastal Policy Statement, Policy 24 (NZCPS) (DOC, 2010) is to state policies in order to achieve the purpose of the RMA in relation to the coastal environment of New Zealand. The NZCPS requires that areas in the coastal environment that are potentially affected by coastal hazards be identified. This process is required to include assessing hazard risks over at least 100 years, including having regard to sea-level rise and the effects of climate change taking into account national guidance and the best available information of likely effects of climate change. Policy 25, reinforced by the over-arching Objective 5, sets requirements to avoid increasing risk of social, environmental or economic harm and from redevelopment or land use change in these areas or locating new development away from areas prone to coastal risks. It also sets requirements to encourage activities that reduce the risk of adverse effects from coastal hazards. The policy also requires consideration, and encourages managed retreat for existing development in areas potentially affected by coastal hazard risk and discourages the use of hard protection structures. Alternatives to hard protection structures, including natural defences are promoted.

Ministry for the Environment guidance for local government on coastal hazards and climate change (MfE, 2017d) framed around a 10-step decision cycle using a dynamic adaptive planning approach. It presents findings and projections of the Fifth Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC), and provides guidance to local government on performing hazard, risk, and vulnerability assessments, and encourages collaborative community engagement. Dynamic (anticipatory) adaptive planning for climate change imapcts on coastal communities and infrastructure is encouraged within this guidance, which reflects the growing understanding of the variability of climate change effects and the wideningwidening range in uncertainty present in sea-level rise and other climate change drivers.

The New Zealand Standard for Land Development and Subdivision Infrastructure (NZS 4404:2010) requires that climate risk is managed throughout the design life of infrastructure, and recommends that an allowance for sea-level rise and increased frequency of extreme weather events is provided. The standard refers to guidance documents from the Ministry for the Environment for specific details.

Under the Section 71 of the Building Act 2004, a building consent authority must refuse to grant a building consent if the land on which the building work is to be carried out is subject to a natural hazard, unless adequate provision has been made to protect the land, building work or other property or to remedy the damage. Additionally, the Act requires a minimum 50-year design life for major building elements, however is silent on designing for climate change, other than by inference in the Building Code (Clause E1) that surface waters, resulting from an event having a 2% AEP shall not enter buildings (which is implied to apply over the design life).

The Local Government Act 2002 provides the mandate for local government to engage with communities around monitoring and responding to evolving climate change risks, in particular relating to the Long Term Plan (LTP), Annual Plans, Infrastructure and asset plans, policies, and funding. Relevant sections include;

- Sections 78, 82, 82A, 87, 95A 95B consultation requirements for LTP and Annual Plans and policies;
- Section 97 is critical in the context of adapation plans, which must be in the LTP if a decision to alter significantly the intended level of service provision for any significant activity undertaken

by or on behalf of the local authority, including a decision to commence or cease any such activity, is made;

- Section 125 requires local government from time to time to assess the provision of water and sanitary services which is a monitoring provision that can be used for monitoring relevant signals and triggers.

The Climate Change Response (Zero Carbon) Amendment Act 2019 provides a framework by which New Zealand can develop and implement climate change policies that contribute to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels. The Act also requires New Zealand to prepare for, and adapt to, the effects of climate change. This includes preparing a National Climate Change Risk Assessment (NCCRA), and National Adaptation Plan (NAP), and reporting on the implementation of the NAP.

In addition, the Act includes an adaptation reporting power - which will also be used to collect information from organisations (including Local Government, Council Controlled Organisations, and lifeline infrastructure utilities) on climate change risks to infrastructure and services. This power will support the NCCRA and NAP and will enable providers of public infrastructure and services, and affected communities, to improve their resilience.

The Civil Defence and Emergency Management (CDEM) Act 2002 encourages and enables communities to achieve acceptable levels of risk by identifying risks and applying risk reduction management practices as well as requiring planning and preparation for emergencies and for response and recovery in the event of an emergency. The CDEM Act also requires a Lifeline Utiliity (defined in Schedule 1, Part B) to "ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency" (Section 60). Providors of stormwater and wastewater systems are Lifeline Utility and as such, this places responsibilities on them to have resilient systems and to adapt to the increasing frequency and magnitude of extreme events as a result of climate change.

There is current misalignment in the various regulatory instruments in regards to climate change adaptation. (MfE, 2017a) identified the following as key issues:

- Lack of a clear legal mandate for councils to plan for and take action under the RMA to reduce climate related risk;
- Competing objectives across legislation and policies related to climate change adaptation, and with resilience and disaster risk reduction; and
- The inadequacy of assessment and planning tools being used under the RMA to account for changing risk and uncertainties when planning now for long timeframes.

In terms of wastewater system design, there is little specific guidance which relates to potential climate impacts.

4 Impacts of climate change on stormwater and wastewater systems

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, rising mean or extreme temperaturestemperatures, sea-level rise and wind (ref Section 2.3.3). An initial range of potential impacts for each system component was developed through consultation with a panel of experts during a workshop in early May 2018. These impacts were further researched through literature review, and are discussed in detail below. The literature review also identified additional impacts not identified during the workshop process.

For each climate impact we have assessed the severity of impact into three categories (low, medium and high). This was based on stakeholder input and will allow focus on those impacts, which are deemed most severe.

High severity	Medium severity	Low severity

4.1 Impact of climate change on stormwater systems

Climate change will impact all elements of stormwater systems, and the functions they provide in protecting communities, natural environments, and the built environment. These functions relate to stormwater conveyance as well as stormwater quality management.

Impacts will range from the occasional inconvenience (e.g. temporary ponding on roads), to short term problems (e.g. flooding leading to minor disruption), through to permanent changes which may make some places unusable for their current purposes. Flooding, erosion and higher water tables may eventually make buildings uninhabitable and community facilities unusable, permanently damage roads and other infrastructure, and cause closure of businesses (PCE, 2015; Sweet & Park, 2014). Ongoing SLR causing decreased levels of service of stormwater and drainage systems, along with disruptive roadway flooding will be the first signs heralding more substantial impacts on residential housing and businesses in low-lyinglying coastal areas.

Many of the existing problems with stormwater are likely to be exacerbated with climate change. Infrastructure age and location affect the level of risk facing urban areas around New Zealand (NIWA et al. 2012). In general, climate change effects on all infrastructure may result in both existing urban areas, and areas where urban expansion is proposed becoming potentially inappropriate (MfE, 2008b). It may also result in existing infrastructure becoming inadequate or inappropriate which may result in the costly retrofitting of systems (MfE, 2008b). The ability of the stormwater system to cope with changes due to climate change will often depend on the nature and design of the system; for example, larger systems with spare capacity may not be as sensitive to increases in catchment flows. Smaller systems, particularly in densely populated areas with limited space for overland flow paths, may be more sensitive.

Climate change will also have a direct and indirect impact on stormwater quality. In particular, increased concentrations of contaminants due to prolonged dry spells interspersed with high intensity rainfall will cause acute impacts on downstream receiving environments. Further impacts from increased temperatures of urban paved surfaces, increased flow-related scour and modified flow patterns (reduced base flow and increased incidence of flashy flows) will potentially all contribute to adverse ecological outcomes.

It is acknowledged that different climate drivers will be experienced differently depending on location. The summary below is intended to capture the range of potential impacts on stormwater systems that may arise from climate change across: conveyance systems, water quality treatment devices, stopbanks and construction management systems.

4.1.1 Impact of climate change on stormwater conveyance systems

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

Table 4.1 summarises the most significant impacts and the severity of impact for each component of the system, based on literature review and stakeholder consultation. Increased rainfall (and 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.

The following sections discuss the impacts of climate change on conveyance systems in more detail, including impacts for conveyance systems in general and those specific to waterways or overland flow paths. Only those climate effects that were identified as having medium and high severity are discussed.

Table 4.1: Summary table of impacts from climate change on stormwater conveyance systems

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
Pipelines	• Decreased levels of service and increased flooding • Damage to infrastructure • Increased inflow and infiltration to combined syst.	• Reduced baseflows • Ground settlement • Increased contaminant concentrations and sedimentation • Higher peak flows	• Increased flooding • Damage to infrastructure • Raised groundwater table • Increased ingress of seawater during coastal flooding	
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 • Landslides, scour and erosion • Increased contaminant loading	• Behaviour changes	• Increased flooding	
Pump stations	• Capacity reached, higher energy requirements		• Corrosion • Capacity reached	• Overheating

*based on workshop with TRG

Key:

High severity	Medium severity	Low severity

4.1.1.1 Impacts of increased rainfall on stormwater conveyance systems

This section discusses the impacts of increased rainfall on stormwater conveyance systems. As summarised in Table 4.1, the most significant impacts are identified to be flooding, damage to infrastructure, increased inflow and infiltration, scour and erosion, and increased contaminant concentrations.

Reduced levels of service and increased flooding: Increased frequency of intense rainfall events is predicted to occur throughout New Zealand, which will lead to increased surface flooding and stormwater flows, and increased frequency of groundwater level changes (MfE, 2008b; NIWA, et al., 2012). There is also potential for increased soil erosion along waterways, including landslides (MfE, 2008b), (for example, in Figure 4.1).

Figure 4.1: Landslide in the Manawatu Gorge (Source: NZTA)

In general, all stormwater conveyance systems experience flooding whenever rainfall is in excess of that for which the system is designed to accommodate (for example, Figure 4.2). This is usually managed by the provision of secondary flow paths, but as peak flows increase, flow paths and waterways will be increasingly under-capacity and the resulting increased flood extents will cause a greater likelihood of damage to properties and infrastructure (MfE, 2008b). Additionally, changes in mean rainfall effects the initial water retention capacity of pervious surfaces (initial abstraction), increasing runoff volumes, and shifting the runoff response of a catchment (Shaw, 2005)

Figure 4.2: Flooding in Christchurch in 2014 (Source: Stacy Squires)

While new conveyance systems are generally designed to accommodate increased rainfall intensity due to climate change, infrastructure that was installed prior to current guidelines will often be under capacity (MfE, 2008a; NIWA, et al., 2012; ONeil, 2010). Additionally, many systems are not designed to manage 'over-design' events in a safe manner.

Impacts on stormwater quality: Urban stormwater quality concerns are currently a major problem in New Zealand. A major aspect of this is contaminated stormwater discharging untreated to the natural environment (Auckland Council, 2015b). Sources of contamination include contaminated groundwater, illegal cross connections or blocked, overloaded or cracked wastewater pipes infiltrating into leaky stormwater systems. These problems are often worst during times of heavy rainfall and will be exaggerated with climate change.

Changes in rainfall patterns (i.e. increased intensity events following extended dry spells) will result in more 'efficient' flushing of urban contaminants into the stormwater system. These will be transported to receiving environments resulting in increased concentrations during small to moderate events. This will increase the frequent of acute impacts on freshwater and coastal ecosystems.

Reduced rainfall combined with increased temperatures could have significant impacts on the quality of surface water resources in northern and eastern New Zealand. In conjunction with this, lower stream flows or lake levels would increase nutrient loading, reduce assimilation capacity and lead to increased eutrophication (MfE, 2008b).

Damage to infrastructure: Increases in wind velocities are often associated with the more intense rainfall events predicted with climate change. This will be location specific but with a trend nationally to increased westerlies. In turn, this will result in changes in rainfall over complex topography – increases upwind of hills and ranges, and may compound some of the issues associated with increasing rainfall mentioned earlier (MfE, 2008b). Additionally, high winds will cause damages due to wind fall, debris and direct damage to infrastructure such as power lines. This can result in blockages of grates, culverts and outlets in the stormwater system, which will also compound some of the impacts listed. Raised likelihood of landslides may also threaten built infrastructure and assets (Neunteufel, et al., 2015). Extreme events may lead to damage to dependant infrastructure (such as power and communications systems) which may cause outages to pumped stormwater systems, leading to flooding.

Increased inflow and infiltration: Urban stormwater quality concerns are currently a major problem in New Zealand. Sources of contamination include contaminated groundwater, illegal cross connections or blocked, overloaded or cracked wastewater pipes infiltrating into stormwater systems. These problems are often worse during times of heavy rainfall and will be exaggerated with climate change.

Scour and erosion: Increases to volume, duration and velocity of flows can cause stream erosion and degraded habitats (Cunningham, et al., 2017). Increased rainfall may also lead to heightened risk of erosion or scour where pipes discharge to the environment, usually at coastal or riverine boundaries (MfE, 2008b). Soil types within the catchment that are erosion prone may experience heightened erosion with increased rainfall or altered wetting and drying patterns. This may cause sediment loads entering the pipeline conveyance system to increase (Shaw, 2005).

Erosion and scour have dual negative impacts, where the act of erosion can cause significant damage to the infrastructure or land, as well as generating pollution. Erosion and pollution from excess sediment can lead to (Auckland Council, 2016 GD05):

- Deterioration of mana whenua, including the mauri of water, mahinga kai, customary rights and kaitiaki initiatives;
- Ecological damage to flora and fauna of freshwater and marine water bodies, such as smothering, deterioration of habitat (stream blockage, reduced light levels, weed growth), abrasion and direct impact to aquatic life);
- Water quality deterioration affecting consumable resources such as mahinga kai;
- Deterioration of aesthetic and recreational values;
- Damage to property and public utilities – drain blockages, sedimentation of ports, marinas, channels and stormwater quality wetlands or dams. Associated disposal costs of dredged material;
- Impacts on recreational and commercial fishing, marine farming and tourism; and
- Loss of habitat in streambeds and banks and also changed downstream habitat due to clogging and sedimentation of the receiving system causing detriment to native species (Cunningham, et al., 2017).

Increased contaminant loading: Scour and erosion associated with higher velocity peak flows cause increases in Total Suspended Solids (TSS) and can also initiate the resuspension of historical sediments (Cunningham, et al., 2017). Higher flow velocities coalesce and tranport more rubbish and debris from the catchment, raisingraising the likelihood of blockages or higher backwater effects that may exceed freeboard allowances. Additionally, nutrients, bacteria and viruses, oil and grease, total dissolved metals, organics, pesticides and gross pollutant loadings may enter waterways more frequently as the catchment hydrology changes (Cunningham, et al., 2017).

4.1.1.2 Impacts of reduced rainfall on stormwater conveyance systems

This section discusses the impacts of reduced rainfall on stormwater conveyance systems. As summarised in Table 4.1, the most significant impacts are identified to be higher peak flows, behavioural changes, reduced baseflow, increased contaminant loading and sedimentation and ground settlement.

Higher peak flows: Antecedent conditions, characterised by reduced rainfall and higher temperatures, influence evaporation rates from organic surfaces and hence the initial water retention capacity. These conditionsconditions can lead to increased runoff response times within a catchment, as dry land results in faster and higher peak flows (Shaw, 2005).

Reduced baseflow leading to blockages: As catchment hydrology changes, long dry periods may lead to increased pipe blockages as reduced baseflows within the stormwater network have insufficient velocity to transport sediment and particulates. Stormwater pipelines are designed with consideration of minimum gradients to ensure self-cleaning of pipes. For example, in Auckland these gradients are designed based on the velocity of flow in the 50% AEP design storm (Auckland Council, 2015a). Currently in most design guidelines, no consideration is given to the likelihood of reduction in rainfall frequency due to climate change, therefore as dry spells increase, the flushing flows necessary to move sediment may not be reached frequently enough to prevent build up and at worst, blockage of pipes.

Reduced baseflow leading to ecological impacts: Stream health will be impacted as watercourses experience more variation in flowrates, and therefore sedimentation and weed growth as well as changes in type/distribution of pest species (MfE, 2008b) (for example, see Figure 4.3). Less water will be available for irrigation in northern and eastern areas of New Zealand, and more generally waterways will see increased problems with water quality (MfE, 2008b).

Figure 4.3: The Selwyn River in Canterbury running dry (Source: John Kirk-Anderson/Fairfax NZ)

Increased contaminant loading and sedimentation: Reduced frequency of rainfall may lead to a build-up of silt, debris and bacteria/viruses in the stormwater network due to a reduction in flushing flows. Contaminants build up in the catchment over time, from sources such as hydrocarbons on roads, heavy metals, litter, and dumping or inadvertent pollution (Auckland Council, 2015b). Reduction in the frequency of rain events causes these contaminants to build up, resulting in higher concentrations of pollution being mobilised once a rainfall event does happen.

Ground settlement: Where pipes are buried in expansive soils (clay), long dry periods (and high temperatures) may cause ground shrinkage associated with dry out. This may cause cracking or misalignment of pipes (Rogers, 1985). As ground surface layers dry out, tree roots may extend further to search for sources of water. This can cause pipe damage from root intrusion (WERF, 2009).

Behaviour changes: Reduction in rainfall frequency can result in changing attitudes towards waterways and overland flow paths. Property owners may be more likely to develop on floodplains or secondary flow paths if they are active less frequently.

4.1.1.3 Impacts of sea-level rise on stormwater conveyance systems

This section discusses the impacts of sea-level rise on stormwater conveyance systems. As summarised in Table 4.1, the most significant impacts are identified to be increased flooding, damage to infrastructure and a raised groundwater table.

Increased flooding: Waterway capacity will be impacted where submerged infrastructure near coastal edges and raised tailwater conditions will lead to increased flooding (Shaw, 2005).

Damage to infrastructure: Effects of sea-level rise, which will be exacerbated from land subsidence, and other changes will vary regionally and locally. Coastal erosion is likely to be accelerated where it is already occurring and erosion may become a problem over time in coastal areas that are presently either stable or are advancing (MfE, 2017d) (for example, Figure 4.4) resulting in damage to coastal stormwater assets. Salt-water inundation back up the network from coastal outfalls or malfunctioning tide flap gates (e.g. debris) may also lead to accelerated corrosion of assets (TRG, et al., 2018).

Figure 4.4: Damage to road at Whakatete Bay due to coastal flooding and wave overtopping(Source: Meghann Rawlings)

Raised groundwater table: Sea-level rise has the potential to raise groundwater levels in coastal areas. This will primarily affect areas where groundwater is already tidally influenced, however effects may be felt more widely than this (MfE, 2017d). A raised groundwater level may cause increased groundwater infiltration into stormwater and wastewater systems, reducing the capacity and increasing water salinity (Bovarnick, et al., 2014). Permanent inundation may deteriorate the condition of pipes as well as compromising pipe bedding (Guo, 2017). High groundwater levels in

South Dunedin are currently thought to be kept artificially low due to infiltration into the stormwater and wastewater network. Testing has found high salinity in wastewater system during high tide (ORC, 2012). It is likely that this also occurs in stormwater pipes which may, in turn, cause damage to freshwater ecosystems at discharge locations.

Changing groundwater levels cause changes to geotechnical properties, potentially increasing the risk of liquefaction during ground shaking (NZGS & MBIE, 2016). Additionally, rising groundwater levels associated with sea-level rise will increase upward forces from groundwater that may cause flotation of pipes or road foundation instabilities affect pipe networks. Specific design approaches would then be required to accommodate this (Auckland Council, 2015a).

4.1.1.4 Impacts of increased temperature extremes on stormwater conveyance systems

This section discusses the impacts of increased temperature extremes on stormwater conveyance systems. As summarised in Table 4.1, the most significant impacts are identified to be reduced baseflow, warmer water temperatures and freezing.

Reduced baseflow: Increased temperatures are expected to result in catchment wide changes in runoff response. Warmer temperatures may result in decreased runoff volumes, as evaporation and evapotranspiration from increased plant water use across the catchment. This may reduce the baseflow in streams and rivers, as observed in the Colorado River (Xiao, et al., 2018).

Warmer water temperatures: Stormwater runoff from paved surfaces can have a significantly higher temperature than runoff from natural systems (Auckland Council, 2015b). Rising atmospheric temperatures will increase runoff temperatures as well as directly increasing water temperatures within waterbodies (Auckland Council, 2013). Reduced rainfall and increased temperatures could have significant impacts on the quality of surface water resources in northern and eastern New Zealand – with lower stream flows or lake levels leading to elevated nutrient loading and increased potential for eutrophication (MfE, 2008b).

4.1.1.5 Impact of climate change on stormwater pump stations

Given the similarities between stormwater and wastewater pumping stations, the reader is referred to Section 4.2.1.4 for a summary of impacts of climate change on pumping stations.

4.1.2 Impact of climate change on stormwater treatment devices

Stormwater treatment devices include a wide range of systems designed to reduce stormwater contaminants (especially suspended sediment) and manage stormwater volumes / peak flows, prior to discharge. The various devices are presented in Section 3.1.2

Table 4.2 summarises the most significant impacts and their severity for each stormwater treatment device, based on literature review and stakeholder consultation. Increased rainfall and sea-level rise were deemed to have a higher severity of impact on most stormwater treatment devices, reduced rainfall was generally deemed to have a medium or low impact and temperature was deemed to have a high severity of impact on wetlands.

The following sections discuss the impacts of climate change on stormwater treatment devices in more detail, including general impacts and those specific to raingardens, wetlands, detention ponds or infiltration devices individually. The discussion focusses on the climate effects that were identified as having medium and high severity.

Table 4.2: Impact of climate change on stormwater treatment devices summary table

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

**Based on workshop with TRG*

Key:

High severity	Medium severity	Low severity

4.1.2.1 Impacts of increased rainfall on stormwater treatment devices

This section discusses the impacts of increased rainfall on stormwater treatment devices. As summarised in Table 4.2, the most significant impacts are identified to be higher peak flows and increased contaminant loading.

Higher peak inflows: Higher inflow volume or more frequent peak inflows will reduce the level of service of stormwater treatment devices. Devices designed for volume control, such as ponds and wetlands may be unable to accommodate increased runoff volumes and will experience a reduced level of service if they are not able to drain before the next large rainfall event occurs. Higher peak flows passing through wetlands and other biological stormwater treatment devices may cause flooding, scour, and damage to aquatic plants and habitat. This emphasises the importance of the design of devices to include a high flow bypass.

Increased storm intensity with prolonged dry periods between events will likely affect stormwater quality with increased concentrations of contaminants being mobilised in first flush flows (Wilson & Weng, 2011; He, et al., 2011). 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). High flows may disrupt the settlement process and shorten the hydraulic residence time within online ponds, resulting in contaminants being washed downstream (Sharma, et al., 2016). It is noted that offline wetlands and raingardens that have been designed to current best practice can be well suited to respond to short duration, high intensity events as the majority of contaminants are delivered in the first stage of rainfall runoff before the bypass is engaged (TRG, et al., 2018).

The impacts of increased rainfall on wetlands have been identified by the New Zealand Department of Conservation (DOC) and include increased loading from nutrient runoff, and changing plant species as water level fluctuations change (Robertson, et al., 2016). The frequency and magnitude of overflow from stormwater treatment devices has been estimated to substantially increase under climate change scenarios (Hathaway, et al., 2014). This may result in an increase in the amount of uncontrolled, untreated runoff discharging to the environment.

Infiltration devices are often used as mitigation against issues that arise from a changing climate by increasing infiltration into the groundwater table and reducing runoff. Increasing rainfall extremes and reduced rainfall frequency (e.g. longer drought period punctuated by intense rainfall events), may reduce the effectiveness of these devices, which operate best when capturing frequent smaller events (Cunningham, et al., 2017). In addition, the increased contaminant concentrations fromfrom increased intensities will further reduce the effectiveness of treating dissolved contaminants and increase the importance of pre-treatment to avoid clogging from particulate contaminants (TRG, et al., 2018).

Raingardens also operate best when capturing frequent smaller events (Cunningham, et al., 2017). Less frequent events with higher peak flows may result in reduced level of service for raingardens.

Higher contaminant loading: Higher peak flows are likely to cause erosion and lead to increases in sediment loads (as discussed in Section 4.1.1), which will in turn be intercepted by downstream stormwater treatment devices.

Clogging of infiltration devices is a common issue, which must be accounted for in the design of these systems. Innovation is ongoing in the industry to reduce the effects of sedimentation, however the capacity of existing systems will be further reduced if higher sediment loading is present in stormwater runoff (Cunningham, et al., 2017).

4.1.2.2 Impacts of reduced rainfall and higher temperatures on wetlands and bio-retention cells

This section discusses the impacts of both reduced rainfall and higher temperatures on vegetated stormwater treatment devices.

Higher temperatures and changes in rainfall could result in a range of impacts on wetland and bio-retention systems (MfE, 2008b), including:

- An increased degree of eutrophication and greater frequency of algal blooms in wetlands;
- An increase in plant morbidity and mortality due to drought stress and a reduction in evapotranspiration capacity;
- Altering of lake margin habitats, including wetlands, with either increased or decreased rainfall (MfE, 2008b);
- Negative impacts on aquatic macrophytes, particularly native species, if lake levels fall (MfE, 2008b);
- A decrease in the habitat range of trout with increased water temperatures (MfE, 2008b); and
- Increased ranges of pest species (e.g., carp), placing even more pressure on aquatic ecosystems (MfE, 2008b).

As summarised in Table 4.2, the most significant impacts are summarised to be plant stress and eutrophication.

Plant stress: Wetlands and raingardens will receive more variation in water volumes and peak flows, as well as experience increased water temperatures and increased evaporation as a result of reduced rainfall and higher temperatures (Xiao, et al., 2018). For wetlands, this is expected to result in reduced water quality, sedimentation and weed growth as well as changes in type/distribution of pest species (MfE, 2008b). Wetlands are designed to mitigate some temperature impacts as the wetland vegetation provides shade and evapotranspiration. However they need to be well vegetated rather than the open-water systems which are common as a result of historic approaches through guidance such as the Auckland Council Technical Publication 10 - TP10 (Cunningham, et al., 2017). Further, wetlands and raingardens, which are designed to be offline, are generally well suited to respond to short duration high intensity events which may be associated with a decreasing frequency of rainfall, as the majority of contaminants are delivered in the first stage of rainfall runoff before the bypass is engaged.

The United Kingdom-funded MaRIUS program (Managing the Risks, Impacts and Uncertainties of drought and water Scarcity) has been developed following the 2011-2012 drought. This project has conducted research into the impacts of drought and water scarcity on society and the environment. The program has found that river-fed wetland ecosystems are more resilient to drought than rain-fed wetlands (such as stormwater quality wetlands) and that many wetland grasses were predicted to lose potential habitat by 2050 due to climate change (MaRIUS, 2018).

Drought stress has been found to cause plant morbidity and mortality (Winston, 2016; Dawson, et al., 2003), which can be particularly severe in unlined systems with permeable underlying soils. Evapotranspiration capacity can also be reduced due to low soil moisture in bio-retention systems. DOC identified the potential for dryland species invasion as groundwater and surface water availability diminishes (Robertson, et al., 2016).

Recent studies in the United States indicated that rising temperatures, changing atmospheric carbon dioxide concentration levels and nutrient levels in runoff (Flanagan, et al., 2015; Megonigal, 2013) may advantage noxious invasive species over native species (Figure 4.5). Diminishing biodiversity due to exotic species invasion may in turn affect wetland performance for flood mitigation, carbon storage, water filtering, overall biodiversity and wildlife habitat (Flanagan, et al., 2015).

Eutrophication: Higher water temperatures and increased evaporation can exacerbate the effects of eutrophication in wetlands (Feuchtmayr, et al., 2009; WERF, 2009). Increased nutrient loading from catchment runoff also can have a major effect, as was experienced within the Whangamarino Wetland in 2017 (refer Case Study 2).

Figure 4.5: Wetlands at the Smithsonian Environmental Research Centre (photo credit: Adam Langley) (Megonigal, 2013)

4.1.2.3 Impacts of sea-level rise on stormwater treatment devices

This section discusses the impacts of sea-level rise on stormwater treatment devices. As summarised in Table 4.2, the most significant impacts are identified to be reduced capacity, salinity and rising groundwater, as discussed below.

Reduced capacity, salinity and rising groundwater: Sea-level rise will affect all stormwater treatment devices in low lying areas as high tailwater levels will reduce the conveyance capacity, potentially leading to flooding and reduced level of service. Waterlogging of wetlands and raingardens due to raised tailwater or groundwater, can cause plants to die or species to move / migrate (Kirwan & Megonigal, 2013).

In some instances, natural wetland systems have been observed to adapt to sea-level rise by increasing bed level. This mechanism occurs through increased settlement of sediment resulting in a build-up of soil and plant matter (Kirwan & Megonigal, 2013). It is particularly pronounced in wetlands with high sediment concentrations, and can be enhanced by rising atmospheric carbon dioxide levels which encourage plant growth. In constructed wetlands however, natural adaptation would not be as effective. If these engineered wetlands fill with sediment and the ecosystem rises, the capacity for the wetland to treat the necessary stormwater flows would reduce (Kirwan & Megonigal, 2013).

4.1.3 Impact of climate change on proprietary stormwater filters

Based on stakeholder consultation, increased rainfall was deemed to have a medium severity of impact on proprietary filters. Reduced rainfall and temperature extremes were deemed to have a low severity of impact and sea-level rise was deemed to have a high severity of impact on proprietary filters. This section discusses the impacts of climate change on proprietary filters in more detail (as summarised in Table 4.3). The discussion focused on the climate effects that were identified as having medium and high severity

Table 4.3: Impact of climate change on proprietary filters summary table

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
Proprietary filters	• Hydraulic performance		• Reduced capacity • Salinity effects	• Odour

**Based on workshop with TRG*

Key:

High severity	Medium severity	Low severity

The impact of climate change on proprietary devices was discussed during an interview with a supplier of stormwater treatment devices, Stormwater 360 (TRG, 2018, T Brockbank, Stormwater 360, personal communication, May 1, 2018). The interview identified hydraulic performance, reduced capacity, salinity effects, durability and odour as the most significant impacts facing proprietary devices..

Hydraulic performance: Hydraulic potential performance would likely be affected as the systems are designed to treat the first flush event. Changes to these inflow patterns will likely affect the performance of systems.

Reduced capacity: Proprietary devices are often installed in low lying locations with limited longitudinal gradient with the surrounding system. The devices contribute further headlosses within a stormwater system, and therefore higher rainfall intensity related to climate change will likely exacerbate flood risk.

Salinity effects: Sea-level rise may result in exposure to a saline environment for some low lying devices. This poses a risk of corrosion of fittings unless they have been specifically designed. Sea-level rise may also deteriorate the performance of filter material due to salinity. Zeolite is a common media in devices, which can react with salt over time.

Odour: In some locations, high temperatures can exacerbate odour problems. Odour is generally only a problem in locations where the composition of contaminant loading contains high biological content.

4.1.4 Impact of climate change on urban stopbanks

Based on stakeholder consultation, increased rainfall and sea-level rise were deemed to have a high severity of impact on stopbanks. Reduced rainfall and temperature extremes were deemed to have a low severity of impact on stopbanks. This section discusses the impacts of climate change on stopbanks in more detail, as summarised in Table 4.4. The discussion focused on the climate effects that were identified as having medium and high severity. The focus here is on engineered stopbanks but ad-hoc or informal (unconsented) berms or stopbanks will be tested further by climate changes.

Table 4.4: Impact of climate change on stopbanks summary table

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
Stopbanks	• More overtoppingoverto pping / flooding (relative to past design criteria)) • Breaches, structural failure, erosion and scour • Structural failure (due to groundwater fluctuation)	• Structural failure (due to ground settlement)	• Flooding • Wave overtopping	

**Based on workshop with TRG*

Key:

High severity	Medium severity	Low severity

As summarised in Table 4.4, the most significant impacts of climate change on stopbanks were identified to be flooding and structural failure.

Flooding: Guidance on climate change effects and impacts for local government in New Zealand (MfE, 2008b), highlights that stop banks and associated systems will be affected by increased rainfall - resulting in reduced capacity and increased frequency of system flooding as well as increased peak flows in watercourses causing erosion. Changing floodplain extents pose an increased likelihood of damage to properties and infrastructure (MfE, 2008b). Raised downstream water level at river mouths, especially from sea-level rise, is also likely to increase the risk of flooding.

Structural failure: Geotechnical failure of stopbanks can be influenced by the duration of hydraulic stress on stop banks, which may be increased as rainfall intensity increases (relative to the original design criteria). Changing frequency of large rainfall events may result in multiple events in a short space of time, causing increased instances of bank-full flows and saturation of the embankment risking piping and geotechnical failure. More frequent and longer dry spells and greater fluctuation of groundwater may cause settlement or instability of stopbank foundations (TRG, et al., 2018). A photograph of the flooding following the stopbank failure at Edgecumbe in early 2017 is shown in Figure 4.6, and discussed further in Case Study 3.

The methods used by local councils to understand, interpret and approach both technical and non-technical river management issues are inconsistent and that this variability may expose some communities to a greater likelihood of asset failure (T+T, 2018). The impacts of climate change on stopbanks will exacerbate this more general systemic issue.

Figure 4.6: Edgecumbe flooding during the breach of the Rangitaiki River stopbank breach (Source: RNZ, 7 April, 2017)

4.1.5 Impact of climate change on construction stormwater management systems

Construction stormwater management systems are temporary assets, with shorter design liveslives. In some respects this makes the systems more adaptable, as systems can be designed to accommodate the new risks posed by climate change. However unless adaptation to system design occurs, or the system is subject to a record rainfall event (not previously encountered), these systems are considered to pose a high risk, as they perform an essential task in water quality management during the early phases of construction. Figure 4.7 shows an example of the extent of uncontrolled sediment runoff in one of New Zealand's streams – as a result of a poorly managed construction activities and erosion and sediment control mitigation. Construction management systems are mainly targeted at the prevention of uncontrolled sediment discharging to waterways, due to the role that suspended sediment plays in impacting water quality and smothering ecosystems (as discussed in Section 5.3.4).

Figure 4.7: Fine-sediment plume in the Marie Stream after an earthworks discharge in April 2017. (Source, Tim O'Connell/Stuff).

4.2 Impact of climate change on wastewater systems

Climate change will impact all elements of wastewater systems, and the essential functions they provide in protecting the health of communities and natural environments.

Impacts will range from capacity and levels of service impacts, to effects on treatment performance and water quality of receiving environments.

Many of the existing problems with wastewater systems are likely to be exacerbated with climate change. In particular, these existing problems relate to infrastructure which is aging (and designed to past climate conditions), or is poorly designed or suited to current conditions (NIWA 2012). In general, climate change effects on all infrastructure may result in both existing urban areas, and areas where urban expansion is proposed becoming potentially inappropriate (MfE, 2008b). It may also result in existing infrastructure becoming inadequate or inappropriate which may result in the costly retrofitting of systems (MfE, 2008b).

The summary below is intended to capture a range of potential impacts of climate change on wastewater systems. It is acknowledged that different climate drivers will be experienced differently depending on location.

4.2.1 Impact of climate change on wastewater conveyance systems

Based on consultation with the TRG, reduced rainfall and sea-level rise were deemed to have a high severity of impact on pipeline conveyance systems. Increased rainfall was deemed to have a medium severity and temperature extremes to have a low severity. The following sections discuss the impacts of climate change on wastewater conveyance systems in more detail, as summarised in Table 4.5. The review focusses on the climate effects that were identified as having medium and high severity.

Table 4.5: Impact of climate change on wastewater conveyance systems summary table

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
Separated Gravity	• Increased overflows • Increased blockages and breakages	• Corrosion due to low flows resulting in increased concentration • Blockages or siltation when combined with increased temp, and reduced water use.	• Pipes float causing cracking • Corrosion • Groundwater ingress leading to loss of functionality and capacity • Erosion/inundation causing damage to infrastructure	• Increased odours
Combined Gravity	• Increased overflows	• Corrosion (as above) • Blockages or siltation (as above)	• Pipes float due to increased groundwater level • Groundwater ingress • Erosion/inundation causing loss of infrastructure	• Increased odours
Pressure	• Increased overflows	• Corrosion	• Pipes float • Groundwater ingress	

			• Erosion/inundation causing damage to 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

**Based on workshop with TRG*

Key:

High severity	Medium severity	Low severity

4.2.1.1 Impacts of increased rainfall on wastewater conveyance systems

This section discusses the impacts of increased rainfall on wastewater conveyance systems. As summarised in Table 4.5, the most significant impacts are identified to be increased overflows, and blockages and breakages.

Increased overflows: MfE (2008a) highlights that more intense rainfall (extreme events) will lead to more inflow and infiltration (I&I) into wastewater networks. This occurs due to stormwater infiltrating the sewer network through cracks, poorly constructed or corroded manholes or gully traps and direct connections (ONeil, 2010; MfE, 2008a). While all types of conveyance systems face similar impacts from climate change, they each have particular features that influence the severity of the impact. Combined systems are the most vulnerable to I&I leading to more frequent uncontrolled discharges of untreated wastewater to the environment. Separated systems are still exposed to I&I through infiltration, but are considered to be less vulnerable as they are typically constructed of more modern materials, plus stormwater inflow volumes are lower. Cracks in a pressure system are more quickly detectable, as a loss of pressure to the system seriously affects system performance.

As wet weather overflow events are expected to increase in frequency and volume (MfE, 2008b) there will be an increased risk of instances of serious environmental contamination. This can also mean increased likelihood of aquifer contamination at the same time, as lower rates of aquifer recharge (due to less frequent rainfall) reduce the dilution of pollutants (Neunteufel, et al., 2015). This, in turn, can pose a risk to public health.

Impacts on receiving environments are discussed further in Section 4.2.2.5.

Blockages and breakages: Increases in wind velocities are often associated with the more intense rainfall events predicted with climate change. Increasing wind velocities will be location-specific but with a trend nationally to increased westerlies. This will result in changes in rainfall over complex topography – increases upwind of hills and ranges, and may compound some of the issues associated with increasing rainfall (MfE, 2008b). Additionally, high winds will cause damages due to wind fall, debris and direct damage to infrastructure such as powerlines (ONeil, 2010). This can result in increased blockages of pipes, pump stations and screens in the wastewater system.

4.2.1.2 Impacts of reduced rainfall and increased temperature on wastewater pipeline conveyance systems

This section discusses the impacts of decreased rainfall on wastewater conveyance systems. As summarised in Table 4.5, the most significant impacts are identified to be corrosion, odour and blockages. As these impacts are closely related, they are discussed together in the following section.

MfE (2008a) guidance highlights that longer dry spells will increase the 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, which have experienced prolonged drought (Marleni, et al., 2012; Naidoo & Moolman, 2016; Yuan, 2010; Tran, et al., 2017; Budicin, 2016). Prolonged drought can result in the enactment of water restrictions and the adoption of sustainable practices such as greywater reuse and low flush toilets – which result in decreases in wastewater flow. This reduction in flow is compounded by the reduction in I&I flows that enter the network from groundwater and stormwater sources (Marleni, et al., 2012; ONeil, 2010).

Reduced wastewater inflow results in an increase in wastewater concentration, as the solids content of wastewater remains the same. This can result in increased likelihood of blockage, odour and corrosion of the reticulated wastewater network (Marleni, et al., 2012; Naidoo & Moolman, 2016; DeZellar & Maier, 1980). The most common cause of blockage is build-up of fats, oils and greases (FOGs), debris, solids deposition and tree root intrusion, which can be accelerated in times of drought (see Figure 4.8). Reduction in water usage can result in insufficient water to move waste and solids through the system as self-cleansing velocities are not achieved (Naidoo & Moolman, 2016).

Malodourous compounds such as hydrogen sulphide (H_2S), volatile organics, sulphur compounds and nitrogenous compounds generally arise from the solids load within wastewater (Yuan, 2010). Increased wastewater concentration and increased temperature increase the likelihood of these emissions, and of particular concern is H_2S, due to its odour nuisance, threat to public health and potential to enhance corrosion in sewer pipes (Yuan, 2010; Marleni, et al., 2012). The risk of pipe corrosion is influenced by pipe age and condition and occurs predominantly in metal or concrete pipes, rather than plastic/PVC (Marleni, et al., 2012). High influent concentrations of wastewater are also usually associated with higher salinity, which adversely affects WWTP process effectiveness, operational costs and effluent quality (Tran, et al., 2017).

Arid and drought prone climates have experienced many of the impacts associated with reduced rainfall. For example, a study on the effect of urbanisation, drought and pollution on the deterioration of water quality in the Taflia Basin in southern Jordan found that a combination of poor infrastructure, drought conditions and high population caused infiltration of wastewater from septic tanks into springs and groundwater. Consequently, high detection rates of electrical conductivity, nitrate, faecal coliform and total coliform were measured in the springs of South Jordan (Al-Kharabsheha & Ta'any, 2003).

Water conservation measures in Los Angeles instigated in 2015 following prolonged drought conditions were reported to have caused widespread corrosion and odours, while water authorities suffered revenue shortfalls. Inadequate flushing flows caused build-up of solids resulting in pipe corrosion, and higher concentration flows, in turn leading to faster wear in pumping stations. Heightened risk of blockage and corrosion resulted in increased maintenance and water starved trees were 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 and carbon (Tran, et al., 2017).

Figure 4.8: Fat, oil and grease build up in wastewater pipeline, Severn Trent, UK (Source: Guardian 12 Dec 2016)

4.2.1.3 Impacts of sea-level rise on wastewater pipeline conveyance systems

As there are many similarities between stormwater and wastewater pipeline conveyance systems, refer to Section 4.1.1.3 for a summary of impacts of sea-level rise on wastewater conveyance systems. As discussed, coastal communities are often prone to groundwater ingress into wastewater systems, which can include saline groundwater. In New Zealand, this is prevalent in cities such as South Dunedin where high groundwater levels are currently thought to be kept artificially low due to infiltration into the stormwater and wastewater network. Testing has found high salinity in wastewater system during high tide (ORC, 2012). This salinity can cause accelerated corrosion in pipe, pump and treatment systems.

4.2.1.4 Impact of climate change on wastewater pump stations

Pumping stations are part of a system and require integrated design, therefore localised problems can affect the wider system. Many of the issues discussed above that affect pipes also affect the pumping station, such as overloading under increased rainfall, salinity impacts from rising groundwater, and blockages arising from build-up of fats oils and grease (refer to Section 4.2.1.2). Increased wind severity and lightning strike associated with more extreme stormy conditions can damage exposed structures, cut off power supply or damage controls (ONeil, 2010).

As temperature ranges shift, the operational temperature range of infrastructure will change. This may expose elements to unprecedented freezing causing failure or deterioration, or heat extremes causing overheating or increased demand for water supply, translating to shifts in wastewater constitution and odour impacts (ONeil, 2010). As discussed in Section 4.2.1.2, these conditions can lead to increased wear within pump stations.

4.2.2 Impact of climate change on treatment plants / processes

Based on consultation with the TRG, increased rainfall, reduced rainfall and sea-level rise were deemed to have a high severity of impact on WWTPs. Increased temperature extremes were deemed to have a medium severity of impact on treatment plants. This section discusses the impacts of climate change on wastewater treatment plants in more detail, as summarised in Table 4.6. The review focusses on those climate effects that were identified as having medium and high severity.

Table 4.6: Impact of climate change on wastewater treatment plants summary table

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
WWTP – general	• Increased inflows • Storm related power outages and road closures	• Increased strength of influent risking breach of toxicity levels	• Flooding and infrastructure damage	• Performance varies with temperature • Odours (due to higher temperatures)
WWTP - Biological Systems (activated sludge / trickling filters)	• Increased inflows leading to more frequent bypassing	• Increased strength of influent risking breach of toxicity levels	• Outfalls may be impacted • Increased pumping heads for outfalls	• Performance may vary with temperature
WWTP - Oxidation Ponds	• Minor impacts as ponds should be able to deal with fluctuation in flows	• Minor impacts as ponds should be able to deal with fluctuation in flows		• Performance may vary with temperature
WWTP - Sludge Management	• No anticipated impact	• No anticipated impact	• Raised groundwater table preventing dewatering	• Performance may vary with temperature
Receiving environment	• Assimilation capacity reduced	• Assimilation capacity reduced	• Assimilation capacity reduced	• Assimilation capacity reduced

*Based on workshop with TRG

Key:

High severity	Medium severity	Low severity

4.2.2.1 Impacts of increased rainfall on treatment plants / processes

This section discusses the impacts of increased rainfall on WWTPs. As summarised in Table 4.6, the most significant impacts are identified to be increased inflows, and power outages

Increased inflows: Increased rainfall will result in larger volumes and peak inflows into WWTPs. While the volume or 'flow' of the wastewater increases, the TSS (Total Suspended Solids) remains the same, resulting in a dilution of the influent to the WWTP which can affect biological treatment processes.

High flows can carry debris associated with storm events, which can reach the treatment plant and cause damage such as blocked screens etc. High inflows can affect the hydraulic performance of the system or overwhelm the infrastructure completely. During extreme weather, system bypasses can be activated, diverting flows past part or all of the treatment process. This causes partially treated or untreated wastewater to directly enter the receiving environment (Tolkou & Zouboulis, 2015; Watercare, n.d.). This can cause public health concerns and result in the closure of swimming beaches (Figure 4.9).

Research has also shown that treated effluent quality can deteriorate during periods of increased inflows into activated sludge secondary treatment systems. The research concluded that WWTP performance decreased during increased wastewater inflows associated with rainfall events, this was primarily attributed to decreased detention times in the treatment processes (Mines, et al., 2007).

Power outages: As with other types of infrastructure, high winds and storminess can raise the likelihood of windfall from trees. This raises the risk of power outages, causing disruption to the operation of plants and reliance on back-up generator systems. Additionally, storm-related road closures can prevent access to treatment plants.

4.2.2.2 Impacts of decreased rainfall on treatment plants / processes

This section discusses the impacts of decreased rainfall on WWTPs. As summarised in Table 4.6, the most significant impact is identified to be increased strength of wastewater influent risking breach of toxicity levels.

Decreased rainfall and drought conditions reduce the amount of water that flows into WWTPs, through less I&I and potential lower household water consumption (as a result of the implementation of water conservation strategies). 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.’

High-strength wastewater flow can cause problems for WWTPs. 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). This higher concentration and reduced flow could see two interrelated problems occur. Firstly, the sedimentation of solids in the reticulation pipes up stream of the WWTP and thus more extensive anaerobic decomposition resulting in production of methane and hydrogen gases, with the latter causing corrosion and odour problems (Pocock & Joubert, 2017). Secondly, salinity levels can increase as influent pollution concentrations increase, which adversely affects treatment effectiveness, effluent quality and operational costs (Tran, et al., 2017).

Lower flows and higher strength wastewater are likely to affect each plant differently, depending on the type and capacity of the individual plant. Plants that rely on trickling filters 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. Plants which incorporate activated sludge systems may benefit positively, due to increase retention times in process tasks and consequential increased solid removal within the clarifiers (Pocock & Joubert, 2017).

4.2.2.3 Impacts of sea-level rise on treatment plants / processes

This section discusses the impacts of sea-level rise on WWTPs. As summarised in Table 4.6, the most significant impacts are identified to be flooding and reduced outfall, as well as raised groundwater table,.

Flooding and reduced capacity for outflow: Sea levels are rising around New Zealand and at an accelerated rate (refer Section 2.3), endangering many coastal and low lying WWTPs. A rising sea level increases the risk of flooding, potential for damage to infrastructure, higher pumping heads for ocean outfalls and may even lead to decommissioning of WWTPs. These prospects would be costly to councils, in terms of financial loss and threats to public health (Tolkou & Zouboulis, 2015). Rising downstream water levels may result in the need to pump effluent, therefore increasing energy requirements (Tolkou & Zouboulis, 2015).

Raised groundwater table: Some wastewater treatment plants practise land-based dewatering of wastewater sludge. Dewatering relies on a groundwater table at a sufficient depth below ground level to allow excess water to infiltrate. A rising groundwater table may prevent adequate dewatering.

4.2.2.4 Impacts of increased temperature extremes on treatment plants / processes

This section discusses the impacts of temperature on WWTPs. As summarised in Table 4.6, the most significant impacts are identified to be WWTP performance varying with temperature, and increased odours.

WWTP performance varying with temperature: Biological reactions naturally occur much faster in higher temperatures. Given the secondary treatment phase within WWTPs relies 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).

During 'sludge digestion', the sludge is required to be heated to 37 degrees. A rise in ambient temperature would mean less energy is required for this heating. Processes such as activated sludge and aerobic biofilm reactors are less dependent on temperature, as a result of higher technological input and mechanization (Pocock & Joubert, 2017) and therefore would be less affected.

Another potential impact of a warmer climate is higher evaporation rates, as with increased temperature the water-holding capacity of the atmosphere increases. For WWTPs this could mean the final discharge standards for effluent become stricter, due to increased salinity in receiving water bodies (Pocock & Joubert, 2017).

Increased odour: Generally, fresh wastewater, particularly residential wastewater, produces a benign musty odour. Wastewater composition transforms in the wastewater network, which produces malodorous compounds (Marleni, et al., 2012). Increased strength of wastewater, changes in the WWTP performance, and increased occurrence of overflows are all likely to increase odour, which may result during warmer temperatures.

Figure 4.9: Public health warning at Auckland beach after sewage overflows after heavy rains (source, Nikki Mandow, RNZ 12 April 2018)

4.2.2.5 Impact of climate change on the receiving environment

As summarised in Table 4.6, the most significant impact of climate change on the receiving environment is identified to be a reduction in the capacity for the receiving environment to accommodate the contaminant load, termed '*assimilative capacity*',.

The concentration of pollutants in the wastewater *influent* is a combination of the load and the volume of water with which the pollutant is mixed (Henze, et al., 2008). How the wastewater *effluent* characteristics will change under climate change will depend on the type and design of WWTP processes. Depending on how these can cope with changes to influent quality (for example, as a result of changing water temperature, water usage/conservation measures and flow patterns), will result in potentially negative effects within receiving environments – such as nutrient enrichment (eutrophication).

According to Chapra (2008) the *assimilative capacity* represents the physics, chemistry and biology of the receiving environment and determines the load/concentrations of contaminants that can be accommodated without exceeding specified concentrations in the receiving waterbody. In other words, this is the threshold at which negative impacts will begin to occur.

Reductions in flows within receiving watercourses could negatively impact water quality, since the assimilative capacity is decreased (Whitehead, et al., 2009; WERF, 2009). Conversely, increased flow would result in increased dilution capacity and increase assimilation capacity.

High concentrations of nutrients (nitrogen and phosphorous) in a receiving waterbody (as result of wastewater discharges) coupled with increased air temperatures can lead to an increased frequency of phytoplankton blooms and subsequent alteration of the trophic balance (Komatsu, et al., 2007) (see Figure 4.10).

A better understanding of the assimilative capacity of sensitive receiving environments under climate change conditions will thus be a critical component in informing the design of WWTPs that discharge to them.

Some systems will be more suitable than others in managing climate changes, such as increases in temperature. As an example, activated sludge (AS) biological wastewater treatment involves biological processes that are temperature sensitive (Henze, et al., 2008). As treatment systems are, in general, very efficient at reducing organic load (in the form of chemical oxygen demand). Increased temperatures could therefore positively impact the efficiency of WWTP since process improvements are experienced over a temperature range of 5 °C to 30 °C (Surampalli & Tiagi, 2004; WERF, 2009).

Figure 4.10: Toxic foam on Utakura River (near Kaikohe) during an algal bloom (Photo Linda Lewis, RNZ Feb 2018)

4.2.3 Impact of climate change on on-site wastewater systems

Based on consultation with TRG, increased rainfall and sea-level rise were deemed to have a high severity of impact on on-site wastewater systems. Decreased rainfall was deemed to have a low severity and temperature extremes to have a medium severity of impact on on-site wastewater systems. This section discusses the impacts of climate change on on-site wastewater systems in more detail, as summarised in Table 4.7. The review focusses on the climate effects that were identified as having medium and high severity.

Table 4.7: Impact of climate change on on-site wastewater systems summary table

	Increased rainfall	Reduced rainfall	Sea-level rise	Temperature
On-site wastewater	• Soakage performance affected when soils are waterlogged • Floatation of below ground chambers • Soil structure damage reducing soakage performance • Ecological changes to soakage fields	• Ecological changes to soakage fields	• Soakage performance affected when soils are waterlogged • Floatation of below ground chambers • Soil structure damage reducing soakage performance • Ecological changes to soakage fields	• Performance varies with temperature • Odours increase

**Based on workshop with TRG*

Key:

High severity	Medium severity	Low severity

As summarised in Table 4.7, the most significant impacts of climate change on on-site wastewater systems are identified to be changes to the soakage field performance resulting from groundwater, ecological and soil structure changes, floating, performance varying with temperature, and increased odours,.

New Zealand on-site wastewater disposal systems are dominated by septic tanks, which generally treat effluent to a minimum standard. Many systems are ageing and while all systems require ongoing maintenance, it has been identified that in many cases this is not being carried out (MfE, 2008c). The MfE investigation found that some systems have a roughly 20% failure rate, where inadequately treated wastewater enters groundwater or surface water (MfE, 2008c). This can happen through mismanagement of domestic wastewater, such as flushing wipes or disinfectants, inadequate maintenance, leaks in septic tanks, incorrect connections, blockage of the disposal field pipes, a disposal field that is too permeable or inadequate separation distance between the septic tanks and the groundwater table (MfE, 2008c).

Changes to the soakage field performance: Climate change is expected to impact the performance of on-site wastewater systems primarily due to alteration of the soil conditions of the on-site disposal field. Increased rainfall intensity and sea-level rise will raise groundwater tables and increase the likelihood of saturated soil. This, in turn, prevents effective treatment of wastewater, resulting in elevated pathogens, nutrients and biochemical oxygen demand (BOD) (Cooper, et al., 2015). Additionally, higher soil temperatures can result in lower oxygen solubility and higher soil microbial oxygen consumption, resulting in further reduction in levels of oxygen available for wastewater treatment (Amador, et al., 2014).

The receiving soil system plays an important role in the further treatment of primary and secondary effluent before the effluent is assimilated into the natural environment. Poor performance of onsite wastewater systems can lead to onsite and catchment-wide contamination, which can place ecosystems and public health at risk. Other potential issues related to poor system performance are: odour, visual impact (exposed hardware and disposal field plant health), ongoing costs of maintenance and repair, electricity demand, mechanical failure and risk of overflow (Dakers, et al., 2009).

Floating or settlement: As discussed in Section 4.1.1.2, expansive soils are susceptible to changes in groundwater levels, and can result in cracking of buried structures if settlement occurs. Conversely, if groundwater levels rise, this can result in changes in buoyancy of buried structures and may cause floatation (Auckland Council, 2015a).

Odour: As mentioned above, poor system performance can lead to increase in odour. Increased temperature is expected to exacerbate this issue.

4.3 Summary of impacts

In order to characterise and further explore impacts and implications, three main summary themes for both stormwater and wastewater have been developed. These themes were chosen by grouping all of the impacts discussed in the literature review into groups with similar types of impacts. The summary themes are listed in Table 4.8.

Table 4.8: Summary impact themes

Stormwater impact themes	Wastewater impact themes
1 - Increased flooding of buildings and assets	**1 - Heightened risk of flooding/ spills and odour**
Increased flooding of buildings and assets is expected to arise from increased rainfall and sea-level rise, as well as rising groundwater – all of which will adversely affect conveyance capacities of existing systems. Refer to Section 4.1.	Increased risk of wastewater flooding, spills and odour arising from the impact of climate change on wastewater systems. This impact is expected to arise primarily from increased rainfall. Refer to Section 4.2.
2 - Loss of land and physical damage to infrastructure; e.g. landslides or erosion	**2 - Water quality deterioration: due to worsening impacts of wastewater discharges**
Loss of land and physical damage to infrastructure impacts are expected to arise from increased severe weather, increased rainfall, sea-level rise, reduced rainfall and increased temperature extremes. Refer to Section 4.1.	Water quality deterioration is expected to arise from increased rainfall, sea-level rise, reduced rainfall and increased temperature extremes – and will potentially coincide with a reduction in assimilative capacity of receiving environments. Refer to Section 4.2.
3 - Water quality deterioration: due to worsening impacts of stormwater discharges	**3 - Damage to infrastructure leading to disruption to wastewater services**
Water quality deterioration arising from the impact of climate change on stormwater systems – leading to ecological health and habitats affected, biodiversity loss, increased algal blooms, increased invasive species. This impact is expected to arise from increased rainfall, sea-level rise, reduced rainfall and increased temperature extremes – and will potentially coincide with a reduction in assimilative capacity of receiving environments. Refer to Section 4.1.	Damage to wastewater infrastructure will result in increased maintenance, repair and disruption to wastewater services due to system component failure will occur at a local and community wide scale. This impact is expected to arise from increased rainfall, sea-level rise, reduced rainfall and increased temperature extremes. Refer to Section 4.2.

The impacts relating to each summary **theme** are summarised in the sections below, and then used to present and describe the *implications* related to each summary theme - within bow-tie diagrams in Section 5.6.

5 Implications of climate change for stormwater and wastewater systems

This section explores the implications of climate change arising from the impacts discussed in Section 4. The implications were developed through literature review and consultation with the TRG during a workshop in early May 2018 (TRG, et al., 2018).

The sections below present the implications research structured according to social (Section 5.1), cultural (Section 5.2), environmental (Section 5.3), and economic (Section 5.5) domains. The literature review is followed by a summary and mapping of the implications (Section 5.6).

Implications are defined within Section 2.2.

It is noted that previous work by Lawrence et al (2018) has explored implications in the context of 'cascades'. Examples were provided within this study relating to wastewater and stormwater systems, however further detail is explored in the sections below.

5.1 Social implications stemming from the impact of climate change on stormwater and wastewater systems

The primary social implication themes stemming from the impact of climate change on stormwater and wastewater have been identified through literature review as*: physical danger and health, increased disruption to residents and businesses,* and *reduced community cohesion and mental health*. These will have more severe impacts on *remote and disadvantaged communities*.

5.1.1 Physical danger and health

5.1.1.1 Extreme events and flooding

During and following an extreme weather event, the population is generally more exposed to physical danger and harm. This physical danger can include drowning or injury by electrocution or debris (Vardoulakis, et al., 2015); (World Health Organisation, 2013). A study in the European region found that deaths as a result of flooding are predominantly drowning (two thirds), followed by injury, heart attacks, electrocution, carbon monoxide poisoning, and fire (World Health Organisation, 2013). In Australia/NZ, the most frequent causes of death during flood events are preventable, due to unnecessary risk-taking behaviours entering floodwaters, particularly attempting to drive (Wright , et al., 2010) ; (Fitzgerald, et al., 2010). Risk of injury remains in the aftermath of flooding events, as clean-up activities are undertaken (Ahern, et al., 2005). Emergency services and lifelines are also likely to be impacted by flooding and other disruption caused by extreme events, which may result in reduced levels of service with consequential patient health impacts (Curtis, et al., 2017); (World Health Organisation, 2013). Even where the buildings and staff may be separated from the immediate points of impact, getting access to the system may be disrupted due to issues such as road closures (Curtis, et al., 2017).

After flooding has occurred, further physical health impacts can arise due to living and working in damp buildings and homes, leading to an increase in respiratory diseases such as asthma, hypersensitivity pneumonitis, rhinosinusitis, bronchitis and respiratory infections (World Health Organisation, 2013); (Zhang, 2010); (The National Institute for Occupational Safety and Health, 2012). Other symptoms identified include nasal and sinus congestion, eye irritation (burning, watery, or reddened eyes), dry, hacking cough, nose or throat irritation and skin rashes or irritation.

5.1.1.2 Reduced water quality

Damaged stormwater or wastewater facilities particularly effect water quality, which may expose communities to unsafe contaminated water. This may occur through direct discharge of stormwater contaminants or untreated wastewater into local areas, or recreational areas with reduced water quality. For example, the Piha Lagoon is regularly unsafe for swimming and displays a permanent health warning due in part to contamination from poorly performing local onsite wastewater treatment (refer Case Study 7). Unsafe water sources or water shortages present a risk of infection (Downing & Cuerrier, 2011; World Health Organisation, 2013) such as faecal-oral disease, vector-borne diseases, asthma, skin rashes, and poisoning (Vardoulakis, et al., 2015); (Ahern, et al., 2005).

5.1.1.3 Odour implications

Repeated exposure to irritants associated with odours has been identified as causing respiratory disorders such as asthma (Schiffman & Williams, 2005). In addition, odour has a negative impact on mood and has been associated with stress (Schiffman & Williams, 2005). The level of acceptability of odour can reduce with repeated exposure, as individuals become more sensitive (Bay of Plenty Regional Council, 2012). For example, individuals may experience physical symptoms such as nausea and headaches, as well as emotional symptoms of frustration, stress, reduced enjoyment and embarrassment (Bay of Plenty Regional Council, 2012); (Shusterman, 1992).

5.1.2 Increased disruption to residents and businesses

Increased frequency of flood events will likely lead to increasing and repeated disruption to residents and businesses. As experienced after the Edgecumbe stopbank failure and the New Lynn floods, both in 2017 (refer Section 6.2.3, Case Study 3 and Section 6.2.4, Case Study 6, respectively), flooding can result in evacuations, road closures (preventing access to homes, work and services), and damage to homes, garages, yards and gardens (Rangitāiki River Scheme Review Panel, 2017).

Repeated flooding that occurred in Queensland during 2008, 2011 and 2013 impacted (often repeatedly) a number of settlements, causing significant damage to homes and property. These communities also experienced ongoing disruption while damaged homes and community facilities were rebuilt, insurance issues were resolved, and preventive measures were completed (Hughes & Sharman, 2015). Disruptions to roads and services such as schools, medical centres and shops can also result in fragmented communities and a loss of amenities. These immediate disruptions may result in short-term distress in many people, which can influence their medium and longer term wellbeing, and affect the mental health of the community (Stanke, 2012), as discussed further in Section 5.1.3. Rising groundwater levels such as those associated with rising sea levels and flood-prone, low-lying areas in South Dunedin (outlined within Section 6.2.4 Case Study 4), can result in chronic damp housing conditions, waterlogged community facilities such as parks and playing fields, as well as waterlogged gardens which can result in the drowning of plants, prevention of growing vegetables, and the general degradation of outdoor living spaces.

Flooding may also lead to the loss of community facilities or the possible abandonment of services such as stormwater or wastewater where they are no longer feasible to operate or provide an appropriate level of service. For example a rise in sea level may compromise the performance of surface and stormwater drainage systems in low-lying coastal settlements (T+T, 2013). Ultimately, recurring flooding may lead to a decision for the community to consider managed retreat, as increasing flood hazard coupled with aging infrastructure and limited funds for repair, make the community unsafe. There are a large number of low-lying settlements around New Zealand which may soon face this decision. Case Study 4 presents the history of flooding within South Dunedin and Case Study 5 discusses flooding within the rural settlement of Ruawai.

In New Zealand, issues of managed retreat (or relevant terminology) have, to date, largely been related to coastal hazards (Hanna, et al., 2017). In areas potentially affected by coastal hazards in the next 100 years, the NZCPS requires that redevelopment, change in land use (including managed retreat) and design for relocatability is encouraged to reduce the risk of adverse effects from coastal hazards. It also encourages the location of infrastructure away from areas of hazard risk, where practicable, and that in areas of significant existing development which are likely to be affected by coastal hazards, a range of options for reducing risk are assessed, including the promotion and identification of long-term sustainable risk reduction approaches (such as relocation of existing development or structures at risk).

However from a social perspective, managed retreat can be undesirable for those communities affected (T+T, 2013). Possible effects that have been identified include (T+T, 2013);

- Social issues for residents and communities that relocate, including the loss of community and identity, employment and the ability to purchase a house of comparable value (in economic and sentimental terms);
- Social issues for the relocated community including overcrowding of community facilities and services, competition for employment and higher house prices;
- Psychological stress from loss of valued aspects of the city, and loss of homes which have sentimental value;
- Health issues due to a loss of control, safety and certainty.

The scale at which retreat is proposed has a major impact on the degree as to which social and health issues are affected. For example, infrastructure may be able to relocated in the first instance (i.e. further back from the coast), rather than the relocation of entire communities.

5.1.3 Reduced community cohesion and mental health implications

There may be a wide range of mental health responses to flood events, such as depression, difficulty sleeping, and anger (World Health Organisation, 2013; Ahern, et al., 2005). This was evident in Christchurch through investigations and engagement with residents who were affected by flooding following the earthquakes (Christchurch City Council, 2014). The 3-year “snapshot” of resident experiences of flood events since the earthquakes was that there was an increase in stress, depression, feelings of hopelessness, frustration, anger and powerlessness amongst people (Christchurch City Council, 2014).

Ongoing flooding events often result in increased rates of long term anxiety, depression, and post-traumatic stress disorder (PTSD) (Vardoulakis, et al., 2015; Ahern, et al., 2005), with mental health effects last from 1-4 years in UK studies, and people more likey to report mental health disorders if there was no flood warning (Tong, 2017). There is evidence these impacts on mental health may be long term and potentially associated with an increased risk of suicide (Curtis, et al., 2017). Within some catchments in Christchurch ongoing flooding has caused significant stress and some residents have chosen to move out of their homes (Christchurch City Council, 2014). Economic stress can also lead to poor mental health (Berry, et al., 2010). This stress could be a result of increased insurance excess, loss of equity in homes, insurance money running out, increased financial obligations such as having to service a mortgage and pay rent, increased electricity and heating costs. For businesses it may cause interruption or closure, impacting individual employees and business owners, which could in turn be a result of damage from a significant event or disruption of ongoing maintenance activities.

Community cohesion can be impacted by depression in the community that expands to affect the collective emotion (Willox, et al., 2012). Community cohesion is important for the people to feel comfortable, safe, and welcome within their local community. In turn, the collective feelings and impressions of a community often strongly influence those of individuals. The loss of cultural sites is also important for the broader community, who may lose community cohesion that has been tied to physical sites (Carmichael, et al., 2018).

Loss of land, or the need to relocate / retreat from hazardous areas can lead to experiences of depression and trauma which for some groups has been described as unable to be economically compensated (Campbell & Campbell, 2007; Koppel Maldonado, et al., 2013). This, and other damage to community and infrastructure can impact an individual's sense of place and belonging – especially in coastal areas where there is usually strong place-based attachment. The distress caused by the loss of sense of place is referred to as 'solastalgia' (Berry, et al., 2010). The pain and sadness is caused as a result of the disruption or loss of place-based activities and pleasure (Willox, et al., 2012). Incorporating a feeling of powerlessness, solastalgia can lead to experiences of isolation and melancholia, and lead to more serious mental ill-health (Albrecht, et al., 2007).

Long term and mental health impacts from extreme event-related dislocation from land was severely felt in case of the Christchurch earthquakes and is still felt to this day (Fergusson, et al., 2014).

5.1.4 Remote and disadvantaged communities

Poorer communities already struggling with limited finances, a poor state of housing and limited employment opportunities are less likely to have resources available to respond, cope and rebuild from climate related hazard and stresses, translating to a lack of adaptive capacity (King, et al., 2010a). Some more remote and disadvantaged communities struggle with unreliable electricity, internet and mobile reception, preventing communication and potentially impacting on community safety in major hazard events (King, et al., 2010a).

In remote areas, many residents are required to travel to their place of work. Frequent flooding of roads including damage due to stormwater infrastructure blockages and scouring, not only affects the connection to workplaces and essential services, but also causes loss of income to those whose commute is disrupted (King, et al., 2010a).

The system as a whole needs to be considered when addressing adaptation to climate change (ISO 14090:2019, Annex A). Limitation of the adaptative capacity of disadvantaged communities may also be compounded by a reduced adaptive capacity of the system to climate stressors or hazards (or compound hazards). These may stretch the ability of the system (governance, financial, societal, environmental) to adequately support all communities (ISO 14090:2019, Annex A). For example, some rural iwi/hapu or communities often exhibit adaptiveness or resourcefulness through experience developed from responding to various past changes, but the adaptive capacity of the local government governance (including funding) and utility services may be over stretched to cope and adapt – which means this vital support is unavailable to the iwi/hapu (King, et al., 2010a).

5.2 Cultural implications stemming from the impact of climate change on stormwater and wastewater systems

In their research into the Manaia community, King, et al (2010a) identified potential implications on the Māori community arising from the impacts of climate change on stormwater and wastewater systems. The following list incorporates these implications, but can be applied to a more generalised cultural context. Many of these implications are relevant to society in a more general sense so are discussed in other sections, however the list is included to provide a holistic view of the implications to Māori communities. Implications that are relevant specifically to cultural concerns are discussed further in this section and are largely related to flooding.

- Structural damage to privately owned buildings and community infrastructure such as marae and schools;

- Damage or destruction of lifeline infrastructure such as roads, water, gas, sewerage, power, communications;
- Loss of hapū-owned farm-land due to increased flooding and erosion resulting in loss of economic opportunity;
- Destabilisation of properties and surrounding lands from coastal erosion, flood runoff and erosion;
- Costs of clean-up, construction and maintenance of protection structures;
- Costs from service disruption to water, power, gas, communications;
- Rising costs surrounding the maintenance, repair and re-design of whānau homes and vital infrastructures to cope with such changes;
- Households may find it more difficult to access adequate insurance cover in the face of increased flood risk;
- Danger of injury and loss of life in the case of extreme flooding events;
- Adverse health impacts: injury, stress, trauma and sickness;
- Increased pressure on formal and informal whānau-based support systems;
- Loss of household contents and family records/heirlooms;
- Adverse impacts on ecology from erosion, sedimentation and pollution from destruction of septic tanks and sewer lines;
- Altered river flows in association with newly configured rivers and streams resulting in changes to flood hazard and ecology;
- Future development in low-lying areas of the flood plain by returning whānau; and
- Degradation, damage and loss of sacred places and sites resulting in loss of identity and whakapapa;

This final bullet point relates particularly to the loss of cultural value, and is discussed further below along with discussion on the loss of cultural infrastructure, the cultural value of water quality and vulnerability through socio-economic disadvantage.

5.2.1 Loss of cultural values

The teaching of matauranga Māori places values, myths and legends as the central system on which their holistic view of the universe is based. Papatuanuku is the personified name for the earth. She married Rangi, the sky father and birthed the elemental gods of wind, storms, lightning, forests, cultivated crops and so on. Papatuanuku is also regarded as the mother of the people, who she has nourished as she nourishes all life, animals, birds, trees and plants. Rivers and streams are regarded as the arteries of Papatuanuku, and are the life giving waters that she shares with all of her offspring (Marsden & Henare, 2003).

Papatuanuku provides the foundation for a symbiotic relationship for all of her offspring, of which the different species contribute to the welfare to other species and facilitate the biological functions of mother earth, such as ingestion, digestion and excretion. In this context, people are the conscious mind of mother earth, are an integral part of her natural order and have a duty to enhance and sustain her systems. Tikanga, or customs of Māori have developed to protect and conserve the resources of Papatuanuku, where kaitiakitanga is the traditional guardianship over natural resources such as native forests, water (wai) and sealife (kaimoana) (Marsden & Henare, 2003). The role as kaitiaki means Māori have the responsibility to look after the lands and water for generations to come (King, et al., 2010a; Durette, et al., 2009). In research into water allocation in New Zealand, the loss of water was seen as being immeasurable and goes to the heart of the identity of iwi and hapū (Durette, et al., 2009). From a customary perspective, one interviewee explained the relationship of water with land is fundamentally important to support the life of that land and its ability to sustain Māori (Durette, et al., 2009).

Research into the way Māori people are affected by climate hazards and related stresses has highlighted cultural concerns for society placing economic values over the value of ecological integrity. The below perspective highlights the critical relationship between human and environmental systems for Māori wellbeing:

"*If you poison the waterways, you poison the people, that's how we feel*" (8 December, 2010 (King, et al., 2012))

And:

In my world, which I have grown up with, everything is connected. The environment is exactly the same. The air, the water, the earth is all interconnected and if one is suffering, the other has to too" (10 December, 2010 (King, et al., 2012)).

The loss of access to and quality of cultural sites can result in a loss of cultural identity for individuals. For physical sites, this is because sites often play a key role in narratives and shared stories of societies (Downing & Cuerrier, 2011; Carmichael, et al., 2018). For tribal communities, *"it is more than being connected or attached to the land, we are part of the land, it is part of us and we are part of it.... the water, the air, all of it runs through our veins and souls. To be here is to live, to be elsewhere is to die to who we are*" (Philippe 2008 cited in Koppel Maldonado et. al., 2013, p 610). Other sources of potential loss of identity can occur due to changing local environments, such as through frequent flooding events or changing water quality, making traditional knowledge less reliable and valuable (Downing & Cuerrier, 2011). In New Zealand tapu land and waterways are particularly important for Māori identity (Voyde & Morgan, 2012).

5.2.2 Loss of cultural infrastructure

Erosion and flooding is likely to result in the loss of or damage to hapū owned property, marae, taonga and community facilities such as schools. Farmland and other communal areas may also be lost or damaged in flood water, rendering them unsafe or unable to be used productively (King, et al., 2010b).

Māori communities have strong connections to their turangawaewae[9] and whanau, leading to increased incentive to inhabit lands regardless of their exposure to hazards such as flooding (King, et al., 2010a). The strong connection to their turangawaewae makes Māori more vulnerable to loss of land or displacement, as this loss must mean a severance of the spiritual relationship they have with their traditionally occupied places (Koppel Maldonado, et al., 2013).

Māori connection to their turangawaewae means that future development of cultural land is likely to proceed regardless of the exposure of that land to climate hazards. Therefore, this is a special group that may proceed with future development in low-lying areas of the flood plain by returning whanau, despite the known risks (King, et al., 2010a).

5.2.3 Loss of cultural value of water quality

Worsening water quality, such as through wastewater discharges, can lead to loss of ecosystem functioning due to a loss of biodiversity. For Māori, this impacts the mauri[10] of the water, and also diminishes the ability of Māori to interact with the ecosystem such as through sourcing native food.

Māori culture regards rainfall and springs as sacred, only suitable for consumption once it has travelled over Papatuanuku (the land). Morgan (2006) describes how stormwater reticulation and

[9] Home grounds through rights of kinship and whakapapa, place to stand.
[10] The life source

the disposal of treated stormwater to water bodies is undesirable, as is out of catchment disposal of stormwater and wastewater. Additionally, increasing frequency of wastewater discharges is of major concern to Māori, as the direct discharge of wastewater to natural water is generally abhorrent, even regardless of the degree of treatment (Bradley, 2016). These cultural priorities render Māori particularly affected by deteriorating stormwater and wastewater systems.

Opportunities to practice mahinga kai[11] would be reduced with reduction in water quality. For example, serious degradation of water quality occurred within the Whangamarino Wetland during the aftermath of ex tropical cyclone Debbie in 2017, resulting in widespread death of native fish and high nutrient and faecal bacterial levels (Refer to Case Study 2). Such a deterioration of the Whangamarino Wetland or any other source of mahinga kai would affect the condition of traditional supplies of food thereby rendering it unsuitable for sustaining iwi and hapū communities. This issue was a concern raised in recent research; as one interviewee explained: "*when we lose the ability to produce food – we lose our reason for being*" (Durette, et al., 2009). A well-used example of loss of food value to the Māori in particular and New Zealanders in general, is the diminished size and numbers of Tuna kuwharuwharu (longfin eel) in waterbodies due to degradation of habitat (Potangaroa, 2010), in particular deteriorating water quality. The loss of the longfin eel, as New Zealand's top freshwater predator, could lead to dominance of invasive species and further degradation of the environment.

5.2.4 Vulnerabilities through socio-economic disadvantage

Vulnerability of Māori to climate change will be varied based on whether, tangata whenua and Māori are living outside their rohe[12] (Stephenson, 2018). However, existing disadvantages in health, education, employment, and housing facing Māori may be exacerbated in the face of climate change risks (Manning, 2015; NZIER, 2003; King, et al., 2010c). This is because the health and well-being of Māori people is often dependent on the condition of their local natural resources and environment, as well as the strong Māori relationship with coastal mahinga kai. Additionally, the proximity of many Māori communities to active coastal processes such as erosion (King, et al., 2010c; Smith, 2014).

Due to the connection to their turangawaewae[13], Māori may choose to live in areas exposed to climate risks. These types of living situations may be unconsented, and are unlikely to be insured, due to ineligibility, high cost or a perceived complexity of obtaining insurance (King, et al., 2010a). This also leads to increased vulnerability to climate related stresses.

In response to this, some Māori communities are already developing their own tikanga based practices to respond to climate change. The more resilient of these communities are often characterised by strong social bonds and long-established processes for nurturing others (Stephenson, 2018).

The more vulnerable of these communities have limited access to economic resources, low levels of technology, poor information skills, remote and sub-standard infrastructure, weak or unstable institutions and governance structures and poor representation in local and central government politics, leaving them inadequately resourced to cope with changing climate and the associated hazards (King, et al., 2010b).

[11] Garden, cultivation or food gathering
[12] Area
[13] Home or place of residence

5.3 Environmental implications stemming from the impact of climate change on stormwater and wastewater systems

This section discusses the environmental implications stemming from the impacts of climate change on stormwater and wastewater systems. We have grouped these implications into: *increased contaminants in waterways, temperature as a contaminant, changing flow regime, stream habitat smothering, geomorphological implications* and *other environmental implications*.

5.3.1 Increased contaminants in waterways

More frequent exceedances of tolerance values to organic and inorganic contaminants can have a multitude of effects on aquatic ecosystems. Wastewater discharges provide an excess source of nutrients (e.g. nitrogen and phosphorous) which can stimulate nuisance growth of aquatic vegetation and cyanobacteria. Key implications of nuisance growth include obstruction of waterways impeding fish migration, reduced water filtration capacity, mats of algal growth limiting the availability of appropriate habitat and greater diurnal fluctuations in pH and dissolved oxygen exceeding stress tolerances for sensitive species (ANZECC, 2000).

Readily available organic material (e.g. sewage effluent) can have an impact on concentrations of dissolved oxygen, due to an increase in microorganisms respiring, adsorbing and using available oxygen. If dissolved oxygen concentrations are consistently low this can cause anoxic conditions within an aquatic ecosystem, such as the ‘blackwater’ event that occurred in Whangamarino Wetland, 2017 (refer Case Study 2). In the worst case this could cause an ecosystem shift to a modified state, resulting in variation / change in community composition, diversity and abundance variations, often causing a decline of sensitive species and an increase in generalist species (greater range of tolerances) (Thrush, et al., 2009). The more frequently an ecosystem is exposed to stressors (e.g. low dissolved oxygen) the less resilient it will become to changes in the future, meaning that an ecosystem shift is more likely to occur (Thrush, et al., 2009).

Organics and inorganics within an aquatic ecosystem can be toxic to aquatic life if tolerance concentrations are exceeded. An example of a toxicant is ammonia which is commonly found in domestic sewage and industrial effluent (ANZECC, 2000). Ammonia toxicity is influenced by pH and temperature, where a lower concentration of ammonia can be toxic when pH is higher, and vice versa (ANZECC, 2000). If there is more ammonia present within aquatic ecosystems due to greater and more frequent overflows of wastewater systems, this could lead to more toxicity in freshwater and/or marine ecosystems detrimental to organisms, particularly fish.

Notwithstanding the direct effects resulting from changes to contaminant loads from wastewater and stormwater discharges, changes to the flow regime or changes in precipitation resulting from climate change may induce, for example excessive nutrient enrichment or eutrophication (Sinha, et al., 2017) (Sinha et al. 2017), with the potential for reduced assimilative capacity of the receiving environment. Assimilative capacity refers to the capacity for the receiving environment to accommodate a contaminant load, discussed further in Section 4.2.2.5.

Deteriorating water quality in waterways, because of increased contaminant concentrations, can reduce the appeal of water-related recreational activities due to issues such as discolouration, bad odour or post contact-recreation-related illnesses. This is likely to result in a reduction in quality of life through the decrease in recreational activities, and the knock-on financial benefits that these activities bring into the local area. Increased algal blooms lead to physical interference with recreational activities and the use of the river, as well as a general degrading of the beauty of the area (Hughes, et al., 2014). Waterways can also be places for religious/cultural rituals and the deterioration of water quality can detract from this appeal, leading to a sense of loss to communities that use it, such as those using Whangamarino Wetland (refer to Case Study 2), and Piha Lagoon (refer to Case Study 7).

5.3.2 Temperature as a contaminant

Temperature as a contaminant can impact aquatic organisms' physiology, growth and behaviour, and in turn affect the community structure as a response to biota stress (Young, et al., 2013). The degree of impact is dependent on the temperature magnitude, duration of exposure, frequency of exposure and spatial extent of exposure (Young, et al., 2013). With predicted temperature rise it could be expected that baseline water temperatures could increase and also anthropogenic flows (e.g. stormwater runoff from impervious surfaces) could be subject to greater peak temperatures due to exposure to more frequent, hotter ground conditions. Species may therefore experience higher 'thermal shock' from more frequent releases of heated water for longer periods of time (Young, et al., 2013). Temperature can also affect algal biomass, pH and dissolved oxygen concentrations that can cumulatively contribute to habitat change or species mortality. In situations where instream biota are already stressed, the life supporting capacity of receiving waters will be further reduced with the addition of further contaminants. For example, the already limited ability for the Waikato River to act as a receiving environment will be further compromised as increasing temperatures cause reservoir and runoff temperatures to increase (refer Case Study 8).

Cyanobacterial algal blooms grow in waters with temperatures above 20°C, so an increase in water temperature is likely to lead to an increase in these species (Oberholster, et al., 2009). Fish, invertebrates and other aquatic fauna exposed to toxins from cyanobacteria become unsuitable for consumption and the same toxins can render the water source unfit for recreational purposes as well. There could also be changes in the fish community structure if summer cold water refuges are lost due to deoxygenation (Havens, 2008). Under certain conditions fish-kills associated with algal activity may also occur in waterways (Hughes, et al., 2014) resulting in unexpected clean-up as well as potentially serious health and environmental implications.

5.3.3 Changing flow regime

A predicted increase in flood flows could result in more 'flushing' events within a stream/river, exacerbated by longer intervening dry spells, leading to less stable conditions for habitat colonisation by particular aquatic macroinvertebrates could modify the community structure. In turn this could affect fish species due to food availability, and there may also be behavioural responses from increased flushing events.

Alternatively, reduced base flows in waterways / lakes / wetlands in some catchments may result in environmental flows not being maintained resulting in a reduction of habitat diversity, in particular specialised fish habitats (Jowett, 2002). Reduced baseflows can also cause other key stressors (e.g. temperature and contamination) to have a heightened impact due to reduced assimilative capacity as described in Section 4.2.2.5.

Stable flow and low flow water provides more desirable conditions for heterotrophic bacterial growth e.g. sewage fungus and nuisance algal growth (Biggs, 2000). Coupled with an increase in nutrients this may cause blooms of bacterial or algal growth (eutrophication) which again has flow-on implications to an ecosystem.

5.3.4 Stream habitat smothering

Increased potential for stream erosion (as described in Section 4.1.1.1) results in changes to bank stability, loss of suitable stream habitat 'smothering' the stream bed with fine sediments, clogging interstitial spaces used as refugia by aquatic fauna and reducing the availability of suitable surfaces for egg laying (e.g. cobbles that are important for native gobiidae species) (Clapcott, et al., 2011).

Increased fine sediment deposition can result in elevated levels of suspended sediments and increased turbidity levels within the water column. This can physically damage fish gills through abrasion and/or clogging which can have a range of physiological impacts to the organism (Cavanagh, et al., 2014). Indirectly, fish can be affected by a decrease in water clarity which alters movement, migration patterns and feeding (Cavanagh, et al., 2014). An example is the banded kokopu (one of the whitebait species) which shows avoidance responses to sub lethal turbidities through reduced migration and feeding (Rowe, 2002).

Bank and channel incision can reduce the connectivity with the floodplain and can also either remove or make galaxiidae spawning habitat unsuitable due to bank slope gradients (Storey, et al., 2011). More channel incision can result in less interaction with the riparian root zone and therefore can impact the filtration capacity of bankside vegetation.

5.3.5 Other environmental implications

Environmental implications beyond those related to waterway health and ecosystems are discussed in this section, including post-disaster construction waste and alternative management of wastewater.

5.3.5.1 Post-disaster construction waste

Flooding related damage to buildings and property are acknowledged to generate additional waste during recovery from a disaster. It is also expected that chronic and more frequent damage to infrastructure will generate increased construction waste as infrastructure repairs are required more frequently. Waste from flooding can be generated in large volumes as the public health concern due to contamination from floodwaters often requires the disposal of all affected household contents (Brown, 2012). Loss of electricity may also cause wastage of food as refrigeration is unavailable (Brown, 2011).

Post-disaster recovery can also have environmental implications associated with both increased consumption of resources, such as new building materials and household items such as furniture, and increased waste disposal requirements. Some building waste contains hazardous materials such as asbestos and arsenic treated woods that require special processes for deconstruction and disposal but which are often disposed of as part of the general waste stream in a disaster setting. Waste generation in a disaster can also bypass any opportunity for reuse and recycling processes that may have otherwise been explored (Brown, 2011).

5.3.5.2 Wastewater "resource recovery" and alternative management

It is possible that factors such as population growth and water scarcity lead to a shift in our approaches to wastewater treatment. This may encourage a move towards WWTPs becoming "resource recovery centres". This may mean moving away from a linear process (take/treat/dispose) for the treatment of effluent, to harvesting energy (electricity generation from biogas), nutrients (from biosolids) and water for reuse. Additionally, wastewater may become an alternative source of drinking water to augment existing surface/ground water supplies as done in countries such as the USA, China, Israel, Singapore and Australia to name a few. (*Mark Bishop, Watercare Services Limited. pers. comm*). At the least, recycled water can be used for irrigation of parks and golf courses (e.g. sewer mining using microfiltration plants (Sydney Water)[14] or reusable irrigation water from Perth's Subiaco WWTP.

The technology for wastewater reuse exists, and may need to be adopted in future scenarios which would require widespread change in mindset (ONeil, 2010), and in particular, in the New Zealand context this would conflict with Māori beliefs.

[14] https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdu3/~edisp/dd_057020.pdf

The adoption of on-site solutions is often seen as a more sustainable approach to wastewater treatment as these are generally much lower impact, and allow for the adoption of natural processes such as composting (Naidoo & Moolman, 2016). The use of these types of wastewater systems is likely to rise as they become more widely accepted as an efficient alternative to traditional wastewater systems. This is currently an area of innovation and new on-site wastewater systems may be developed that can cope well with the changing environment while minimising impacts on the environment (Naidoo & Moolman, 2016).

5.4 Regulatory implications

The abovementioned environmental implications can cause difficulty in achieving regulatory requirements. Regulatory requirements and policies are continuing to evolve, with stricter limits and standards for stormwater and wastewater discharges. This changing policy environment, along with evolving, future socio-economic 'pathways', will intersect with the pressures from the changing climate – the end result of which is difficult to foresee. However, given what we currently understand, it is likely that these factors will combine to exacerbate adverse outcomes, rather than improve outcomes. An example of the complex relationship between the regulations and receiving environment is the Waikato River, which is the receiving environment for a number of wastewater discharges and also water takes, discussed further in Case Study 8.

5.5 Economic implications stemming from the impact of climate change on stormwater and wastewater systems

Economic implications stemming from the impact of climate change on stormwater and wastewater systems can be grouped into the following four main types of costs:

A	Loss or stranding of property and assets (including land), cost of repairing, rebuilding or replacing assets, and cost of preventative measures.
B	Foregone production or lower efficiency of production.
C	Medical and related costs.
D	Higher insurance (only the component of the premium that represents the price for the service of insurance is an economic cost).

These main costs and other minor costs are discussed in the following sections. We note that in this study, the term 'costs' refers to resource costs to the whole economy, which are not necessarily the same as financial costs to a particular party such as an individual or local government. We also discuss direct costs and indirect costs, where direct costs comprise the directly consequential effects on businesses, residents or home owners caused by the loss of service from the stormwater or wastewater facility. Indirect costs comprise the flow-on effects on supplying industries e.g. business interruption and reduction in production of goods and services (Ranger, et al., 2011).

Much of the research into the economic consequences of damage to stormwater or wastewater facilities does not follow standard economics theory - which can easily lead to double counting and different ways of valuing the same thing. For example Wedawatta, et al. (2014) list the following costs, with our suggested classification (relating to the four main cost types, above, and direct or indirect costs) following in parentheses:

- Damage to premises (A, direct)
- Damaged or lost stock (A, direct)
- Damaged or lost business equipment (A, direct)
- Moving to temporary business premises (B, indirect)

- Loss of trade and production (B, direct)
- Loss of income (B, direct)
- Reduced profit (B, direct)
- Supplies to the business delayed (B, direct or indirect)
- Supplier impact (B, indirect)
- Disrupted travel to customers (unclear, may not be an economic cost, or be counted elsewhere)
- Customers disrupted (probably counted elsewhere, such as in lost sales)
- Staff unavailable to work (unclear, could be C)
- Forced reduction of number of employees (counted in loss of income above)
- Staff anxiety (possibly C)
- Loss of power and/or telecommunications (A, direct or B, indirect)
- Loss of water supply (A, direct or B, indirect)
- Increase in costs (too vague, counted elsewhere)
- Increase in insurance premiums (D).

5.5.1 Loss or damage costs

Replacing or repairing damaged assets, or taking preventive action to improve their resilience against climate change events are all costs related to the loss or damage of assets. Loss of assets is not confined to buildings and infrastructure, but includes for example, flooding from a damaged stormwater or wastewater facility or overloaded on-site treatment systems, that could lessen the attractiveness of natural tourism areas (Wang, et al., 2017); (Fatoric, et al., 2017). This could have flow-on effects to foregone production costs (discussed further in Section 5.5.2) relating to foregone output and employment, and further up the production chain to impact on supporting industries such as agriculture, services, and transportation (Fauzel, et al., 2017). Loss of land through flooding or erosion will lead to the temporary or perhaps permanent loss of economic potential, for example, the extensive damage to New Lynn businesses during the March 2017 floods, and the resulting repairs over the subsequent months (Refer Case Study 6). This will have particular impact on Māori.

5.5.2 Foregone production costs

Foregone production costs are often described as business disruption costs and may be manifested in reduced operational hours for business owners and reduction or loss of employment for employees. Lower socio-economic groups are likely to be particularly vulnerable to such effects as they have less financial security to sustain themselves during periods of lost employment ((Gasper, et al., 2011)).

With regard to foregone production costs, we also draw a distinction between direct costs and indirect costs. Indirect costs (the flow-on effects on supplying industries) are not necessarily limited to the geographic area where the initial impacts occur. Where businesses are unable to operate, the role they play in value chains in other areas will also be disrupted, including goods and services that are unable to be delivered or sold (Surminski & Hankinson, 2018).

Foregone production costs can be exacerbated by construction works (which could be a component in loss or damage of asset costs). Affected businesses may face lower revenue as potential customers avoid dust, noise, vibration, and perceived safety risks. Businesses may face additional costs for promotion and making alternative arrangements such as leasing additional car parking.

Businesses that sell products that are readily available in other stores are likely to be particularly affected. However, in these scenarios the true economic costs are likely to be less than may initially seem to be the case, as one party's loss is another party's gain.

Indeed some parties can benefit from the full amount of what is actually a national economic cost. For example where infrastructure has been rebuilt there could be a need for ongoing maintenance, providing an economic opportunity for local businesses to deliver these services (Fatoric, et al., 2017). Of course if there is a local shortage of suitable workers those benefits will accrue to workers from other regions, albeit that local businesses may benefit from supplying accommodation and related services.

5.5.2.1 Timing

Although direct costs and indirect (supply chain) costs have a logical separation in terms of the phasing of the processes of production, there is frequently also a time dimension to consider. This can be quite long. A post-disaster study found that larger capital and more complex projects were more likely to be prioritised over maintenance works, which were more likely to be postponed (Hayat & Amaratunga, 2014). Hence while major damage may be repaired, resulting in disruption to communities and businesses (but getting them operational relatively quickly) more minor damage and regular maintenance may not be undertaken, leading to longer periods of impaired loss of service from other types of infrastructure.

Ongoing disruption from maintenance or lack of progress on local maintenance concerns may lead to a loss of consumer confidence in service providers. Over the longer term, areas that face ongoing disruption do not create a stable environment for investors. Thus asset values in these areas are likely to fall (Hallegatte, et al., 2016). We might label this as indirect loss or damage of asset costs.

However, the appropriate sequencing of repairs after an event is likely to be highly event and location-specific. It is beyond the scope of this report.

5.5.3 Medical and other related costs

The most apparent costs in this category are for medical treatment in immediate response to an extreme event. There are also longer term costs, however, such as reduced mental health and reduced ability to cope leading to anti-social and criminal behaviour. Loss of livelihood such as through loss of or reduced employment, or reduced business operation can also lead to criminal behaviour (Agnew, 2011). There may be equity impacts with poor, marginalized and vulnerable communities being disproportionately affected (Adger, 2001); (Edward & Sumner, 2013).

5.5.4 Insurance costs

Asset owners, including home owners, residents, and business owners, are likely to face increasing insurance premiums due to increased and/or ongoing damage ((Surminski & Hankinson, 2018)). In addition, in areas that have been directly affected, it may not be possible to renew insurance to cover losses from future events (Salmeemul, et al., 2007).

Insurance is a cost that is frequently misunderstood. Insurance is a way to distribute costs over space and time. Only the component of the premium that represents the price for the service of insurance is an economic cost. Although an increase in underlying risk raises the probability of asset damage, which is certainly an economic cost that is already included under loss or damage of asset costs.

Nevertheless this does not mean that insurance coverage is unimportant. Its presence or absence could affect the speed of reconstruction, thereby affecting foregone production costs.

5.5.5 Other economic issues

5.5.5.1 General equilibrium effects

General equilibrium effects are relevant to how the costs defined above are measured, and are not formally a separate type of cost. General equilibrium effects occur when a local extreme event is significant enough to change some important relative prices in the economy. For example the loss of farmland could lead to (temporary) shortages of certain types of food, causing an increase in food prices throughout the whole economy – not just in the directly affected area. Again there could be equity implications for households who spend a relatively high proportion of their income on food (Hallegatte, et al., 2016)).

Another example is shortage of construction workers, causing a change in relative wage rates or a shortage in concrete and steel due to increasing global demand, driving up prices.

These types of effects are not usually included in the above costs, calculation of which is generally based on prevailing and observable prices. Thus in some circumstances the costs could be understated.

5.5.5.2 Loss of life

Loss of life is more likely to occur from a sudden failure of stormwater or wastewater facilities than from the gradual effects of climate change on such facilities. The component that is economic loss is attributable to fewer working years, valued according to either the human capital method (where workers are irreplaceable and production processes are fixed), or the friction cost method (where over time inputs may be varied and new people employed). Either way this loss is a type B cost.

There is also non-economic loss to consider, which is the value that society places on a life irrespective of any lost working years. One option to estimate this value is to use the NZTA's Value of Statistical Life (Leung, 2009) and subtract the component that corresponds to lost production.

5.6 Implication mapping

Implication maps have been developed in order to show the various relationships between climate hazards, impacts and implications - for each of the six impact themes developed from the impacts literature review, introduced in Section 4.3. In order to clearly demonstrate linkages between initial (first order implications) and higher order implications, bow-tie diagrams have been developed. These enable a simple visual representation of the linkages and cascades between impacts and implications.

Analysis of the implications followed principles from logic modelling – crossing a wide range of stakeholders, including individuals, community groups, the broad community, local businesses, business supply chains, and local government (similar to Lawrence et al., 2019) . Relationships between implications were identified, including those that occur during or immediately after a climate change impact, and subsequent implications over the medium to long term, including those from gradually evolving stressors. Longer term implications can often occur through multiple pathways, increasing the likelihood of these implications occurring, even if some of the shorter term implications do not eventuate.

The bow-tie diagrams present the climate change impacts <u>leading to</u> the **impact theme** (refer to section 4.3), and the most important implications <u>as a result of</u> that impact theme.

The bow-tie diagrams should be interpreted in the following way:

- Left hand side – climate change impacts – summary of impacts on stormwater or wastewater infrastructure.
- Central – summary impact theme – this is a specific physical result in our communities of each of the climate change impacts.
- Right hand side – implications – summary of environmental, social, cultural, and economic implications of the impact theme on a range of receptors e.g. individuals, businesses, communities, the environment, and regulatory bodies etc. Multiple, parallel pathways to the key implication are shown in a box. **Key implications** are denoted with coloured boxes relating to the social, environmental, cultural and economic domains. Key implications are those deemed by the authors to be more significant and overarching. For the social and cultural domains, these key implications generally relate to those that play out over the longer term.
- Arrows identify relationships between implications, where one implication can be a precursor to another. Circular arrows indicate feedback loops, indicating a cyclical relationship.

Key implications are colour coded according to the following key:

Social	**Environmental**	**Cultural**	**Economic**

For example, a loss in community facilities can contribute to a reduction in community cohesion, which in turn is known to contribute to reduction in mental health of individuals. As mental health is the long term implication from the loss of community facilities, and other implications also lead to this reduction, mental health is identified as a key implication.

Exploration of the implications highlighted in the bow-tie mapping is presented below. Discussion is structured according to the social, environmental, cultural, and economic domains.

5.6.1 Implications arising from increased stormwater flooding

Increased flooding is one of the summary impact themes arising from the impact of climate change on stormwater systems. Figure 5.1 shows a summary of the impacts identified in the literature review that lead to flooding. It also summarises the associated social, cultural, environmental and economic implications that are discussed in below.

The key implications for the impact theme of flooding are: loss of income and increased costs for residents/ home owners, and business owners (discussed with broader economic implications in Section 5.5); physical disruptions (i.e. closed roads, stormwater and wastewater systems not working, evacuation of homes) and associated reduced mental health for residents (discussed with broader social implications in Section 5.1); loss of cultural identity (discussed with broader cultural implications in Section 5.2); and environmental damage and reduced resilience of waterways (discussed with broader environmental implications in Section 5.3).

Disruption to residents and businesses is an immediate implication of flooding events. As abovementioned, residents may need to evacuate, roads may be closed causing disrupted access to homes, work and services, and there may be a loss in amenity (i.e. gardens and community facilities). This is evidenced during the flooding events in Whakatane discussed further in section 6.2.1 (Case Study 1). Flooding can also cause a range of immediate and longer-term health issues for these residents. Clean-up activities are likely to cause temporary closure of businesses and schools. Costs are likely to be incurred by businesses and the community due to replacement and repair of damaged assets, as well as any medical costs relating to injury. As businesses may not be operational, this has potential to lead to disruptions to supply chains over the short to medium term, if the businesses are key players in supply chains outside of the affected area. If flooding is frequent, and costly for business owners to respond to, there may be a reduction in investment interest in the medium term. These business disruptions and uncertainty may result in direct loss of income for employees and business owners from the immediate to medium term. There is then a cyclical relationship between loss of income and business stability, as residents have reduced ability to spend with local businesses, placing further pressure on businesses. A general increase in costs is incurred by business owners and the community over the medium and long term due to ongoing repair, the cost of preventive measures, mental health or chronic injury or health costs and increasing insurance premiums or excesses (or insurance withdrawal eventually for certain impacts).

During flooding events and in the immediate aftermath, residents are at risk of physical injury (including driving or entering floodwaters) and illness. These events can result in post-traumatic stress disorder from the event. Even where events may not be severe, frequent flooding events can lead to chronic stress for residents over the medium term. Flooding can also lead to solastalgia over the short to medium term, or a loss of sense of place, through the disruption or loss of place-based activities in the community. These implications can lead to further reduced mental health in the community over the medium to longer term.

Damage to sites of cultural value from flooding can lead to a loss of connection to cultural identity over the medium to long term. Similarly, disruption to cultural practices, such as lack of access to cultural sites, or reduction of environmental processes, can also lead to a loss of cultural identity. Loss of cultural identity in turn can lead to reduction in mental health.

Environmentally, increased flooding events would result in more ‘flushing events’ within waterways, and may also increase the presence of contaminants in waterways, destabilising and clogging habitat. These impacts are immediate, and may lead to a disruption in the aquatic ecosystem over the medium term. Over the longer term, this leads to reduced resilience of the waterways to recover from events and potentially increase eutrophication of water bodies, which would reduce the assimilative capacity for anthropogenic discharges. Flooding events also generate large volumes of waste and debris due to damaged property immediately after the event. This leads to increased consumption and land disposal requirements over the medium and long term.

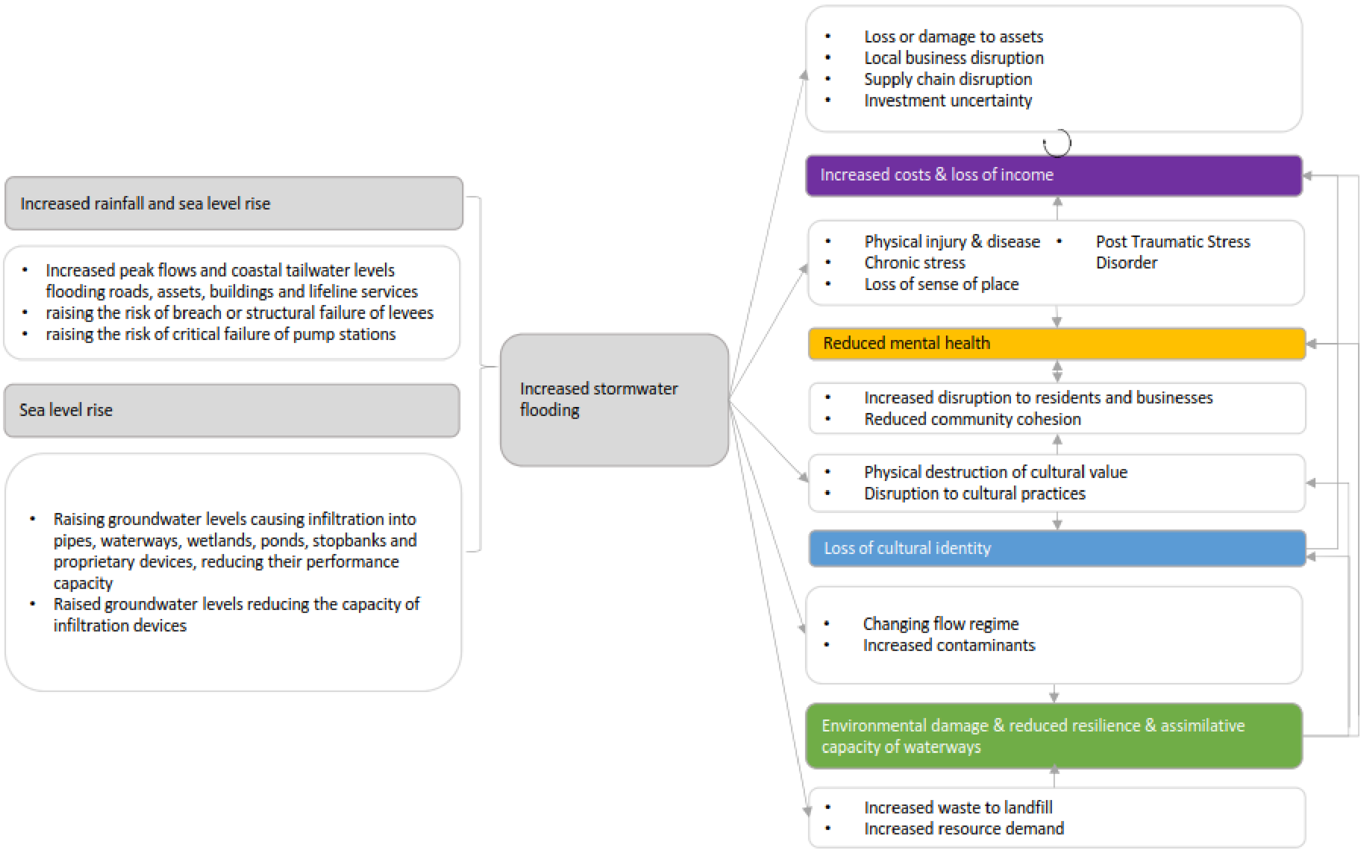


Figure 5.1: Summary of impacts resulting in increased flooding and the associated social, cultural, environmental and economic implications

5.6.2 Implications arising from loss of land and damage to stormwater infrastructure

Loss of land and direct physical damage to infrastructure are two of the fundamental implications arising from the impact of climate change on stormwater systems. Figure 5.2 shows a summary of the impacts identified in literature that lead to loss of land and damage to infrastructure. It also summarises the associated social, cultural, environmental and economic implications.

The key implications for the impact theme of loss of land and damage to infrastructure are: loss of income and increased costs for residents and business owners (discussed with broader economic implications in Section 5.5); reduced mental health for residents and impacting the community as a whole (discussed with broader social implications in Section 5.1); loss of cultural identity discussed with broader cultural implications in Section 5.2); and environmental damage and reduced resilience of waterways (discussed with broader environmental implications in Section 5.3).

Disruption to residents and businesses is an immediate implication of damage to infrastructure or loss of land. Damage to stormwater systems from blockages or the floating of pipes can result in flooding of houses, roads and infrastructure. Temporary closure of businesses or roads may be necessary while repairs are made. Increased maintenance related to both event-based damages and chronic deterioration of infrastructure will result in increased costs as well as a potential loss of reputation for service providers and may ultimately lead to managed retreat.

Environmentally, damage to infrastructure may result in increased contaminants entering waterways through erosion related sedimentation as well as a deterioration in the performance of water quality treatment devices. These impacts are immediate, but will also occur due to chronic deterioration of infrastructure. The increased contaminant load will lead to a disruption in the aquatic ecosystem over the medium term, leading to a reduced public amenity and reduced resilience of the waterways to recover from events. Increased requirement for repair and replacement of stormwater infrastructure will lead to increased consumption of resources and increased land disposal requirements over the medium and long term. Damage to sites of cultural value from loss of land can lead to a loss of connection to cultural identity over the medium to long term. Similarly, disruption to cultural practices, such as through lack of access to cultural sites, or reduction of environmental processes, can also lead to a loss of cultural identity. Loss of cultural identity in turn can lead to reduction in mental health.

Socially, a reduction in mental health is expected to occur as a result of economic, environmental and cultural implications relating to damage to infrastructure and loss of land in the medium and long term. Business disruption and costs, reduced amenity of waterways and a loss of cultural identity can lead to reduced mental health.

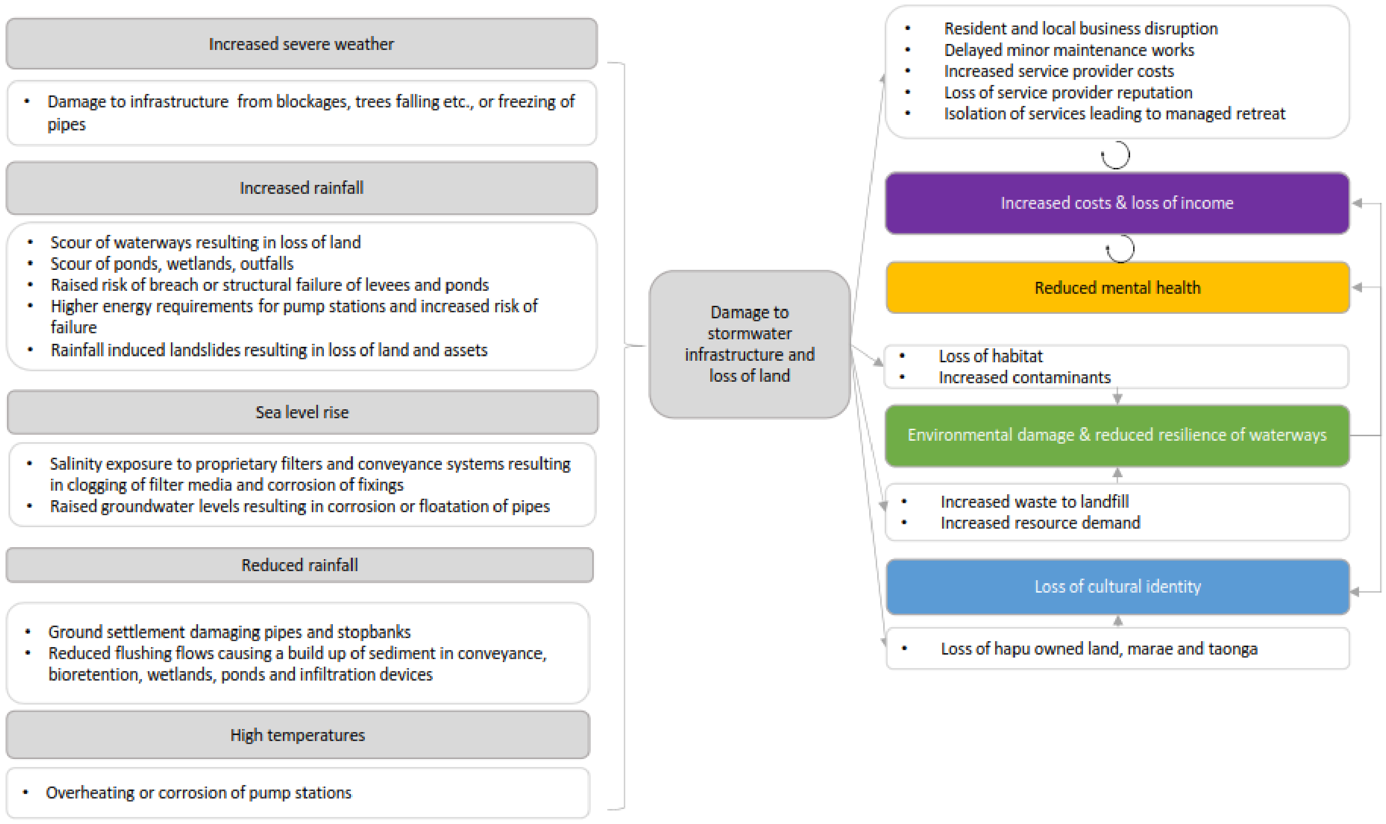


Figure 5.2: Summary of impacts resulting in damage to infrastructure and the associated social, cultural, environmental and economic implications

5.6.3 Implications arising from stormwater related water quality deterioration

Reduced water quality is one of the fundamental implications arising from the impact of climate change on stormwater systems. Figure 5.3 shows a summary of the impacts identified in the literature review that lead to reduced water quality. It also summarises the associated social, cultural, environmental and economic implications.

The key implications for the impact theme of water quality deterioration are: reduced resilience and assimilative capacity of waterways (discussed with broader environmental implications in Section 5.3), reduced physical and mental health for residents and impacting the community as a whole (discussed with broader social implications in Section 5.1); loss of cultural identity (discussed with broader cultural implications in Section 5.2); and loss of income and increased costs for residents and business owners (discussed with broader economic implications in Section 5.5);

Water quality deterioration will occur in response to both event based and chronic impacts of climate change on the stormwater system, causing additional environmental degradation (over and above any existing impacts e.g. land-use change, development). Increased contaminant loading will occur over varying timescales depending on the nature of the source of contaminant. Increased contaminant loading may lead to habitat smothering and increased toxicity. Higher peak flows and lower low flows will result in a changed flow regime of watercourses. Increased rainfall and higher peak flows can result in the reduced capacity of water quality treatment systems to treat flows. These issues will lead to damage to the aquatic ecosystem over the medium term. Over the longer term, this leads to reduced assimilative capacity (resilience to recover from events) of waterways. Potentially increased in-situ eutrophication or persistent low flows (from rainfall changes) may reduce the assimilative capacity of receiving waters for stormwater and wastewater discharges, thus constraining development or leading to higher treatment costs. Deterioration of water quality will therefore, have a negative overall effect on ecosystems and the services they provide and that communities rely on.

Water quality deterioration can lead directly to an immediate loss of cultural values, which can be persistent over medium and long timespans. Reduced resilience of waterways is likely to cause disruption to cultural practices, leading to a loss of connection to cultural identity over the medium to long term. Loss of cultural identity in turn can lead to reduction in mental health.

Exposure to poor water quality can lead to an increased incidence of disease over the short to medium term. Additionally, reduced amenity of waterways can disrupt place-based activities in the community, which can lead to solastalgia, or a loss of sense of place, over the short to medium term.

Increased preventive maintenance and water quality management costs are likely to be incurred by service providers in the short to medium term as a response to water quality deterioration. These costs may be passed on to the community through rates and taxes, all of which may contribute to a loss of service provider reputation. There is also the potential for service withdrawal and managed retreat. This can however lead to complex social issues (dependent of the scale of retreat proposed). Water quality deterioration is also likely to result in a loss of tourism, resulting in medium and long term economic impact.

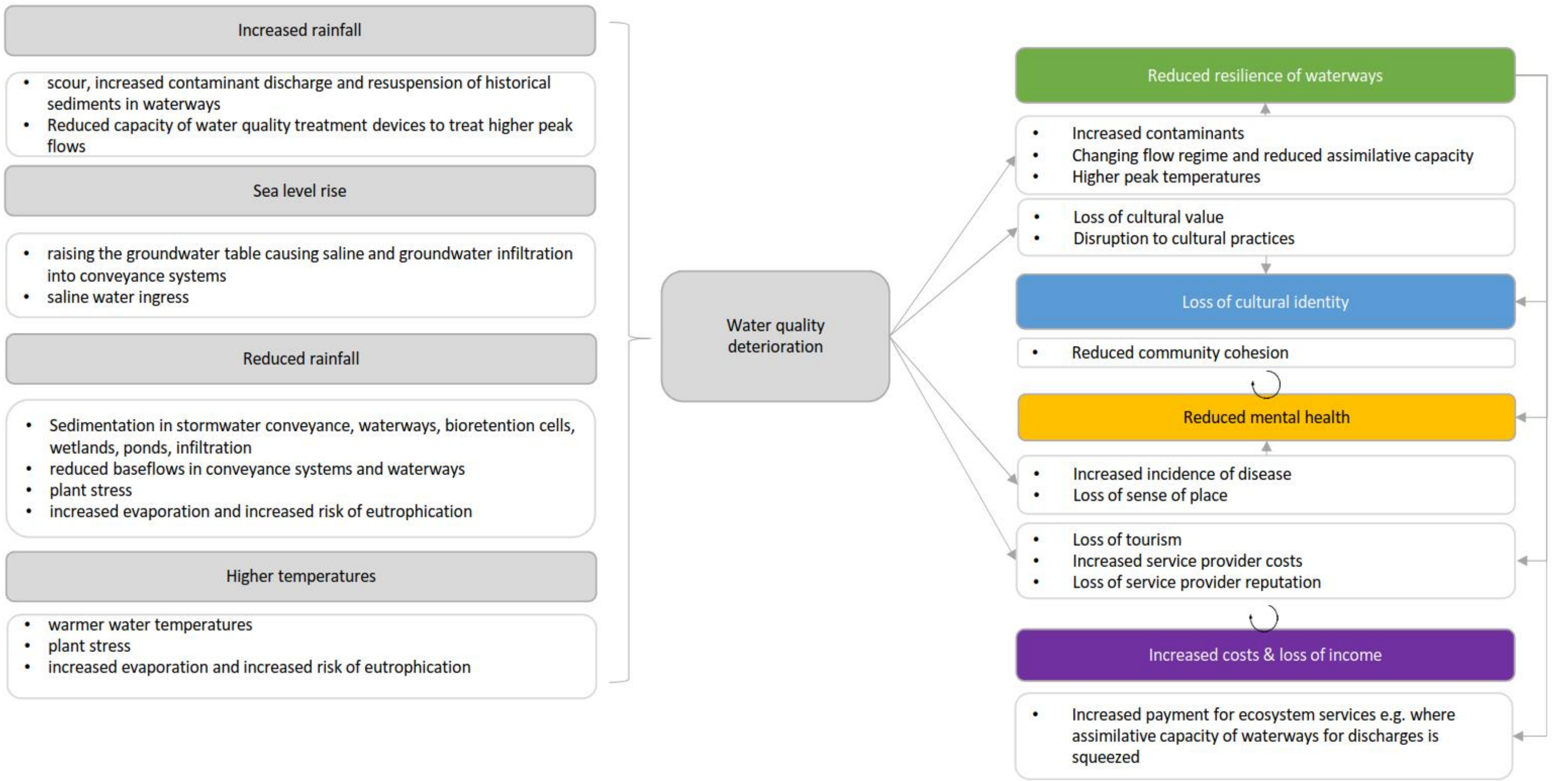


Figure 5.3: Summary of impacts resulting in water quality deterioration and the associated social, cultural, environmental and economic implications

5.6.4 Implications arising from wastewater nuisance flooding, spills and odour

Nuisance flooding, spills and odour is one of the summary themes arising from the impact of climate change on wastewater systems. Figure 5.4 shows a summary of the impacts identified in the literature review that lead to flooding, spills and odour. It also summarises the associated social, cultural, environmental and economic implications.

The key implications for the impact theme of wastewater nuisance flooding, spills and odour are: loss of income and increased costs for residents and business owners (discussed with broader economic implications in Section 5.5); reduced mental health for residents and impacting the community as a whole (discussed with broader social implications in Section 5.1); loss of cultural identity (discussed with broader cultural implications in Section 5.2); and reduced resilience of waterways and assimilative capacity (discussed with broader environmental implications in Section 5.3).

Disruption to businesses and residents is an immediate implication of wastewater nuisance flooding or spills. Clean-up activities are likely to cause temporary closure of businesses and roads, and nuisance flooding and spills may also result in the evacuation of homes. Businesses may incur clean-up costs, and a loss of income due to foregone production.

Exposure of residents to untreated wastewater resulting from spills poses an immediate threat to public health, and associated deteriorating water quality can also be a source of illness over the short and medium term. Increased pathogens from human/animal waste wil lead to restrictions on recreational water activities amd gathering kaimoana in the wider region. Repeated exposure to odour can lead to respiratory disorders, and have a negative impact on mood. These implications can lead to further reduced mental health in the community over the medium to longer term.

Wastewater spills can lead directly to an immediate loss of cultural values, particularly from the presence of human waste. Reduced resilience of waterways is likely to cause disruption to cultural practices, leading to a loss of connection to cultural identity over the medium to long term. Loss of cultural identity in turn can lead to reduction in mental health.

Increased discharge of nutrients entering waterways as a result of spills can promote algal growth and increase toxicity. These impacts are immediate, and may lead to a disruption in the aquatic ecosystem over the medium term. Over the longer term, this leads to reduced resilience of the waterways to recover from events.

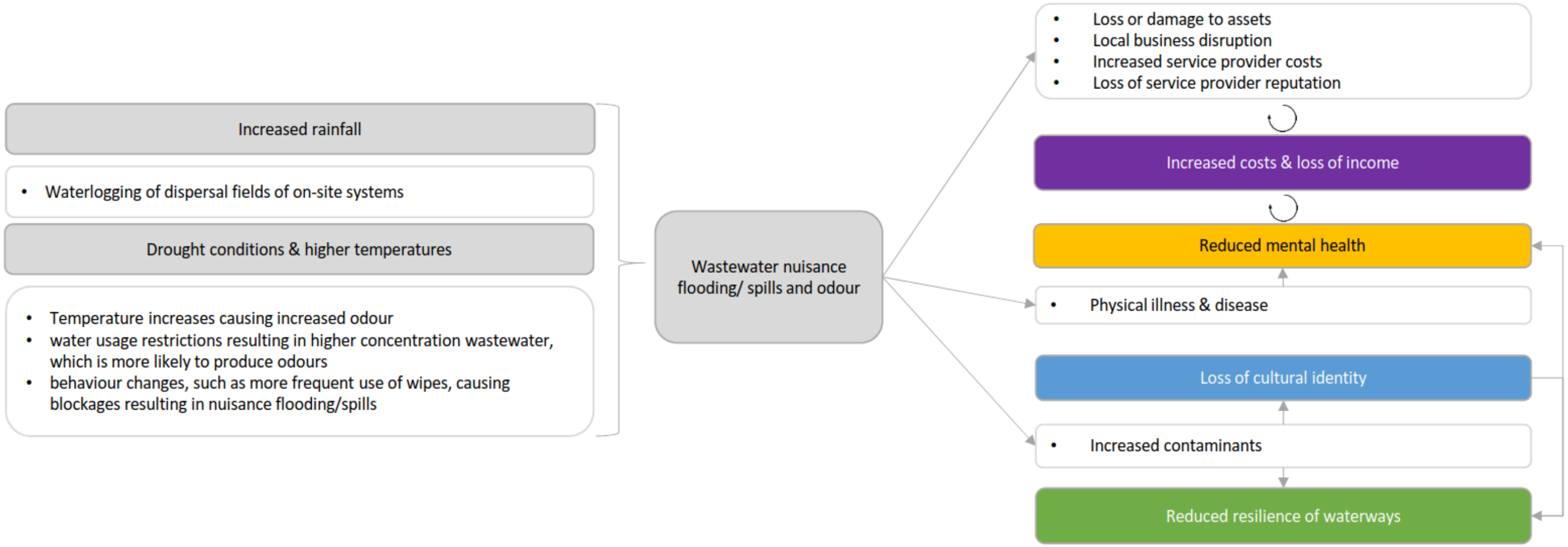


Figure 5.4: Summary of impacts resulting in heightened risk of nuisance flooding, spills and odour and the associated implications

5.6.5 Implications arising from water quality deterioration due to increased uncontrolled wastewater discharges

Reduced water quality is one of the fundamental implications arising from the impact of climate change on wastewater systems. Figure 5.5 shows a summary of the impacts identified in the literature review that lead to reduced water quality. It also summarises the associated social, cultural, environmental and economic implications. There are numerous crossovers with the implications arising from water quality deterioration due to stormwater.

The key implications for the impact theme of water quality deterioration are: reduced resilience of waterways (discussed with broader environmental implications in Section 5.3), reduced mental health for residents and impacting the community as a whole (discussed with broader social implications in Section 5.1); loss of cultural identity (discussed with broader cultural implications in Section 5.2); and loss of income and increased costs for service providers, residents and business owners (discussed with broader economic implications in Section 5.5).

Water quality deterioration will occur in primarily in response to the increased discharge of wastewater contaminants during high rainfall – including via combined sewer overflows (CSOs). Other more chronic damages to wastewater infrastructure will contribute to deteriorating water quality over a longer term. Increased discharge of nutrients entering waterways as a result of spills can promote algal growth and increase toxicity. These impacts are immediate, and may lead to a disruption in the aquatic ecosystem over the medium term. Over the longer term, this leads to reduced resilience of the waterways to recover from events. Increased pathogens from human/animal waste will lead to more restrictions on recreational water activities and gathering mahinga kai in the wider region.

Discharge of wastewater related contaminants (particularly containing human waste) into water bodies can lead directly to an immediate loss of cultural values, which can be persistent over medium and long timespans. Reduced resilience of waterways is likely to cause disruption to cultural practices, leading to a loss of connection to cultural identity over the medium to long term. Loss of cultural identity in turn can lead to a reduction in community cohesion and a reduction in mental health.

Exposure to poor water quality can lead to an increased incidence of disease over the short to medium term and reduced recreational and seafood gathering opportunities. Additionally, reduced amenity of waterways can disrupt place-based activities in the community, which can lead to solastalgia, or a loss of sense of place, over the short to medium term. These implications can lead to further reduced mental health in the community over the medium to longer term.

Increased preventive maintenance and water quality management costs are likely to be incurred by service providers in the short to medium term as a response to any rising water quality deterioration. These costs may be passed on to the community through rates and taxes, all of which may contribute to a loss of service provider reputation. Water quality deterioration is also likely to result in a loss of tourism, resulting in medium and long term economic impact.

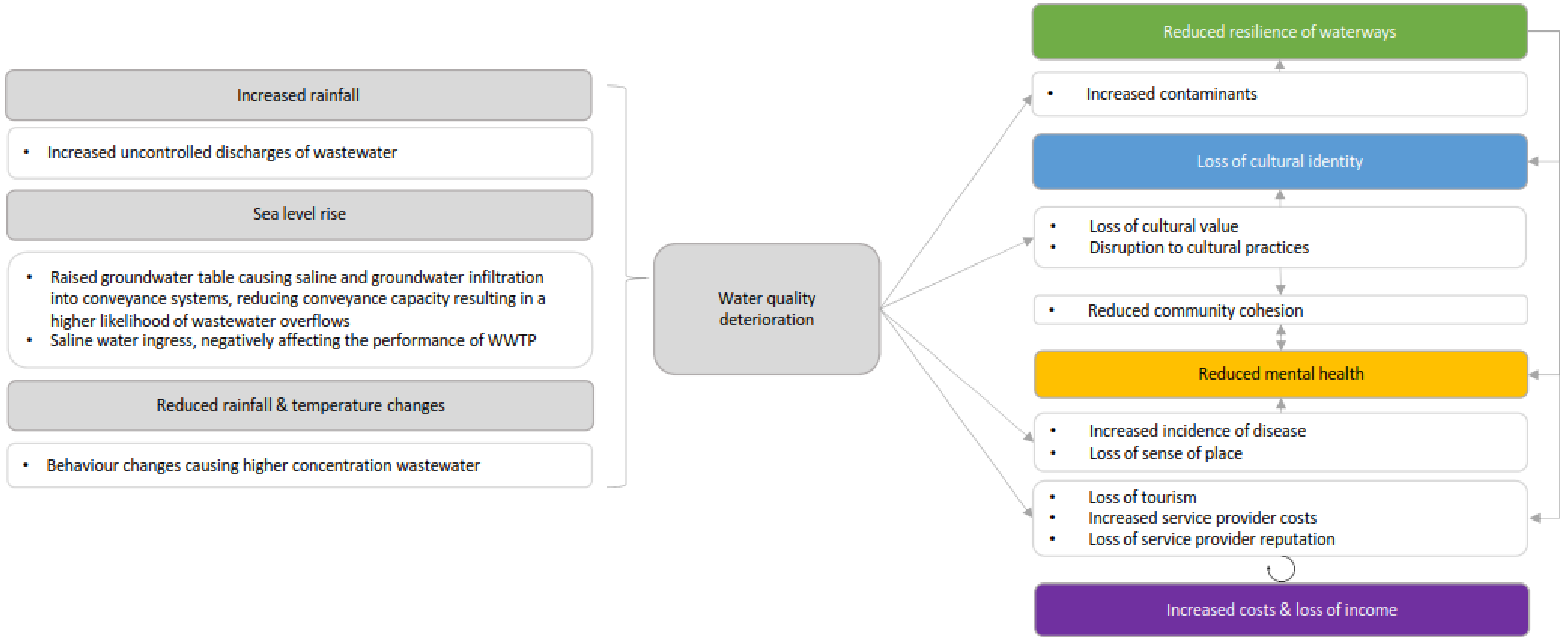


Figure 5.5: Summary of impacts resulting in water quality deterioration and the associated social, cultural, environmental and economic implications

5.6.6 Implications arising from damage to wastewater infrastructure

Damageto infrastructure is one of the fundamental implications arising from the impact of climate change on wastewater systems. Figure 5.6 shows a summary of the impacts identified in the literature review that may result in damage to infrastructure. It also summarises the associated social, cultural, environmental and economic implications that are discussed in the following section. There are numerous crossovers with the implications arising from damage to stormwater infrastructure.

The key implications for the impact theme of damage to wastewater infrastructure are: loss of income and increased costs for residents and business owners (discussed with broader economic implications in Section 5.5); reduced mental health for residents and impacting the community as a whole (discussed with broader social implications in Section 5.1); loss of cultural identity (discussed with broader cultural implications in Section 5.2); and environmental damage and reduced resilience of waterways (discussed with broader environmental implications in Section 5.3).

Disruption to residents and businesses is an immediate implication of event-based damage to wastewater infrastructure. Loss of services to residents is likely to cause stress, and due to wastewater systems not working (toilets not flushing, showers unusable etc) temporary evacuations of homes may be required. Repair works are likely to cause temporary closure of businesses and schools, incurring repair costs and loss of income due to foregone production until wastewater services are functional. Chronic damage to infrastructure, such as higher strength wastewater causing corrosion, will require increased maintenance, repair and running costs. These costs are likely to be incurred by service providers in the short to medium term, but may be passed on to the community through rates and taxes, all of which may contribute to a loss of service provider reputation. Service withdrawal and managed retreat may be considered if loss of land and damage to wastewater infrastructure is likely. The complex social issues arising from managed retreat are discussed in Section 5.1.2. The scale of retreat i.e. whether infrastructure can be moved back from the coast in the first instance, or whether whole communities need to be relocated will have an influence on the social issues which arise.

Increased levels of nutrients can enter waterways as a result of a reduced level of treatment. This is particularly acute where on-site wastewater treatment devices are affected, as these systems are usually subject to much less frequent performance monitoring relative to wastewater treatment plants. Increased discharges of nutrients can promote algal growth and increase waterway toxicity, leading to a disruption in the aquatic ecosystem over the medium term. Over the longer term, this leads to reduced resilience of the waterways to recover from events. Increased pathogens from human/animal waste during outages and repairs will lead to temporary restrictions on recreational water activities and gathering mahinga kai in the wider region. Increased damage to wastewater infrastructure also generate increased volumes of waste due to the need for repairs or an increased rate of failure. This leads to increased consumption and land disposal requirements over the medium and long term.

Discharge of wastewater-related contaminants into water bodies, especially containing human waste, can lead directly to an immediate loss of cultural values, which can be persistent over medium and long timespans. Reduced resilience of waterways is likely to cause disruption to cultural practices, leading to a loss of connection to cultural identity over the medium to long term. Loss of cultural identity in turn can lead to a reduction in community cohesion and a reduction in mental health.

Damage to wastewater infrastructure leading to poorly treated wastewater (for example due in on-site wastewater treatment dispersal fields) or poor water quality can lead to an increased incidence of disease over the short to medium term if residents are exposed. Additionally, reduced amenity of waterways can disrupt place-based activities in the community, which can lead to solastalgia, or a loss of sense of place, over the short to medium term. These implications can lead to further reduced mental health in the community over the medium to longer term.

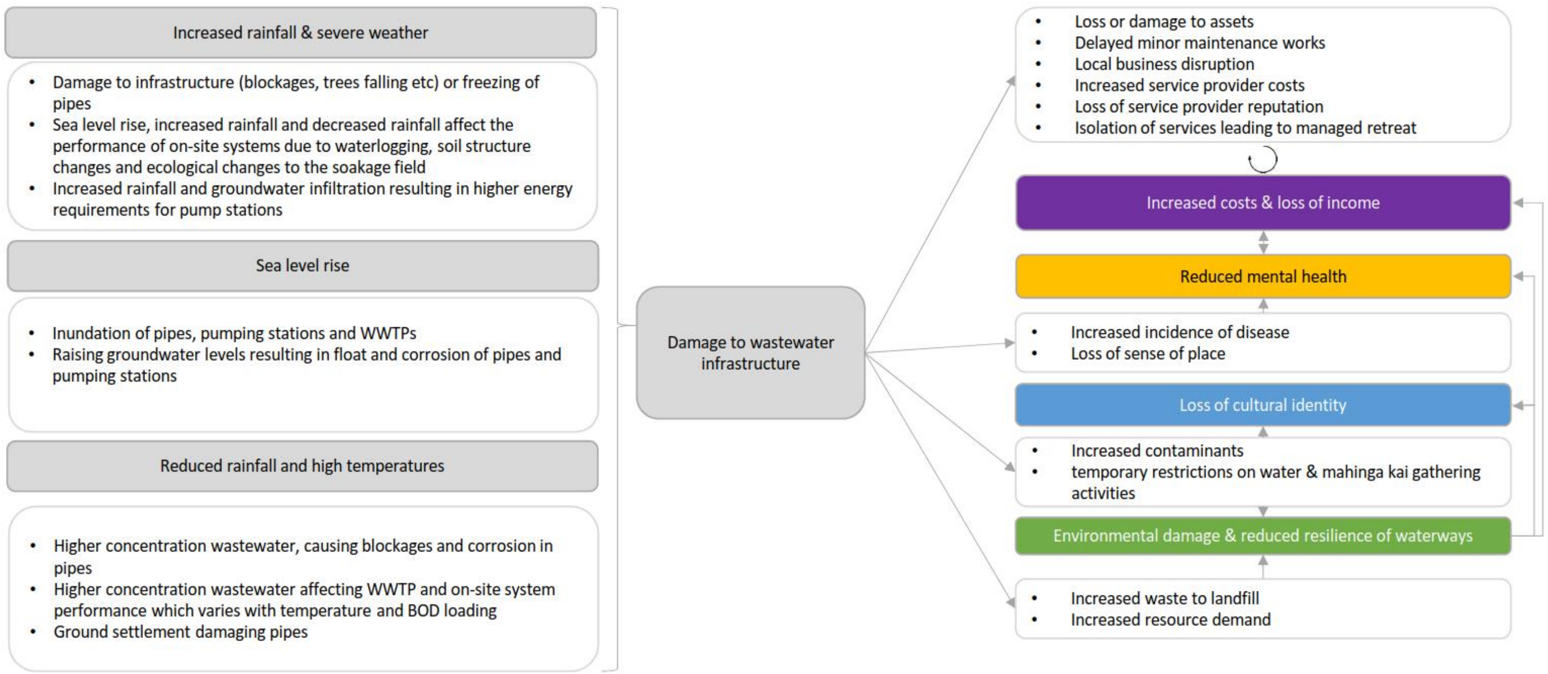


Figure 5.6: Summary of impacts resulting in damage to infrastructure and the associated social, cultural, environmental and economic implications

5.6.7 Summary

Across the impact themes, recurring implications are evident. The primary recurring social implication was that of community disruption, including loss of stormwater and wastewater services, evacuations of homes, road closures and loss of access to homes and services, losses of amenity (gardens private and public), and community assets. These disruptions (which can be ongoing and recurring) to people's lives can result in a reduction in mental health. This occurs as a result of residents dealing with physical impacts such as injury and disease, chronic events, and loss of personal income. Other implications include a loss of sense of place, restrictions on water activities and mahinga kai gathering and reduction in community cohesion which leads to reductions in mental health within communities.

A common cultural implication for Māori identified is a loss in cultural identity. This is associated with potential loss of cultural values, damage or loss of cultural land, marae and taonga, and a reduced mauri of waterways which may diminish the ability of Māori to participate in cultural practices such as gathering of food. Māori communities were identified to be particularly affected by loss and damage to their whenua and wai ora, as many have a strong connection to their ancestral lands and waterways, to which a large aspect of their identity is tied.

Environmental implications included the reduced resilience of waterways resulting from increased wastewater overflows, increased discharge of stormwater contaminants, and stresses from SLR and temperature changes, resulting in a multitude of effects on aquatic ecosystems. As well as the aforementioned cultural implications, this also has cascading social implications on quality of life due to decreased opportunity for recreational activities, as well as having regulatory implications.

Economic implications include direct costs associated with replacing or repairing damaged assets, the cost of action taken to improve resilience (which could be managed retreat), and foregone production such as loss of income due to business disruption, and increasing insurance costs associated with these economic losses.

6 Regional analysis

In this section of the report, a high-level analysis of climate projections and physical/social attributes across New Zealand is presented – with the purpose of identifying 'hot spots' where the greatest impacts of a particular type may be expected. This will help to provide better insights into the extent of climate impacts and enable better decision-making and adaptive approaches to risk reduction across areas where there may be similar outcomes around New Zealand.

Through discussion with the TRG, a number of factors were highlighted that are likely to make cities, towns and communities more vulnerable to climate impacts on stormwater and wastewater systems. The following factors have been identified which may combine with regional climate-change to increase climate risk to that community:

- Communities that rely on pumped stormwater systems (or are currently struggling with gravity systems)
- Communities with environmentally compromised waterways (with diminishing assimilative capacity)
- Communities that are protected by stopbanks
- Communities with low-lying coastal WWTPs
- Communities with WWTPs which discharge to rivers
- Communities with low-lying areas prone to flooding or which have groundwater levels which exhibit a tidal signal.
- Other factors that may lead to specific community vulnerabilities. E.g. socio-economic factors, small rating base.

The following sections summarise regional climate projections across New Zealand, and discuss the factors that may make communities more vulnerable to climate change.

6.1 Regional climate projections across New Zealand

Climate change projections have been developed, which identify regional variation across New Zealand (MfE, 2018b). These regional variations have been summarised in the climate impact map shown in Figure 6.1. While warming and sea-level rise occur across the country, there are regionally differing climate projections for rainfall and wind, as summarised in Table 6.1.

Table 6.1: High level regional climate projections summary (MfE, 2018b).

Climate driver	Extreme events	Region
Increased temperature	Increased fire risk	Nationwide
Decreased rainfall	Droughts	Northland Bay of Plenty Gisborne Hawkes Bay Marlborough/Nelson Canterbury Central Otago
Increased rainfall	Flooding Landslides	Nationwide
Sea-level rise	Coastal flooding from storm/wave events, increased beach/cliff erosion, groundwater rise,	Nationwide

	gradual saline inundation at higher spring tides.	
Winds	Physical damage (e.g. trees, buildings, assets)	Nationwide

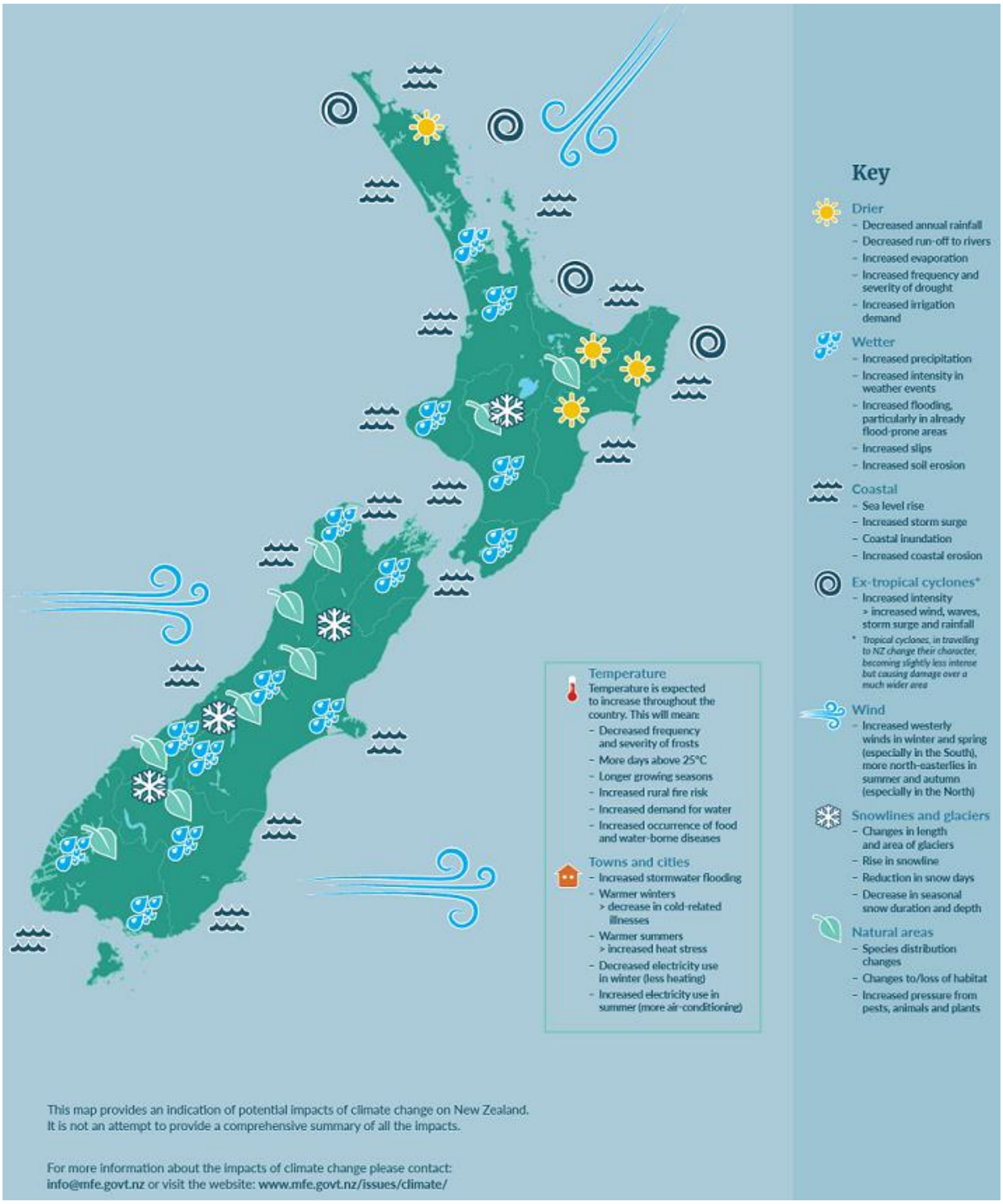


Figure 6.1: Climate change projections for New Zealand (MfE, 2017c)

6.2 Stormwater and wastewater factors that will affect regional vulnerability

A number of key stormwater and wastewater factors that will affect regional vulnerability have been identified.

Some of New Zealand's communities are characterised by more than one of these factors. For example, communities with low lying areas that are prone to flooding may also be protected by stopbanks, and have a pumped stormwater system.

6.2.1 Communities that rely on pumped stormwater systems

Communities that rely on pumped stormwater systems (or areas where the gravity system is compromised) will be more vulnerable to increasing rainfall and extreme events due to the fact that these systems will have a finite design capacity, and often no secondary system (or redundancy) (see Case Study 1). 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, as discussed in Section 4.1.1.5. In particular, most areas will receive significant increases in extreme rainfall (from a warmer atmosphere), but areas of New Zealand that are projected to become wetter or have extended dry spells will also contribute to increased risk from adverse antecendent conditions for those communities or cities that have a significant sections of their stormwater systems reliant on pumping include:

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

Note: Areas with pumped stormwater systems such as Napier are not expected to see a wetter climate but will still have increased vulnerability due to increased extreme rainfall events (such as ex tropical cyclones and convective storm systems) from more moisture in a warmer atmosphere and through exposure to rising seas and coastal flooding.

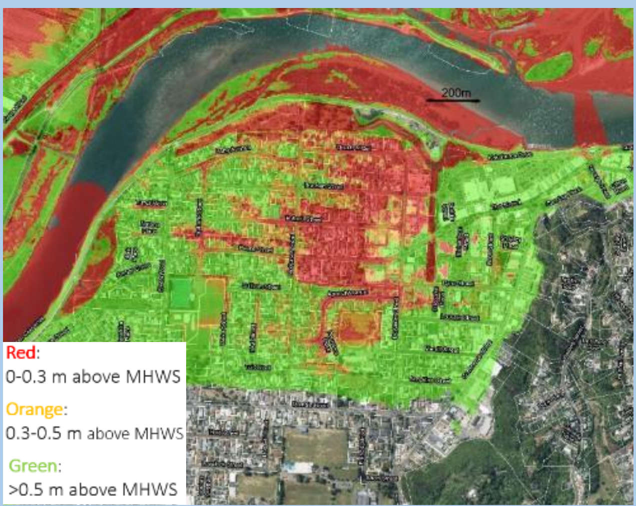
A case study relating to Whakatane is presented below.

Case Study 1: Whakatāne

Whakatāne is a low lying coastal community that relies largely on a pumped stormwater network to manage its stormwater. As seen in the image below, a significant proportion of the CBD is 0.3 m or less above mean high water springs (MHWS), leaving it vulnerable to flooding. The town is situated at the mouth of the Whakatāne River, and is nestled between the river and the steep hillside of Kohi Point. This constrained geography limits the area of flat land available for development.

The pumped stormwater system is designed to cope with a 1-in-10 year flood event.Recently the town has experienced multiple large rainfall events, and these combined with urban intensification, other land-use changes, silt build-up in the stormwater pipes, and an elevated groundwater table have led to severe flooding. Whakatāne's stormwater system consists of a network of pipes and open drains supplemented by 14 stormwater pump stations. When water reaches a certain capacity in these pipes, the pumps are automatically activated to assist discharge of the stormwater into the Whakatāne River. Whakatāne District Council reports that the pumps are under-capacity, and in general it is not possible to increase the capacity of this network by activating the pumps earlier, as this can cause them to run out of water and seize, resulting in costly damage (Whakatane District Council, 2019).

As the severity and frequency of flood events increases with climate change, the stormwater system capacity is becoming increasingly insufficient and maintenance costs are rising. The increase in severe flood events is also thought to be linked to a rising groundwater table, reducing infiltration capacity and further exacerbating flooding, especially in low-lying urban areas. Not only does the flooding impact residents and businesses due to evacuations, road closures and extensive damage to property, but it also damages the stormwater network, further reducing its capacity. The result of multiple consecutive flood events can cause disproportionate damage, due to the build-up of debris and silt in the network leading to blockage during subsequent storm events, resulting in significant repair costs (Whakatane District Council, 2019).



Whakatāne ground elevations relative to MHWS (left, source: Whakatāne District Council); flooding in Whakātane (right, source: Jamie Hedges, Weather Watch)

Information for this case study referenced from (Whakatane District Council, 2019).

6.2.2 Communities with environmentally compromised waterways

Communities that have environmentally compromised waterways will be more vulnerable to most aspects of a changing climate. Waterways provide a range of social, environmental, cultural and economic benefits to the community, for which waterway health is critical. Water quality deterioration is caused by a wide range of factors, such as increased erosion, contaminant 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 (see Case Study 2). Of particular concern are waterways which receive WWTP effluent, where any decrease in assimilative capacity will apply further constraints (discussed further in Case Study 7 and Section 6.2.6).

Urban areas that have an ageing network are likely to have an elevated risk of water quality deterioration, as these areas are unlikely to provide water quality treatment to modern standards, and are likely to be subject to more infrastructure breakages which can lead to uncontrolled discharge of wastewater or erosion and release of stormwater contaminants.

The distribution of stream health across New Zealand is shown in Figure 6.2 [15], represented using the Macroinvertebrate Community Index (MCI). 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). These waterways will be placed under further stress as urban water quality deteriorates in response to the impacts of climate change, as discussed in Section 0.

Rural areas are also at risk, especially where stream health is poor and pollutant loading can be severe. A recent example includes the Whangamarino wetland as discussed within Case Study 2.

[15] The MCI at 512 monitoring sites across New Zealand from data collected from 2007-2011. Classification of MCI has been undertaken according to the methodology presented in Stark and Maxted (2007)

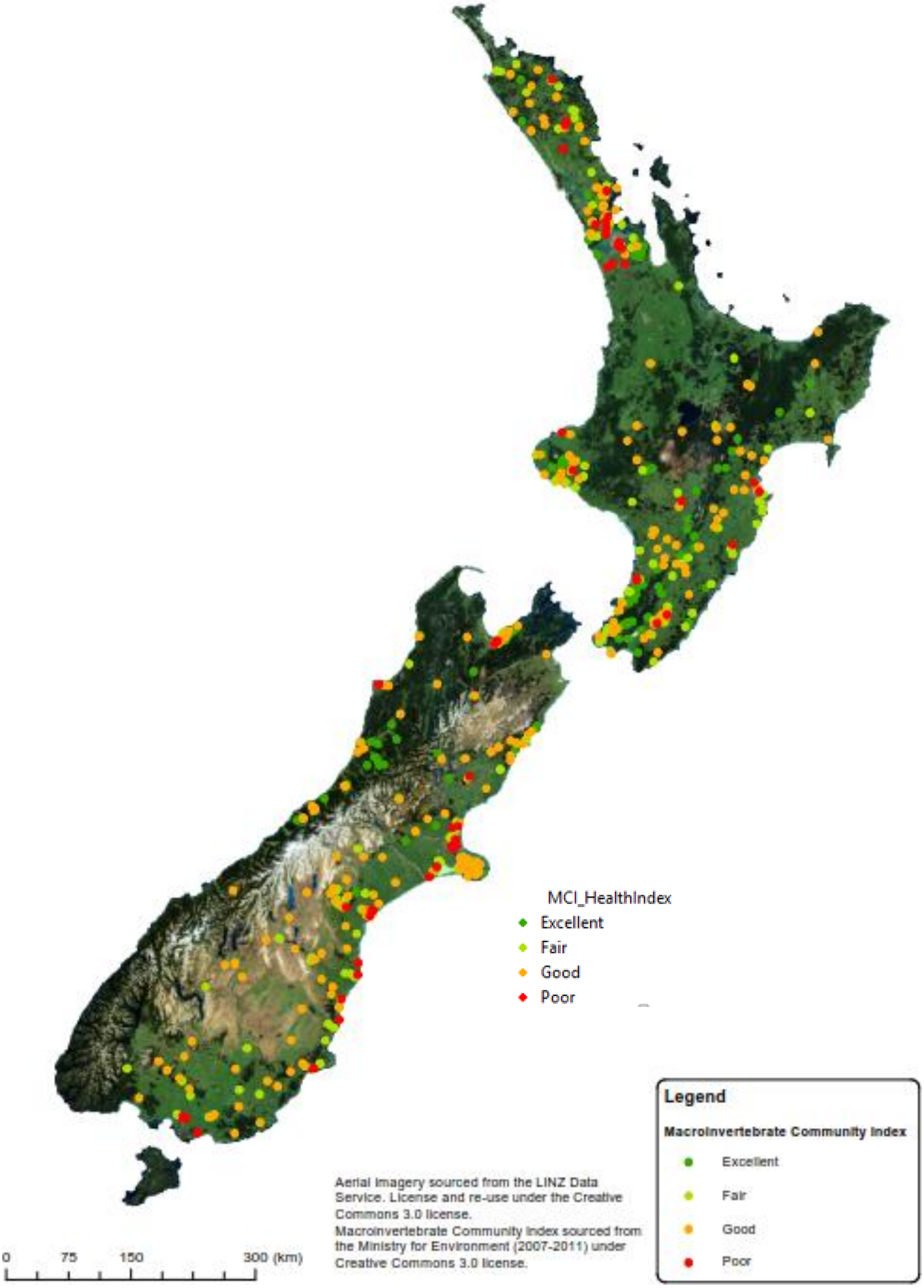


Figure 6.2: Map showing Macroinvertebrate Community Index (MCI). Source: (MfE, 2016)

Case Study 2: Whangamarino wetland

The Whangamarino Wetland is New Zealand's second largest wetland, and is a Ramsar site. The convention on wetlands, called the Ramsar convention, is an intergovernmental treaty which provides for the conservation and sustainable use of wetlands. The wetland is located in the Northern Waikato region, and is an important component in flood control measures in the area. It is also used for recreational hunting grounds, is a site for gathering mahinga kai, a habitat for native fish birds, and is an ecological tourist attraction.

Under global climate change projections, the north-eastern Waikato Region is projected to have more dry periods punctuated by more intense rainstorms (MfE, 2018). In March-April 2017, ex tropical cyclones 'Cook' and 'Debbie' delivered heavy rainfall across the central North Island, and resulted in floodplain inundation (behind the flood scheme infrastructure) in the Lower Waikato region. These weather systems had significant water quality and ecological impacts on the wetland. Following these high intensity rainfall events, water quality monitoring sensors revealed widespread 'blackwater' events (defined by zero dissolved oxygen (DO)) that ultimately resulted in widespread mortality of native and invasive fish. The blackwater event in the Maramarua River lasted for approximately two months, with only periods of minor recovery of oxygen during this event. Spot measurements of nutrients during the rise of the flow indicated very high levels of nutrient and faecal bacterial counts (above 40,000 colonies /100 ml) suggesting a disproportionate supply of nutrients occurring during the early phase of rain runoff. (Ryan, E; David, B. Waikato Regional Council. Personal communication 23 November, 2018).

Current catchment management and creation of the flood protection scheme has led to reduced resilience in the wetland system, including; significantly altered hydrology, longer duration blackwater events, lost connectivity, and reduced availability of refuge areas. Additionally, extended dry spells can promote plant growth where wetland water levels have dropped. This can be problematic when flooding causes plants to die off due to submergence, triggering bacterial processes associated with plant decomposition. As the effects of climate change are experienced, this type of ecological damage is expected to occur more frequently. (Ryan, E; David, B. Waikato Regional Council. Personal communication 23 November, 2018).


Whangamarino Wetland (left, source: DOC) and nearby fish mortality during 2017 floods (right, source: Andrew Rumsby, PDP & Waikato Regional Council)

Information for this case study referenced from (Ryan, E; David, B. Waikato Regional Council. Personal communication 23 November, 2018).

6.2.3 Communities that are protected by stopbanks

Communities protected by stopbanks will be particularly vulnerable to climate change as more intense rainfall occurs nationwide. This is because stopbanks have a finite design capacity (often based on a design level from decades ago), and can have a catastrophic consequence of failure (see Case Study 3). Increasing peak flows anticipated with climate change, and frequency of inundation will put further stress on the stopbanks, raising the risk of overtopping or failure (Section 4.1.4). Many areas are protected by stopbanks, including:

- Hauraki Plains (coastal and riverine stopbanks)
- Lower Waikato
- Manawatu
- Lower Hutt
- Wairarapa
- Canterbury
- Otago
- Southland
- Tasman
- West Coast
- Northland
- Whanganui
- Bay of Plenty
- Hawkes Bay
- Gisborne

Areas within New Zealand that are immediately protected from flooding by stopbanks are presented in Figure 6.3. These areas receive a direct benefit, and as such, would otherwise be subject to flooding during a relatively minor storm event.

An example of stop bank failure is in Edgecumbe (Bay of Plenty), as discussed in Case Study 3.

Figure 6.3: Extent of areas that receive a direct benefit from stopbank protection. Source: (T+T, 2018)

Case Study 3: Edgecumbe stopbank protection

On Thursday 6 April 2017, at approximately 8:30 am, flood waters associated with ex-tropical cyclone Debbie caused a breach in the Rangitāiki River stopbank at College Road, resulting in widespread flooding and damage to the Edgecumbe township. While no loss of life occurred, the disruption to the lives of many residents and the functioning of the town were of major significance. Some fifteen houses were rendered permanently uninhabitable with more than 250 requiring significant repairs (Rangitāiki River Scheme Review Panel, 2017).

Edgecumbe is located in the Rangitāiki River Basin approximately 10 km inland, in a subsiding faulting rift at the eastern end of the Taupo-Rotorua volcanic zone (Houlié & Stern, 2017). . The hydrology of the region is extensively modified using stopbanks and land drainage channels. In 1973, the proximity of College Road and existing properties to the river bank meant that a concrete 'floodwall' was constructed, rather than raising the stopbank level. The 1987 earthquake caused river bank slumping and foundation failure of the College Road floodwall, which required significant repairs, and in 1993 the floodwall was raised and upgraded. A large flood event in 1998 was the first time, following the 1993 upgrade, the water levels rose above the original river bank crest level, during which seepage (hydraulic piping) and stopbank heave were observed, requiring further repairs to the wall (Rangitāiki River Scheme Review Panel, 2017).

The level of floodwaters and the duration of the flood are of particular importance to floodwall and stopbank stability – with sustained periods of elevated flood level only occurring twice in the floodwall history prior to the 2017 failure. Ultimately this is what caused the failure in 2017, with the Rangitāiki River Scheme Review (2017) finding that the 2017 floodwall failure was a result of a build-up of pore water pressure in the ground, and that it was a progressive failure. The review panel came to the following conclusion:

"… the Panel has concluded that the historic framework which has governed the development of the Rangitāiki River Control Scheme is at or near the end of its useful life. Frameworks now being more widely adopted look towards allowing greater room for rivers to move. This change is underlined by the near-certainty that climate change is leading to more severe and more frequent extreme weather events of the sort that occurred in April this year."

Seepage immediately in front of the floodwall at 07:04 on 6 April (left). The breached College Road floodwall at 11:00 on 6 April (right). Source for both: (Rangitāiki River Scheme Review Panel, 2017).

Information for this case study referenced from (Rangitāiki River Scheme Review Panel, 2017).

6.2.4 Communities with low-lying areas prone to flooding

Communities that have low lying areas that are prone to flooding will experience increasing difficulty as the climate changes (see Case Study 4 and Case Study 5). Low-lying coastal communities will be subject to rising groundwater (often influenced by tide levels), coastal erosion, coastal flooding (storm surges+ tide+waves) all exacerbated by ongoing sea-level rise, and will also likely experience compounding surface water flooding during rainfall events or combined storm-tide and river flood levels. Stormwater infrastructure and communities exposed to fluvial or pluvial flooding will be similarly affected, particularly as most areas will experience increasing extreme rainfall intensity for any given duration, with shorter durations such as 1-hour likely to increase by 12-17% per 1°C rise in temperature (MfE, 2018b).

All major towns and cities in New Zealand are located at coastal or riverine locations, and most have low-lying areas that are already prone to flooding. Many of New Zealand's smaller towns and communities are also prone to flooding. Additionally, many of these communities are protected by stopbanks or pumped stormwater systems as described in preceding sections.

A recent study funded by Local Government New Zealand (LGNZ, 2019) has identified the regional exposure of stormwater and wastewater systems to increments of sea-level rise above mean high water springs (MHWS) (refer Figure 6.4). This work identified the length of public pipes located within each region at 0.5 m, 1.0 m, 1.5 m and 3.0 m above MHWS, based on available Council GIS pipe networks and a patchwork of regional LiDAR. This work identified that the region with the highest asset exposure to sea-level rise was the Hawke's Bay region, with over 1100 km of stormwater pipes and 5000 manholes exposed with 3.0 m SLR above the present MHWS. Other regions with significant exposure were identified to be Canterbury and Auckland, both with close to 400 km of pipes exposed (excluding Auckland Transport owned pipes in Auckland).

Results from the same study identified Christchurch as having the highest exposure of wastewater pipes, with approximately 700 km of pipes exposed with 3.0 m SLR, followed by Bay of Plenty (close to 500 km), and Wellington (approximately 400 km) - see Figure 6.4. Greater Wellington has the greatest exposure of wastewater manholes, with over 8000 manholes exposed with 3.0 m SLR (see Figure 6.5). Northland has the greatest exposure of wastewater pump stations, with over 220 pump stations exposed with 3.0 m SLR (see Figure 6.6). The Waikato Region has the greatest number of wastewater treatment plants exposed within a 3.0 m increment of SLR (see Table 6.2).

Table 6.2: Wastewater treatment plants (WWTPs) exposed at various increments of sea-level rise above Mean High Water Springs (MWHS)

	Number of WWTPs exposed at 0.5m above MHWS	Number of WWTPs exposed at 1.0m above MHWS	Number of WWTPs exposed at 1.5m above MHWS	Number of WWTPs exposed at 2.0m above MHWS
National	***11***	***21***	***30***	***67***
North Island Total	**11**	**20**	**24**	**48**
Waikato Region	5	9	12	24
Northland Region	3	4	4	8
Bay of Plenty Region	0	3	4	10
South Island Total	**0**	**1**	**6**	**19**
Canterbury Region	0	1	4	9
Otago Region	0	0	1	5

Nelson Region	0	0	1	1

Source: (LGNZ, 2019)

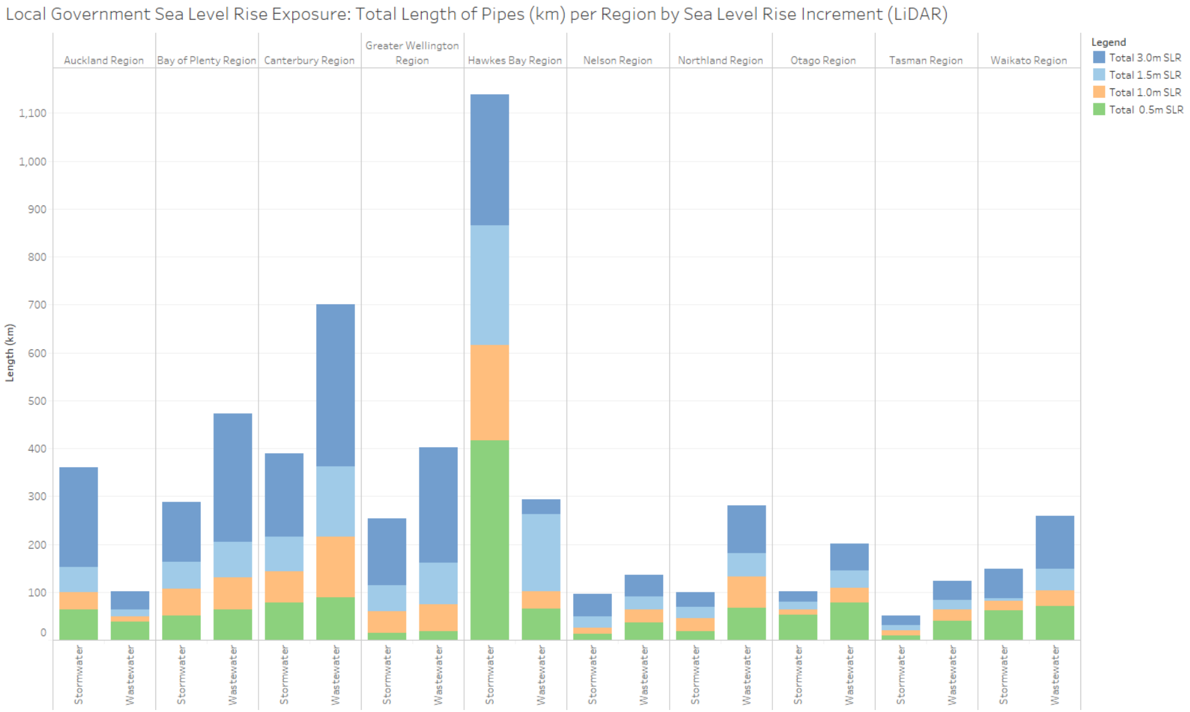


Figure 6.4: Length of exposure of stormwater and wastewater pipes to incremental sea-level rise (LGNZ, 2019)

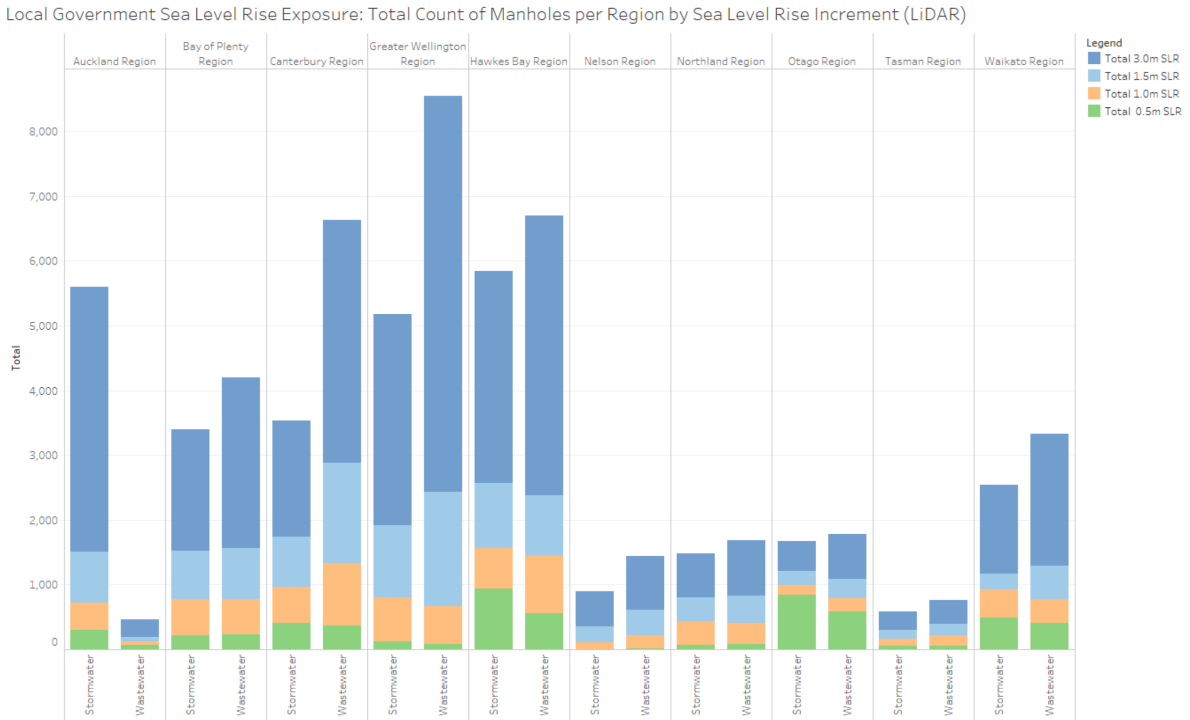


Figure 6.5: Count of exposure of stormwater and wastewater manholes to incremental sea-level rise (LGNZ, 2019)

Figure 6.6: Count of exposure of wastewater pump stations to incremental sea-level rise (LGNZ, 2019)

Case Study 4: Dunedin's rising groundwater

The suburb of South-Dunedin is a low-lying coastal plain and former marsh area with a very shallow groundwater table that exhibits a tidal signal and will therefore be affected by sea-level rise, but is not subject to direct coastal flooding. South Dunedin comprises 600 ha of predominantly residential area, most of which is less than 3 m above mean sea level (Goldsmith & Hornblow, 2016). The area was converted from marshy wetlands in the mid-1800s due to demand for flat, dry land (MfE, 2017a). The groundwater connection to the surrounding sea level makes the area vulnerable to increasingly high groundwater table (Rekker, 2012) and compound flooding risks from combinations of high groundwater and rainfall.

The community has multiple water management issues associated with the low-lying position. It relies on pump stations to move stormwater and wastewater, and experiences sea water rising up through the networks during spring tides (Goldsmith & Hornblow, 2016). Heavy rainfall events have occurred frequently over the last decade with numerous instances of localised flooding, attributed both to surface run-off and high groundwater. A major flood event occurred in 2015 (Goldsmith & Hornblow, 2016) causing widespread disruption to residents and businesses, including road closures, property damage, as well as public health risk from wastewater overflows due to the heavy rain.

The South Dunedin wastewater infrastructure is ageing and is mostly due for refurbishment before 2050 (Rekker, 2012). Aged wastewater networks are prone to leakage. An investigation prior to 2012 found pervasively cracked and frequently butt-jointed pipe lengths in the South Dunedin stormwater and wastewater networks, creating a significant potential for infiltration (Rekker, 2012). Further testing also showed extensive saline intrusion into the wastewater network at high tides (Rekker, 2012).

Relative to the land, sea level has risen about 14 cm over the last century (MfE, 2017a). As sea levels continue to rise, the stormwater and wastewater issues that are currently experienced will be worsened. Rising sea levels are expected to raise the groundwater table further (MfE, 2017a), therefore the South Dunedin sewer network maybe increasingly subjected to saline intrusion. Any saline intrusion could impact the performance of the wastewater treatment plant, as excess groundwater increases the volumes requiring treatment, and higher salinity potentially reduces the treatment plant performance. Modelling suggests that even the slightest increase in sea levels would produce groundwater ponding in parts of the South Dunedin plain (Rekker, 2012). Higher groundwater would cause damp housing conditions, waterlogged gardens and outdoor community facilities, and nuisance flooding, particularly during times of high rainfall (MfE, 2017a), all of which have community health implications.


Images showing historical natural features land reclamation from pre 1850s (left) to today (right) (source: Otago Regional Council)

Case Study 5: Ruawai / Raupo Land Drainage District - Inundation

The Raupo Land Drainage District is a low lying alluvial plain located where the Northern Wairoa River discharges approximately 700,000 tonnes of silt every year into the northern end of the Kaipara Harbour. It incorporates 8545 ha of prime rural land which produces nearly $50 million in dairy annually, as well as kumara, beef and other agricultural and horticultural products. The area is a considerable contribution to the economy of Kaipara District. The Raupo Land Drainage District lies behind 70 km of coastline stop banks, centred on the small town of Ruawai, and is overseen by a local committee in partnership with Kaipara District Council.

Under the leadership of the existing Raupo Drainage Committee and a very involved rural community, the Raupo land drainage district functions very well; they've set their own level of service for nearly 100 years and have been very active in identifying issues and allowing for maintenance and replacement of key infrastructure. There have been issues in the past with stop bank failures, flood gate failures and also heavy rain causing widespread flooding. Due to the rural nature of the land, whilst there may have been some restrictions placed on the flooded area for a few days at peak events in the past, there has not been significant wide spread damage or loss of life.

The infrastructure for the District was very well designed and well thought out in the early 1900s. It has a stepped network of canals and gates so that there is the ability to mitigate any flooding within a certain portion of the district. The majority of infrastructure is quite old; in 2017 the committee and the land drainage technician identified that the seaward facing flood gates would need to be investigated. As a result a large scale replacement programme within the drainage scheme is underway. Currently the replacements and maintenance are being fully funded by the ratepayers in the targeted rate area, with some land holders paying as much as $60,000 per annum. One large flood gate can cost upwards of $100,000 to replace.

The Raupo Land Drainage District is currently functioning very well considering the level of investment available, and the fact that there are no alternative sources of funds such as the government schemes which allowed it to be created in the first instance a century ago. As sea levels continue to rise and the climate continues to change, we are likely to see heavier periods of rain coupled with higher tides, salt water intrusion, higher Wairoa River floods and other risks associated with these changes which may have serious implications for the future of the district and its ability to continue to operate in its current form. With a cost of stop bank replacement at around $1000/m and 70 km of seaward facing stop bank, the amount of investment needed in this area to ensure its safety is well beyond the means of the local residents, the Kaipara District Council and the Regional Authority. Without the ability to fund the required protection of this area and the community living here, we will only be able to look to relocation of the residents, the losses of 8545 ha of high production land, and State Highway 12.

Images showing Ruawai Township (left) Early 1900's drainage canal and floodgate (right). Source: Matthew Smith, Kaipara District Council.

Case Study 6: Urban flooding in New Lynn

In March 2017, Auckland experienced particularly high rainfall and multiple heavy downpours to become one of the wettest March's on average across the Region (NIWA, 2017). Whangaparoa (north of Auckland) received 497% of its usual March rainfall, the second-wettest month (of any month for Whangaparoa) and Māngere recorded 315% of its usual March rainfall (the third-wettest month, of any month Māngere) (NIWA, 2017).

Throughout March, severe flooding was experienced across Auckland, including 220 properties flooded in West Auckland (NIWA, 2017). A localised downpour in New Lynn on the 12th of March saw people trapped in cars and stores, and roads closed by flood waters. A blocked culvert triggered flooding as water backed up and eventually overtopped the culvert, flowing over Great North Road. This led to extensive scour damage on the downstream side of the culvert; adjacent buildings were undercut and a large section of the road and footpath were eroded (NZ Herald, 2017).

The resulting damage ultimately led to the demolition of the business buildings adjacent to the stream, and months of repair work causing ongoing congestion in one of Auckland's busiest stretches of road. Local businesses suffered from the loss and damage to their property and stock, lost production hours while clean-up and repairs were undertaken, and loss of patronage as pedestrian access was severely limited while the repair works were completed (NZ Herald, 2017).

This event highlights how vulnerable Auckland's infrastructure can be. Despite regular maintenance from Council to clear debris, the blockage that occurred during the event was enough to cause serious damage.

Flooding and scour damage in New Lynn during March 2017. Source: NZ Herald, Jason Valentine-Burt (left), Dean Purcell (right)

6.2.5 Communities with low-lying coastal wastewater treatment plants

Communities with existing, low-lying coastal wastewater treatment plants will be significantly 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 riverine, coastal or harbour environments, and are usually located within close proximity to the coastal zone (refer Figure 6.7). Many risks associated with sea-level rise threaten to severely impact the levels of service that are provided by this infrastructure. Performance failure due to inundation or infrastructure damage have the potential to cause serious social, cultural, environmental and economic implications as discussed in Section 5.1.

Increasing uncontrolled wastewater discharges will have particularly serious water quality implications in locations where treatment plants discharge to rivers, estuaries and harbours. Communities located near to enclosed harbours or estuaries will potentially be at most risk - in relation to health and loss of amenity implications associated with wastewater discharges

Figure 6.7 illustrates volumes of treated wastewater discharged from treatment plants, and whether this it to land, freshwater, harbour or coastal receiving environments. Examples of towns and cities where discharges occur to estuaries or harbours include;

- Raglan
- Blenheim
- Invercargill
- Parts of Auckland around the Manukau Harbour.

It is noted that communities with low-energy estuarine and lagoon environments can also be adversely impacted by diffuse contamination such as that from on-site wastewater treatment devices (such as septic tanks). This is a known problem within the Piha community and is discussed within Case Study 7.

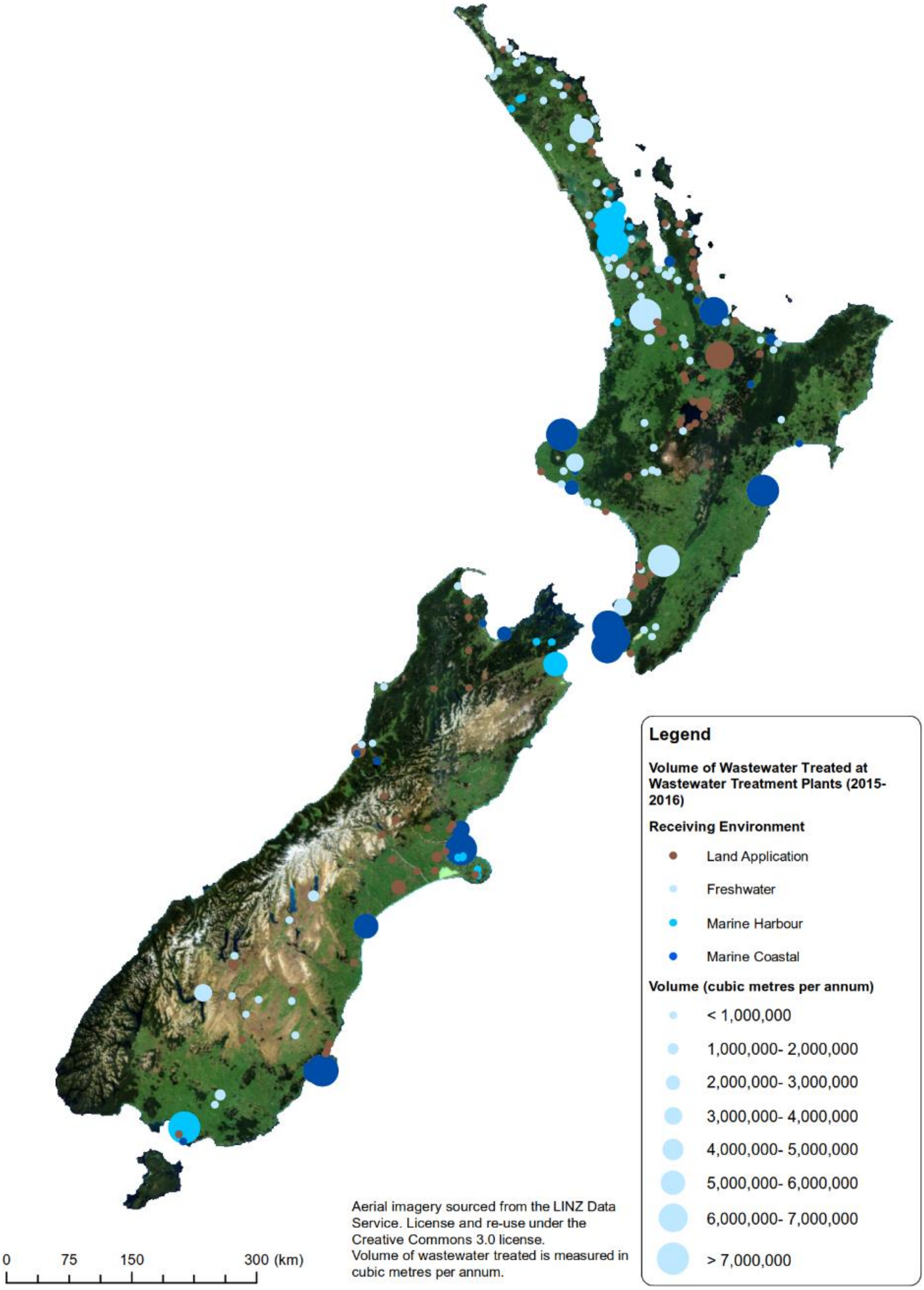


Figure 6.7: Wastewater treatment plants in New Zealand showing volume treated and receiving environment (green = freshwater, brown = land, dark blue = marine coastal, light blue = marine harbour). Source: (Water New Zealand, 2018)

Case Study 7: Piha Lagoon

Auckland's West Coast is famous for its natural features, some of the lesser known being the lagoons nearby several of the famous black sand beaches. Lagoons create a unique environment for wildlife, drain broad catchments, provide a safe place for children to swim, and were a place of ceremony (formerly for Tangata Whenua). Unfortunately, Piha lagoon consistently experiences extremely poor water quality levels, to the extent that the lagoon is unsafe for swimming for extended periods (Ducker, 2015). Concerns have been raised regarding water quality in the West Coast lagoons since the early 1980s, with the first water quality test for E.coli performed in 1985, revealing high faecal indicator bacteria concentrations (Noble & Neale, 2016). Regular testing has indicated that water quality is worse during summer months, when the beachside population is at its highest (Noble & Neale, 2016).

The reasons behind the water quality issues appear varied and complex, however regular monitoring indicates that the main source of contamination is human, due to poorly performing septic tanks (Ducker, 2015). The small seaside community on the west coast of Auckland has no public sewerage system, so private homes rely on septic tanks for wastewater treatment. Council estimates between 10% and 25% of septic tanks are not working properly (RNZ, 2017). These private systems are likely to be the main source of contamination, through leaks and infiltration to the surrounding groundwater and stormwater runoff. There are ongoing discussions between the community and council about improving the poor state of infrastructure, and a financial incentive has been established to encourage property owners to upgrade their septic systems (RNZ, 2017).

The effects of climate change will worsen the water quality issues experienced at the Piha Lagoon, unless these contamination issues can be resolved. In particular, some parts of the community have high groundwater levels, which are likely to be affected by rising sea levels. An increase in the groundwater table is likely to exacerbate existing operational issues with septic tanks, cause further damage to the tanks, increase the likelihood of groundwater contamination and reduce the efficiency of dispersal fields. The loss in lagoon water quality causes a loss of a recreational amenity, poses a public health risk, and has resulted in spiritual and cultural loss, as the lagoons were once highly regarded as taonga.

Piha lagoon water quality health warning (Source: Simon Smith, Stuff)

6.2.6 Communities with wastewater treatment plants which discharge to rivers

Communities with WWTPs which discharge to rivers will be vulnerable to climate change due to a combination of factors as discussed in previous sections. These include:

- Communities that discharge wastewater to rivers in regions predicted to experience wetter conditions will be at more risk of increased uncontrolled discharges causing negative water quality implications in rivers (as discussed in Section 5.3.1).
- Communities that discharge wastewater to rivers in regions predicted to experience hotter and drier conditions will be at more risk of higher strength wastewater, which may not be treated to a suitable level (refer Section 4.2.2.2

At the same time as the above is occurring, rivers may experience reduced / limited assimilative capacity as a result of a changing climate such as eutrophication (from increased rainfall) and more persistent low flows (refer Section 4.2.2.5).

The following major cities are examples where river or estuary discharges occur and which may experience adverse climate-related effects.

- Hamilton
- Whangarei (upper Harbour estuary)
- Palmerston North
- Queenstown and Wanaka
- Stratford
- Paraparaumu.

Case Study 8: Waikato River

The Waikato is the longest river in New Zealand, and the Māori name Waikato translates as 'flowing water.' However the water quality of the Waikato River is adversely affected by a number of environmental influences, including the eight hydro dams installed along its 125 km length (Waikato Regional Council, 2017). The River receives wastewater discharges from point sources (such as industrial discharges and wastewater treatment plants) and non-point sources (such as farm runoff and urban stormwater) (Waikato Regional Council, 2018). There are currently more than 80 point source discharges into the main stem of the Waikato River, and a further 1,600 discharges to the streams and rivers that drain into the Waikato (Waikato Regional Council, 2018).

The River has ongoing problems with a number of significant contaminants. The level of arsenic has more than doubled since the late 1950s, due to discharge from the Wairakei Geothermal Power Station to the river (Waikato Regional Council, 2018). The upper river experiences dark tea coloured staining due to discharges from the Kinleith Mill and the lower river has high bacteria levels such as E.coli, the cause of which is attributed to non-point sources such as rural runoff (Waikato Regional Council, 2017).

The ability to modify, or discharge certain contaminants to, the Waikato River is regulated within the Waikato Regional Plan. For example, regulations require that no discharge to the river can change the temperature of the water by more than 3°C, exceed 25°C, or adversely affect the passage and spawning of fish in an area defined as significant indigenous fisheries and fish habitat, without obtaining resource consent (Waikato Regional Council, 2012). This relates, for example, to the Huntly Power Station, which cannot legally operate at higher river temperatures (Dickie, B. Waikato Regional Council. Personal communication 12 September 2018). The allowable composition of discharge to the river from the Hamilton WWTP is nitrogen-limited over the summer months, when the receiving environment is warm and contains a higher nutrient rich groundwater fraction (due to upstream pastoral intensification over recent decades). Smaller treatment works are seasonally prevented from discharging to the river at all, for example, the Waihou Township, which must contain or irrigate to land over summer (Dickie, B. Waikato Regional Council. Personal communication 12 September 2018).

River sensitivity to discharges will only become more of an issue in parts of the country where climate change projections estimate longer, hotter drought periods. In the Waikato, this will be further exacerbated by the upstream land use that has resulted in elevated concentrations of diffusely sourced nutrients, and where population growth is anticipated (Dickie, B. Waikato Regional Council. Personal communication 12 September 2018).

Huntly power station on the bank of the Waikato River (left) and dairy runoff (right) Source for both: (RNZ, 2016)

6.2.7 Other factors leading to specific vulnerabilities: low socio-economic status

There will be other non-physical factors that may result in a region having specific vulnerabilities to climate change. These relate mainly to factors which may reduce coping (adaptive) capacity within communities. These could include income level, education level or health problems. The primary factor identified was socio-economic status, as discussed below.

Communities with a low socio-economic status will be more vulnerable to stress from climate change, as discussed in Section 5.1. The effects of climate change may worsen existing vulnerabilities. People with a low socio-economic status generally have less capacity to act to reduce their exposure to hazards, and less ability to repair their lives after damage has occurred (Stephenson, 2018).

Beyond the direct risk from extreme events, New Zealand's infrastructure and associated communities are likely to face incremental impact over time. For example, increasingly high water tables or gradual erosion will deteriorate the condition of infrastructure. This will lead to financial implications for house and business owners as the value of assets decline while the assets themselves require increasing amount of repairs. This is expected to result in a desire for communities and business owners to move away from exposed areas, leaving families and individuals 'stranded' when property values have decreased (Stephenson, 2018). These property owners may be unable to afford the repairs and end up living in substandard housing. Tenants may face similar problems when landlords see little value in repairing damage to assets with declining value (Barnett, 2015). Councils too, with small rating bases, will also be constrained in their adaptive capacity to cope with pressures on infrastructure from climate-change impacts and their community expectations

Many former refugees have the additional difficulty of language and, socio-economic barriers, as they are in the process of integrating into New Zealand's formal and informal institutional and social structures (Stephenson, 2018).

The socio-economic status of a community can be partly assessed using the Social Deprivation Index, which combines nine dimensions of census data (availability of communications, income, benefit support, employment, qualifications, home ownership, family support, living space and transport) (Atkinson, et al., 2014).

Areas with the highest Social Deprivation Indices are shown in Figure 6.8. This map indicates that significant parts of Northland, Gisborne and Bay of Plenty have the highest social deprivation, followed by large parts of Hawkes Bay, Manawatu-Whanganui, and West Coast. It is these areas that may experience more forcefully the impacts and implications of climate change in general, and as a result of damage to stormwater and wastewater systems.

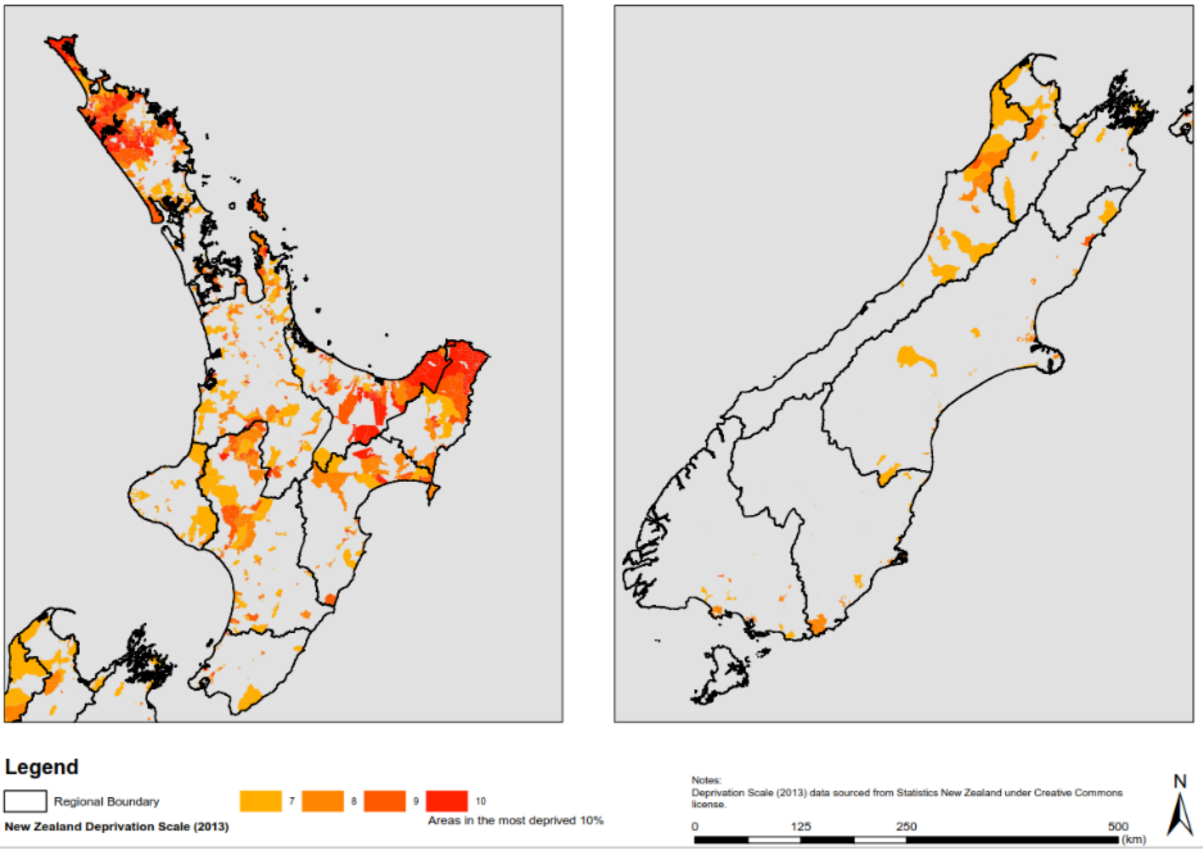


Figure 6.8: New Zealand deprivation scale (NZDep2013), showing areas with the highest (most deprived) deprivation index. Source: (Atkinson, et al., 2014)

7 Guiding principles for local government decision-makers

This Deep South Challenge funded project presents the findings from research focused on the following question:

What are the potential direct and indirect social, cultural, economic and environmental impacts of climate change on storm-water and wastewater systems?

These direct and indirect impacts have been framed in this report as *impacts* and *implications* of climate change on the abovementioned systems. This section discusses broader national and sectoral issues within New Zealand, as relates to these impacts/implications, and suggests a range of guiding principles for local government decision-makers.

7.1 National and sectoral context

This research has identified a wide range of possible or potential impacts and implications from climate change on stormwater and wastewater systems - which will require deliberate and planned management responses, in tandem with monitoring the changing performance, in order to adapt.

When considering approaches and principles for adaptive management it is important to recognise the range of interrelated issues and initiatives within a national and sectoral context – some of which may present additional risk, while others may provide opportunities for co-beneficial outcomes if considered collectively. These include:

- The Draft National Policy Statement for Freshwater Management - NPSFM (MfE, 2019a) which prioritises the health and wellbeing of waterbodies and freshwater ecosystems. This proposal also aims to strengthen Te Mana o Te Wai as the framework for freshwater management, better provide for ecosystem health (water, fish and plant life), better protect wetlands and estuaries and has a strong focus on improved management of stormwater and wastewater.
- New Zealand's aging stormwater and wastewater infrastructure is recognised as a significant issue for nearly all New Zealand communities (New Zealand Government, 2015). This, combined with the challenges councils face with respect to funding (especially those with a small rating base) and growth, or in some cases, declining populations (Controller and Auditor General , 2019) means the impacts of climate change will likely be more severely felt.
- As discussed in previous sections, residents and homeowners living on the coast, or within flood-prone areas or where groundwater exhibits a tidal signal, are likely to become increasingly disrupted or impacted as climate changes. This has implications for insurability of both private and public property and infrastructure. Some insurers in New Zealand appear to have begun adjusting their products and pricing to reflect emerging climate risks, and some existing properties could ultimately become uninsurable for climate or weather-related risks (Reserve Bank of New Zealand, 2018).
- The New Zealand Government's *Living Standards Framework* (New Zealand Treasury, 2018) establishes uses the four capitals of social, human, natural and financial to measure intergenerational wellbeing. This aligns also with the Wellbeing Budget which aims to 'meaningfully address complex problems like child poverty, inequality and climate change', through consideration of social, environmental and economic implications together (New Zealand Treasury, 2019).
- The Climate Change Response (Zero Carbon) Amendment Act 2019 provides a framework by which New Zealand can develop and implement climate change policies that contribute to the global effort to reduce greenhouse gas emissions, as well as requiring New Zealand to prepare for, and adapt to, the effects of climate change. This includes preparing a National Climate Change Risk Assessment (NCCRA), and National Adaptation Plan (NAP), and reporting on the implementation of the NAP.

Notably, and in relation to the above points, LGNZ (2019) found that "the long-term decisions that councils face require an understanding of future climate risks, and that these need to be considered along with other current and future pressures relating to land use, growth and renewals, as well as the real possibility of insurance retreat over the medium to longer term".

With the above related initiatives and issues in mind, below we discuss and propose a range of guiding principles for local government – when managing the impacts of climate change on their stormwater and wastewater systems.

7.2 Guiding principles

Local government is charged with meeting the current and future needs of communities for infrastructure, local public services, and regulatory functions (Local Government Act, section 10b). In carrying out it's many planning and regulatory decision-making functions under the Resource Management Act, local government must also have regard to the Act's sustainable management[16] purpose and matters of importance. Sustainable management includes concepts of enabling communities to provide for their wellbeing and heath & safety, considering the needs of future generations and safeguarding the life supporting capacity of air, water, soil and ecosystems. Matters of importance include: managing significant risks of natural hazards (Section 6 (h)), kaitiakitanga and the effects of climate change (Section 7 (a) and (i).

The focus of regional (and unitary) councils and district or city councils can differ however. Regional councils focus on decisions that relate to resource use and hazard management (including stopbanks), while city and district councils provide core services that can impact on resources including land, water and coastal areas. All levels of local government have a part to play, therefore, in managing and responding to the impacts of climate change – including those which impact on stormwater (including flood control) and wastewater systems.

In 2017, LGNZ produced two key documents. The first was a position statement (LGNZ, 2017a) which highlighted the need for *collaboration within and across the sector*, the need to *incorporate climate change impacts/implications into decision-making* for land-use and urban development, and the need to *consider the effects of climate change as part of an all-hazards approach to managing risk*.

The second was a *Climate Change Declaration* (LGNZ, 2017b) signed by a large number of mayors, which proposed a series of broad guiding principles for decision-making on climate change. These were based on established legal[17] and moral obligations placed on Government when considering the current and future social, economic and environmental well-being of the communities they represent, and are as follows:

- *Precaution*: There is clear and compelling evidence for the need to act now on climate change and to adopt a precautionary approach because of the irreversible nature and scale of risks involved.

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16 Resource Management Act Section 5(2): "In this Act, sustainable management means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and (b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment."

17 These Guiding Principles are established within the: Treaty of Waitangi, Resource Management Act 1991, Local Government Act 2002, Civil Defence and Emergency Management Act 2002, Oslo Principles 2014, Principles of Fundamental Justice and Human Rights.

- *Stewardship / kaitiakitanga*: Each person and organisation has a duty of care to safeguard the life-supporting capacity of our environment on which we all depend and to care for each other.
- *Equity / justice*: It is a fundamental human right to inherit a habitable planet and live in a just society. The most vulnerable in our community are often disproportionately affected by change and natural hazards.
- *Anticipation*: Long-term thinking, policies and actions are needed to ensure the reasonably foreseeable needs of current and future generations are met.
- *Understanding*: Sound knowledge is the basis of informed decision making and participatory democracy. Using the best available information in education, community consultation, planning and decision making is vital.
- *Cooperation*: The nature and scale of climate change requires a global response and human solidarity. We have a shared responsibility and can not effectively respond alone. Building strong relationships between countries and across communities, organisations and scientific disciplines will be key.
- *Resilience*: Some of the impacts of climate change are now unavoidable. Enhancing the resilience and readiness of communities and businesses is needed so they can thrive in the face of changes

In 2019, LGNZ produced a document 'Exposed: Climate Change and Infrastructure' (LGNZ, 2019) which provided councils with guidance to better understand and manage climate risk to infrastructure (including data requirements and assessment methods), as well as providing a series of questions that elected members could ask of staff in order to ensure they remain well informed and to ensure effective long-term planning for infrastructure. These questions were framed within four areas of focus:

- Understanding local government's role in managing climate change impacts.
- Community engagement.
- Data collection and reporting processes.
- Planning, capacity and decision-making.

There is commonality around the language and focus of these LGNZ publications, particularly in relation to collaborative approaches, data and information management and approaches to planning and decision-making. It is noted that this also aligns well with the *characteristics for effective adaptation* developed by the Climate Change Adaptation Technical Working Group (CCATWG, 2017) – and which include the need to be: a) **informed** on how the climate is changing and what impacts are likely, b) **organised** with a common goal, a planned approach, appropriate tools, and clear roles and responsibilities, and c) to take **dynamic action** to proactively reduce exposure and vulnerability to climate change.

Other jurisdictions have also developed principles for responding to climate impacts. For example, the *Australian National Climate Resilience and Adaptation Strategy* (Australian Government, 2015) developed a series of guiding principles as follows:

- *Shared responsibility:* Governments at all levels, businesses, communities and individuals all have important roles to play.
- *Factor climate risk into decisions*: Consider the current climate and future change in all our decisions.
- *Assist the vulnerable*: Support those who are vulnerable to disaster risk and climate change.
- *Evidence-based, risk management approach*: Apply the best available science.

- *Collaborative, values-based choices:* Respect the knowledge and experience of those affected, and involve them in decision-making.
- *Revisit decisions and outcomes over time:* Review actions regularly, look for flexible choices and opportunities.

Researchers at the University of Sydney undertook a review of leading practice in planning for climate change (Gurran, et al., 2008) and summarised the following as common principles within leading practice on climate adaptation:

- Uphold the principles of ecologically sustainable development in designing adaptation and mitigation approaches, including environmental integrity, social equity and participation, economic viability and the precautionary principle. This is critical for communities whose populations include higher proportions of lower income and socially disadvantaged groups.
- Prioritise actions worth doing anyway, which for coastal communities mean actions that have multiple benefits for the environment, for managing coastal processes, for the affordable and efficient provision of infrastructure, for nature based amenity and tourism and for more socially cohesive settlements.
- Use a sound evidence base, for identifying and justifying planning responses to climate change. Many councils with a smaller rating base will need assistance in accessing, interpreting, and applying consistent and reliable sources of scientific information about climate change scenarios.
- Plan now, to prevent further risks associated with climate change. Coastal communities experiencing rapid population growth will experience pressure for rapid development approval, before climate change considerations have been factored into planning and assessment frameworks.

Based on the above review and discussion, it can be seen there are a number of common themes which appear. The following series of guiding principles are therefore proposed - which we believe will best enable local government to manage the impacts of climate change both broadly and also specifically for wastewater and stormwater systems:

Guiding principles for local government decision-makers – for managing impacts of climate change on wastewater and stormwater systems.

1 *Factor climate risk into decisions*: Consider the current and future climate in all decisions for infrastructure – including asset management, renewals, planning etc.

For stormwater and wastewater systems, this could mean:

- Understanding and monitoring climate change risk and performance for stormwater and wastewater assets, along with monitoring changes in community, iwi/hapū and stakeholder perceptions of the levels of service (they may cope with more to remain in place – or cope with less, if flooding or wastewater performance becomes untenable).
- Reviewing and updating design standards to incorporate latest knowledge on the impacts of climate change and eventually moving to adaptive design standards (e.g. (Ayyub, 2018) Ayyub et al., 2018).
- Incorporating climate risk and funding models into the 30-year asset management plans and infrastructure strategies, and ensure resilience / adaptation measures are identified.
- Councils and central government agencies working together, within and across the sector, to understand and agree on best practice and develop a plan to improve maturity of practice from 'awareness' to 'advanced performance'[18] in risk and resilience planning and

[18] Refer to International Infrastructure Management Manual (2015) for further information on a basic maturity index framework.

decision-making. This would shift asset management focus from response-based action to anticipatory action that reduces risks ahead of reaching adaptation thresholds (as per MfE (2018a; 2017d).

- Developing and regularly updating climate change adaptation plans for infrastructure and communities.
- Identifying key critical assets (such as low-lying WWTPs) that will require adaptive measures for continued performance, with agreed adaptive management plans and timeframes.

2 *Base decisions on evidence and current national guidance, supported by sound data and local knowledge:* This is the basis of informed decision making and participatory democracy, and is mandated for coastal development in the NZCPS (e.g. the end of Policy 24). Using the best available information in education, community consultation, planning and decision making is vital. It is noted that many smaller councils will need assistance in accessing, interpreting, and applying consistent and reliable sources of scientific information about climate change scenarios and impacts/implications. Local knowledge is also vital, and should include matauranga Māori understanding.

For stormwater and wastewater systems, this could mean:

- Ensuring a robust environmental / natural hazard monitoring plan that captures relevant data on an ongoing basis, at an appropriate frequency and granularity - in order to enable planning for both gradual and event based climate hazards. For example, monitoring water quality, rainfall, runoff and groundwater levels and the magnitude and frequency of various levels of events consistently and in an ongoing manner to quantify changes driven by climate change.
- Monitoring of environmental changes and use of matauranga Māori knowledge to inform an understanding of changes, and to inform decision-making, and solutions.
- Ongoing monitoring of stormwater and wastewater network and asset performance, including outages and sewer overflows.
- Proactively developing an understanding of stormwater network performance under existing and future scenarios to provide a more complete understanding of flood hazard risk to the community (so that appropriate investment decisions can be made) – as per recommendations within OAG (2018). For stormwater systems, this should include an understanding of the increasingly important role of secondary flowpaths or for flood schemes, the implications of residual risk.
- Ensuring that asset information is up to date and available, and exposure of assets to climate hazards/stressors is monitored.
- Communicating risk to communities in a transparent and ongoing manner.

3 *Cooperation and collaboration:* Councils, government, business, communities, lifeline services, Māori, researchers and other experts all have a role to play and opportunities for collaboration should be identified and advanced[19]. In particular, the knowledge and experience of those affected should be respected and they should be involved in decision-making. Additionally, councils should look to address internal structural and policy barriers/misalignments to enable good decision-making.

For stormwater and wastewater systems, this could mean:

- Better co-ordination and integration of effort within and across councils to create efficiencies in data collection and analysis, and to share practice and resources. This was highlighted by LGNZ (2019) with specific mention of: variation across councils in terms of

[19] This principle aligns with the fifth recommendation from the Office of the Auditor General's Review of Managing Stormwater systems to reduce the risk of flooding (OAG, 2018).

asset and financial data availability, as well as systems and formats in which the data is held; and lack of integration between spatial infrastructure data and financial information.

- Sharing of best practice in climate risk assessments, adaptation planning, stormwater and wastewater management and design (e.g. water sensitive urban design, flood management etc).
- Looking for opportunities for regional / national funding for projects that have benefits across multiple councils. For example, common design guidelines, data gathering to benefit multiple councils, common systems and adaptation approaches etc.
- Engaging with stakeholders according to best practice (such as that developed by the International Association for Public Participation – IAP2) and endeavouring to meaningfully collaborate with stakeholders.
- Identify and address structural and policy misalignments with councils with respect to management of stormwater and wastewater systems.

4 *Stewardship / kaitiakitanga and precaution:* Each person and organisation has a duty of care to safeguard the life-supporting capacity of our environment on which we all depend and to care for each other. This must include upholding a) the principles of the Treaty of Waitangi, b) intergenerational sustainability, and c) the principles of ecologically sustainable development in designing adaptation and mitigation approaches, including environmental integrity, social/cultural equity and participation, economic viability and the precautionary principle. On this last point, there is clear and compelling evidence for the need to act now on climate change and to adopt a precautionary approach because of the irreversible nature and scale of most of the risks involved.

For stormwater and wastewater systems, this could mean:

- Shifting planning and asset management focus from response-based action to anticipatory planning and action where possible to avoid reaching adaptation thresholds where impacts become untolerable.
- Embedding *water sensitive urban design* approaches within council standards and developing upskilling and education initiatives around this – incorporating matauranga Māori principles.
- Ensuring that the management of stormwater and wastewater is considered within broader land use, ecological, social and cultural constraints.

5 *Prioritise the most vulnerable:* The most vulnerable in our community are often disproportionately affected by change and natural hazards. Adaptation responses must support those who are most vulnerable to climate change impacts.

For stormwater and wastewater systems, this could mean:

- Identifying vulnerable communities and working with them to understand climate hazards that may affect them, and developing response and adaptation strategies that are acceptable, effective and recognise the unique social/cultural/economic circumstances of each community.

6 *Long term, adaptive thinking:* We require long-term thinking, policies and actions to ensure the reasonably foreseeable needs of current and future generations are met. We also need adaptive pathways, with a mix of short-term actions and long-term options, which are adaptable and flexible to allow for uncertainty (especially so in relation to ongoing sea-level rise) - and we must review actions regularly, in the light of targeted monitoring, to avoid maladaptation or decisions which may 'lock-in' vulnerability of assets or communities for a long time ((MfE, 2017d)). Fast-tracking of adaptation may be desirable if a wrong decision

today will make us more vulnerable in the future and if those effects are costly to reverse (MfE, 2019).

For stormwater and wastewater systems, this could mean:

- Careful development of adaptation options and plans which consider the range of possible future scenarios, including unintended consequences, maladaptation, lock-in etc.
- Consideration of a range of 'typologies' of adaptation options, from hard physical defences, to flexible/modular solutions, to emergency response / early warning systems – as well as appropriate pathways/signals/triggers for each agreed option (as per MfE Coastal Guidance – (MfE, 2017d)).
- Consideration and awareness of broader implications of insurance and un-insurability due to climate change[20]. Councils, asset owners and communities must be aware of their insurability and liability, with mechanisms in place to manage the changing risks. More generally, lenders, property owners and developers should evaluate property security in a way which places less reliance on backward looking valuation models and considers long-term changes in risks arising from climate change[21].
- Securing funding sources to ensure the risks of climate change are well understood, and that investment can be made to maintain an acceptable level of service.

7 *Prioritise actions with multiple benefits or which have 'low-regrets':* Prioritise actions worth doing anyway, which may have multiple benefits for the environment, for managing coastal processes, for the affordable and efficient provision of infrastructure, for nature based amenity and for more socially cohesive settlements.

For stormwater and wastewater systems, this could mean:

- Identifying actions which meet other national / sectoral challenges such as freshwater quality, aging infrastructure, biodiversity or GHG reduction.
- Considering nature-based systems based on water sensitive urban design principles.
- Adopting 'flexible' working methods to take advantage of opportunistic projects which may arise unexpectedly and which offer co-benefits, as well as financial savings.

7.3 Closing comments

Much of New Zealand's stormwater and wastewater infrastructure is vulnerable to the rising risks associated with a changing climate, including sea-level rise or increasing extremes of temperature, rainfall and/or drought. The nature of existing stormwater and wastewater systems, often designed on past climate and sea level ciriteria, mean that they will be significantly impacted in a wide variety of ways including the increasing occurrence of compounding hazards.

The findings in this paper provide an evidence base to understand not only the *impacts* but the consequential *implications* across the economic, environmental, cultural and social domains.

Many of these impacts are already emerging and action will be required now, in order to mitigate worsening impacts. Councils therefore need to be aware of climate risks in order to make important long-term decisions relating to their infrastructure. These decisions need to be considered along

[20] Research is currently ongoing in this areas, such as the work done by Storey et.al., (2018).
[21] As recommended in the Reserve Bank of New Zealand November 2018 Financial Stability report (RBNZ, 2018)

with other current and future pressures relating to land use, growth and renewals, as well as the real possibility of insurance retreat over the medium to longer term.

In addition to presenting impacts and implications for wastewater and stormwater systems, and indicating where these may manifest around New Zealand, a range of guiding principles have been proposed for Councils. The authors hope that this research can better inform councils and asset owners/managers of climate risks to their stormwater and wastewater systems, as well as assisting them with adaptation decision-making - for what is undoubtedly an uncertain climate future.

8 Applicability

This report has been prepared for the exclusive use of our client Deep South National Science Challenge, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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