CLIMATE CHANGE & STORMWATER AND WASTEWATER SYSTEMS

Motu Note #28

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SUMMARY HAIKU

Coastal drains and pipes
combined with climatic change,
need thought and action.

ABSTRACT

We know climate change is happening and we know stormwater and wastewater systems are vulnerable. What we don't know is how these impacts will unfold over varying places and times. This discussion paper provides an overview of our current knowledge, and outlines priority research areas to help adapt our stormwater and wastewater systems for a changing climate. The paper draws on a range of expert input, including academia and Crown Research Institutes, the public and private sectors, and specifically water service providers and consultants. Research priorities are: to understand direct and indirect impacts, to identify adaptation opportunities within redevelopment and retrofit, to explore solutions to reduce dependence on legacy delivery mechanisms, and to identify potential improvements in stormwater risk management.

1. INTRODUCTION

Climate change is increasingly creating severe risks for New Zealand's coastal water infrastructure. The Intergovernmental Panel on Climate Change identified key climate risks to New Zealand being continuing sea level rise and the increased frequency and intensity of flood damage on our low-lying and coastal infrastructure (IPCC, 2014). Extreme rainfall events are expected to become more frequent and more severe. Even modest sea level rise will increase the reach of storm surges and king tides and the extent of rising groundwater. Much of New Zealand's population is located at the coast or in floodplains and so directly exposed to these climate change hazards. For Māori, the indigenous people of Aotearoa New Zealand, the relationship of people to water is deeply connected with identity and well-being. Harmonious interaction with water systems is crucial to these cultural values. Yet, our urban centres rely on systems which were not designed with climate change in mind. These are likely to experience increased failures and decreases in levels of service over the coming decades.

In this discussion paper we focus only on wastewater and stormwater systems connected to reticulated networks. The supply of potable water is out of scope for this paper.

Stormwater and wastewater systems are particularly vulnerable to climate change as the discharge points of these systems are often at the lowest elevation of populated areas. Even small changes in rainfall extremes, including intensity and duration, can overwhelm the design capacity of these systems. In low-lying areas where groundwater is linked to the sea, sea level rise will affect the performance of stormwater systems and wastewater systems where infiltration occurs. Droughts will also affect the performance and maintenance of wastewater systems. Increased urbanization associated with new greenfield housing, and densification in existing areas will also challenge existing design parameters. Furthermore, some of the stormwater and wastewater systems most exposed to climate change hazards are aging. Funding any replacement is already challenging in some areas, where there are declining rate bases due to population shifts towards urban centres, combined with caps on local government lending. However, as systems are replaced there is an opportunity to redesign for resilience.

Successfully adaptating stormwater and wastewater systems to climate change presents challenges to decision-making practices, which have to operate under multiple types of uncertainties, with complex interactions and dependencies. For example, there is uncertainty regarding the scale and location of climate hazards; when the increased frequency of these hazards will become apparent; the degree of exposure and vulnerability caused by economic growth and demographic changes; and potentially cascading effects between interdependent areas and sectors. The purpose of this document is to identify the gaps in current knowledge most salient to New Zealand decision makers.

Earlier this year, the Deep South National Science Challenge held a dialogue with practitioners and researchers from eighteen New Zealand organizations involved in long-term decision making on stormwater and wastewater systems. See Appendix 1 for a list of dialogue participants.

We introduce climate change in section 2, and stormwater and wastewater infrastructure in section 3. In section 4 we detail the likely risks from climate change. Potential adaptations are explored in section 5, and in section 6 we identify issues within the engagement and decision making space. Section 7 summarizes the high priority research questions identified by practitioners and researchers who participated in the Deep South National Science Challenge dialogue.

2. CLIMATE CHANGE IN AOTEAROA NEW ZEALAND

Since the Swedish scientist Svante Arrhenius first published on "The Greenhouse Effect" in 1896, the scientific community has been strengthening the science surrounding climate change (Weart, 2008). Warming of the climate system is now unequivocal (Pachauri et al., 2014). Extreme weather events have changed as a result; there has been a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy rainfall events (Pachauri et al., 2014). Coastal sea levels have risen by up to 22cm over the last century, consistent with global trends (MfE, 2017), and are almost certain to rise at a faster rate in future (Royal Society of New Zealand, 2016). More frequent and intense rainfall events are very likely on a global scale (Pachauri et al., 2014; Stocker et al., 2013).

Aotearoa New Zealand will be physically affected by climate changes. Projected changes in rainfall due to climate changes will vary seasonally and regionally. These changes will also vary year to year and from decade to decade due to interactions with existing natural processes such as El Niño. These changes will affect stormwater and wastewater systems most notably with regard to rainfall intensity, drought severity, and coastal inundation. For example, it is very likely that there will be an increase in rainfall for the west of both the North and South Islands for winter and spring, while it gets drier in the east and north (Ministry for the Environment, 2016). In summer, it is likely that the east of both islands will be wetter, while the west and central North Island is drier. As a consequence, flood hazards in Aotearoa New Zealand are very likely to become more intense and frequent (Pachauri et al., 2014). We also have the seventh largest coastline in the world (Goff et al., 2003) and sea level rise is counted as one of the country's top three climate change hazards (Reisinger et al., 2014).

Much of our country's population and infrastructure is exposed to these climate hazards. Our largest cities and many of our towns are located in floodplains or on the coast. Approximately 6.6% of our total population and NZ $52 billion worth of our built assets are located within a particularly exposed [1] area (Bell et al., 2015; Bell et al. 2016). Dunedin is highly exposed to climate change hazards. Christchurch has the most extensive land area exposure to this elevation, though Auckland, Waikato, Bay of Plenty, Hawke's Bay, and Wellington also all have significant exposure (Bell et al., 2015). The coastal and riverine locations of most discharge points mean that sea level rise and increases in extreme rainfall under climate change are likely to present significant challenges to stormwater and wastewater systems.

Aging assets built prior to official guidance on climate change, and decades of constrained local and central government funding of reinvestment in those assets, means that exposed stormwater and wastewater systems are vulnerable to climate change hazards. Significantly, this change is happening to an environment that is already rapidly altering due to population growth, housing supply and urbanization, all of which will increase demands on the current system capacity and operation in a dynamic manner (Boston & Lawrence, 2017). As this is an environment with funding challenges, this adaptation will be difficult. However, renewal is needed in any case, which provides an opportunity for redesign.

1. The 0-3m ground elevation zone relative to mean high water spring.

3. STORMWATER & WASTEWATER SYSTEMS

The term "three waters" (or "urban water" in some discussions) refers to drinking or potable water, wastewater and stormwater. The provision of these systems, and the services delivered by them, are a core requirement for territorial authorities under the Local Government Act 2002. In general, network infrastructure and treatment plants are only established for urban towns and cities, although there are some community-based schemes. Rural dwellers are typically self-sufficient. The scale of the sector is significant: recent reports estimate that stormwater infrastructure has a replacement value of around $8.6 billion (Castalia, 2014) whereas the wastewater network has the highest replacement value of the three waters at $15.8 billion (LGNZ, 2015). Aotearoa New Zealand's stormwater and wastewater assets include 24,000 kilometres of public wastewater network with more than 3,000 treatment plants, and over 17,000 kilometres of stormwater network. These assets have long lifetimes, and the timeframes involved in replacing/maintaining/upgrading are also extensive.

3.1 Stormwater

Stormwater systems are designed and constructed to take account of topography, climate, regulatory context, and intensity of development. They therefore vary widely across Aotearoa New Zealand (SPM Consultants Ltd, 2009). Primary stormwater networks are typically designed to drain run-off arising from frequent, low intensity rainfall events – often defined as 10% Annual Exceedance Probability (AEP) events (i.e. a 1 in 10 year event) – utilizing the natural fall of a catchment and gravity systems to minimize frequent nuisance flooding. Primary stormwater networks are comprised of underground pipes and tunnels.

Knowing that heavy, intense rainfall events will not be catered for by the primary network, prudent planning in Aotearoa New Zealand has been based on the provision of overland flow paths (the secondary network), which will cater for larger events. Roads are often used – keeping the excess water off private property where possible. These overland flow paths are designed to minimise the impact of urban flooding by providing space for the flood water away from buildings and infrastructure. However, there are some low lying sites where water cannot drain away because there is no natural fall and where pumps are routinely used. Napier City is an example, where three-quarters of the city is reliant on pumped stormwater systems due to the low lying terrain.

These networks typically discharge into waterways. Water quality is affected by our choice to discharge into waterways, as visible and dissolved pollutants are flushed from land surfaces (Charters et al., 2016; Fraga et al., 2016). In recent years treatment of stormwater related contaminants has seen the construction of treatment devices, which are now an accepted part of some stormwater networks in Aotearoa New Zealand. Many of these devices use natural systems, although they are designed as engineering components, and can include wetlands, raingardens or swales (these can be considered part of our green infrastructure). Underground, 'grey infrastructure' treatment devices are also used.

The historical view of stormwater as a nuisance to be avoided rather than a resource to be maintained, has lead to a focus on the rapid and efficient draining of urban areas. As extreme events increase and urbanization progresses, this approach is leading to an increase in the possibility of flooding (White, 2010). Internationally, the engineering and planning communities have tried to address these related impacts by changing water networks within "water sensitive cities". Many factors inhibit transitions of this nature such as the structures and norms of decision-making, or the difficulty in adopting a long term catchment perspective (White, 2017).

3.2 Wastewater

Wastewater systems consist of mainly reticulated schemes collecting wastewater from residential or commercial properties and transporting it to treatment facilities.[2] The wastewater is treated, and then discharged either at the coast, to waterways, or to land treatments, generally in pine forests. Aotearoa New Zealand's use of land treatment for wastewater is relatively unusual. In larger cities, networks were designed to maximise the use of gravity, creating a network which flowed downhill towards the coast. Pumping stations were then installed, providing the ability to pump sewage through a "rising main" to take the wastewater uphill to the treatment plant - often via several more pumping stations along the way. These pumping stations form a considerable proportion of the capital value associated with wastewater systems. One example of the treatment process involves Christchurch's wastewater treatment plant. Here wastewater is split into different treatment and discharge paths. Bio wastes are taken to digesters after which the bio solids are dried and returned to the land surface. Bio gases are recycled in power generation plants. Liquids flow through filters, clarifiers, aeration tanks, and oxidation ponds before finally being discharged coastally or through riverine outfall.

2. Though this practice of transferring faecal matter through water is common, it is also abhorrent to Māori for cultural reasons.

Where reticulated schemes are not available, decentralized[3] systems such as septic tanks are managed on private property. Aotearoa New Zealand has a high proportion of households with decentralized systems – around 270,000 domestic on-site systems (including around 60,000 used for holiday homes) of varying performance (MfE, 2008b). We focus on reticulated systems in this discussion paper.

3.3 Interactions between stormwater and wastewater

In general, stormwater and wastewater networks in Aotearoa New Zealand are separate systems. However, stormwater “inflow and infiltration” into the wastewater network is a significant problem. Inflow is used to describe direct flows of stormwater into the wastewater network – and can arise from issues such as illegal connections of stormwater into the wastewater network or from surface water flowing into gulley traps in residential properties. Infiltration refers to stormwater or groundwater flowing into the pipes or manholes where they have cracked – which happens due to ground movement. This means that during rainfall, the wastewater network can be prone to overflowing. Generally, the wastewater network has been designed so that, in the event of an overflow from the wastewater network, it is able to discharge into the stormwater network or the nearest stream or estuary.

In a small number of locations, stormwater and wastewater networks are combined. These combined networks are subject to increases in stormwater inflows as urbanisation increases, as well as increases in the wastewater inflows. These systems typically overflow frequently. Wastewater system overflows are a significant public health concern both in Aotearoa New Zealand and abroad due to the discharge of untreated sewage into watercourses. Systems that discharge wastewater to water bodies or via stormwater are particularly concerning for Māori (Morgan, 2006; Voyde & Morgan, 2012). The Environment Act and Resource Management Act attempted to recognize these concerns first raised in early claims to the Waitangi Tribunal (Morgan, 2008).

4. RISK UNDER CLIMATE CHANGE

We now detail our knowledge of climate change risks in the stormwater and wastewater sectors. It is clear that stormwater and wastewater systems are vulnerable to sea level rise, coastal storms, and heavy rainfall. Wastewater systems are also vulnerable to drought. During the dialogue process, participants confirmed that in Aotearoa New Zealand we have limited understanding of the range and extent of the social, cultural, economic, and environmental impacts; and what risks these pose and how they may interact over sectors, scales, and timeframes.

4.1 Understanding the risk from climate change

Recognizing that hazards, exposure and vulnerability determine the actual risk from climate change allows more effective ways of managing those risks, rather than focusing primarily on changes in the physical climate (Royal Society of New Zealand, 2016).

Hazards, exposure and vulnerability are complex, interdependent variables. Hazard is the potential occurrence of adverse climate events that could cause loss and damages. Exposure relates to the presence of people, livelihoods, and ecosystems in places that could be affected adversely by those hazards. For example, in an urban, densely populated environment more people and assets are exposed to a given hazard than in a sparsely populated rural environment. Vulnerability refers to the propensity of people and assets to be adversely affected by exposure to a hazard. Adverse effects can be physical and non-physical, including social and cultural effects.

3. Distributed or onsite

Case Study: South Dunedin

In South Dunedin even very modest levels of sea level rise will place pressure on the area's stormwater and wastewater systems (Fitzharris, 2010). Approximately 10,000 residents live within South Dunedin and approximately 4,000 school students are educated in South Dunedin, many of whom travel into the area for their education. The ground water in South Dunedin rises and falls with each tide. The stormwater system there is designed for a one in two year event, which will be reduced as the climate changes. The area is also highly exposed to terrestrial flooding as the runoff from the surrounding hills funnels into South Dunedin. In July 2017, heavy rain infiltrated the wastewater system and contaminated water overflowed onto urban roads (Otago Regional Council, 2017).

Recent flooding events have raised questions concerning the community's tolerance for an ever wetter environment and the level of health and safety the community aspires to maintain. Collaboration across various local agencies has highlighted the importance of a more integrated management of the water cycle with up to eight "waters" being identified. These encompass the usual three waters as well as sea water, groundwater, surface ponding, grey water, and deep ground water. It is acknowledged that the interactions between the waters will change in an uncertain manner as a result of climate change.

4.2 Direct Impacts

Sea Level Rise

Over the past century, Aotearoa New Zealand's average rise in mean sea level has been similar to the average global rate – therefore future projections of global sea level rise are generally applicable (Bell et al., 2015; MfE, 2017). This trend will have a driving effect on what we expect to be a 'normal' event. For example, recent analysis of four main ports found that extreme sea levels which are currently expected to have a 1% AEP (a 1 in 100 year event), will occur on average at least once per year (or more) after only a 0.3 to 0.45m sea level rise relative to present-day mean sea level (Stephens, 2015).

Our infrastructure will be affected in a number of ways. Historically, much water and sewage treatment infrastructure is located on floodplains or the coast, due to the need to discharge to nearby sources of water (White, 2010). Sea level rise creates tailwater conditions in outlet pipes for both wastewater and stormwater systems that discharge into tidal areas. This gravity gradient reduces relative to sea level (Johnston, et al., 2014). In some locations, this is already causing backflow of seawater through onto parks and roads during king tides. Rising sea levels can raise coastal groundwater levels, increasing infiltration into wastewater pipes and thereby reducing the overall capacity of these systems. This can result in sewerage overflows (Rotzoll & Fletcher, 2013). Higher groundwater levels can also expose pipe networks to damage from liquefaction events (Tonkin & Taylor, 2013). Beyond pipes, the plants themselves are also vulnerable to climate change. In some locations, sea level rise can also result in the intrusion of salt water into wastewater and stormwater systems, and wastewater pumping stations. Saltwater corrodes pipes and machinery and disrupts the biological processes in wastewater treatment ponds (Bovarnick et al., 2014; Rouse et al., 2017).

The impact of sea level rise is dependent on the tidal range of a particular location. Wellington is an example of a small tidal range, whereas Auckland has a large tidal range. Sites with small tidal ranges are more sensitive to sea level rise because where tides are small sea level rise is a larger proportion of the existing tide (Stephens, 2015).

Coastal Storms

Climate change projections anticipate that the number and intensity of extreme events will increase in the future. Aotearoa New Zealand has so far observed a statistically significant increase in waves in the 99 percentile wave height based on the 1985-2008 period (Young et al., 2011). Beyond driving exposure to coastal properties, this brings a number of impacts

for the operation of our infrastructure assets. As sea level rises, low lying wastewater treatment plants will increasingly be at risk of inundation during storm surges. Coastal storms can cause direct physical damage to low-lying wastewater treatment plants and pumping stations through wave action and high winds and indirect damage through power outages (Kenward et al., 2013).

Extreme Rainfall

Rainfall totals have increased in the southwest of the South Island and have decreased in the north of the North Island (Griffiths, 2007; Reisinger et al., 2014). Rainfall changes are expected to change on an east-west gradient, with increases on average in the west and decreases in the east and north (MfE, 2016b). Our infrastructure has been developed with 20th century weather patterns in mind. Changes to intensity and distribution will have an effect on their operation, most notably with regard to flash flooding.

Extreme rainfall can overwhelm both wastewater and stormwater systems and can restrict maintenance access routes (e.g. manhole covers and tunnels) needed to restore service. Wastewater systems most at risk from extreme rainfall are those with combined wastewater and stormwater pipes. This includes approximately 200 km of pipes in Auckland city (Water New Zealand, 2016). However, even when wastewater and stormwater systems are separated, intense rainfall events can result[4] in Rainfall Dependent Inflow and Infiltration (RDII). This is where stormwater enters into wastewater pipes overloading the capacity of those pipes to transport wastewater (Water New Zealand, 2016). Once untreated or partially treated wastewater is discharged it can threaten public and private domains including: residential and commercial buildings; terrestrial, fluvial and marine ecosystems; potable water supplies; and cultural and recreational outdoor spaces including beaches and waterways (Kenward et al., 2013).

Drought

Drought can disrupt gravity-fed wastewater systems by slowing overall flow and allowing solids to accumulate at pipe joints, leading to blocked pipes and subsequent breaches. Drought can also raise concentrations of ammonia and other contaminants such as hydrogen sulphide to the point where they interfere with biological treatment processes and can create safety issues for maintenance crews (Bovarnick et al., 2014). Aotearoa New Zealand is yet to experience the length of drought expected to cause these impacts. However, droughts are likely to increase in severity and frequency and wastewater systems will require additional maintenance to protect existing levels of service.[5]

4.3 Indirect Impacts

Failure of stormwater (and to a lesser extent wastewater) systems can have cascading impacts on other systems. Flooding of major sections of the transportation infrastructure can in turn result in major disruptions to social and economic activity, such as access to work and school. In extreme cases, flooding may also cut off evacuation routes endangering the lives of residents, visitors and emergency personnel (Johnston et al., 2014).

4 (and has resulted)

5 https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios

Wastewater failures can have significant economic impact in locations where commercial activity is directly dependent on healthy waterways and beaches, particularly if extreme weather events coincide with peak demand. Many coastal towns and city suburbs in Aotearoa New Zealand experience population swells during summer months, which stretch the capacity of each location's wastewater systems. Failure of wastewater systems during these periods can disrupt recreational activities and could have a long term economic impact if news images and social media reports of untreated sewage spilling into waterways undermines a location's aesthetic appeal (Bovarnick et al., 2014).

5. POTENTIAL ADAPTATIONS

Adaptation is defined as: "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm, or exploit beneficial opportunities" (IPCC, 2014). Adaptation approaches (which might include retreat) need to consider the spatial scale on which interventions should focus, and how different adaptation options will perform and interact. These can range from adaptations independently applied to specific buildings, or infrastructure assets, through to modification at the scale of a community, or an entire catchment (Zevenbergen & Gersonius, 2007).

The dialogue participants highlighted potential opportunities at each of these scales to reduce stormwater and wastewater flow through decentralized approaches. They also noted these opportunities may be being missed in the redevelopment of brownfield sites and retrofits of existing assets as well as in the development of greenfield sites. The dialogue participants noted particularly that a change from thinking in terms of "failsafe" to "safe to fail" was a good start in this space. A failsafe mentality focuses on achieving stability, whereas a safe to fail mentality considers resilience, specifically the capacity of systems to re-organise and recover from change or disturbance (Ahern, 2011).

5.1 Building Scale

Building scale approaches seek to increase the resilience of individual assets when they are exposed to a stormwater or wastewater hazard. Innovative approaches include flood resilient buildings where the lower section of a structure may be treated with a water proof sealant and flood proof boards are installed on entrances (White et al., 2016). More traditional approaches include raising minimum floor levels and the temporary installation of sand bags immediately prior to a flood (Christchurch City Council, 2014). Building scale approaches can be appropriate for managing some parts of stormwater and wastewater systems as these approaches can ensure that important assets are less vulnerable to climate change. In some cases they can reduce exposure by preventing stormwater and wastewater overflows from breaching a building's exterior. Integrated approaches adopted across multiple buildings can manage water on a community level. For example, water can be held back in storage areas or reservoirs, or slowed down to give the receiving infrastructure time to adjust to extreme events, or be retained as a resource to be used on site. There is also opportunity for source reduction for both wastewater and stormwater at the building scale, including implementation of onsite treatement re-use greywater[6], to reduce wastewater loads, and rainwater harvesting and living roofs and walls to reduce stormwater generation (South East Water, 2017). These opportunities are easier to introduce for new buildings than retrofitting into existing buildings, though this can also be achieved.

5.2 Community Scale

Community or city scale approaches often focus on the management of wastewater and stormwater networks. A possible adaption would be to change the design standards to account for future shifts in AEP. Without investment in upgrades to existing systems, and higher design parameters for new systems, we can expect systems to fail more frequently and operate at reduced levels of service.

International examples suggest city scale initiatives that focus on decentralized approaches can minimize stormwater and wastewater flows at source and thus dramatically reduce demand on existing wastewater and stormwater systems.

5.3 Catchment Scale

Internationally, countries experiencing increased impacts associated with climate change are moving towards a risk-based and integrated catchment approach. This links upstream and downstream, via a focus on understanding how water flows through an entire catchment from the sources through the various pathways to the eventual receptors (European Union, 2007). This systemic approach has broadened the range of stakeholders who play a role in managing risks by including both

6 Blackwater is water which has faecal matter in it. Greywater is dirty water without faecal matter (like that produced by a washing machine or shower). Wastewater is a mix of either or both of these.

We would like to acknowledge the generous contribution of dialogue participants' time and effort, both during and following the dialogue meetings. We also acknowledge peer-review from Professor Jonathan Boston of Victoria University of Wellington, Sue-Ellen Fenelon of Ministry for the Environment, Frances Sullivan of LGNZ, Dr Stephen Knight-Lenihan from the University of Auckland, and Noel Roberts from Water New Zealand; thank you for your time and helpful comments.

International Case Study: Philadelphia

Philadelphia is investing US$2.4 billion over the next 25 years through its "Green City, Clean Water" plan to use soil, aquifers and wetlands to capture and filter urban runoff. This includes reverting one third of the city's impervious surfaces into porous vegetated gardens and parks to absorb, filter, and temporarily store storm water. The city is also restoring wetland and waterway ecosystems to enhance the natural filtration of pollutants as part of its wastewater treatment (Bovarnick et al., 2014).

structural and non-structural solutions. Structural solutions can include larger pipes, upstream floodgates to divert water flows away from urban areas, or isolation valves to limit the impact of city scale failures on downstream locations (Johnston et al., 2014). In some ways this may be considered current practice in much of Aotearoa New Zealand, but a catchment perspective goes beyond the traditional actors and agencies to also integrate agricultural or land-use practices.

Non-structural solutions may comprise aspects such as early warning systems, or education. Most notably, however, this type of solution covers the planning system and the type, function, and location of development. For instance, stronger planning policy can restrict development in exposed locations or build in extra storage capacity to existing areas, it can also influence the location of new critical infrastructure, or facilitate resilient design that can restrict runoff and limit the impact of new development on existing infrastructure (White, 2010). Non-structural solutions may also include financial mechanisms to transfer risk through insurance and subsidization of off-grid-on-site wastewater treatment as a prerequisite of transferring wastewater services to private ownership (Johnston et al., 2014).

6. ENGAGEMENT & DECISION MAKING

6.1 Aotearoa New Zealand adaptation: roles and responsibilities

Central government sets the direction by: setting the legislative and policy framework; providing information and guidance; funding research and publishing information on climate change; and preparing for and responding to major natural hazard events (MfE, 2016a). Climate change adaptation is also noted as a concern in the National Infrastructure Plan (NIU, 2015) and is required to be given effect under the New Zealand Coastal Policy Statement 2010, which has statutory power under the RMA. The Ministry for the Environment updates guidance on climate change scenarios, rainfall and coastal hazards which apply to stormwater and wastewater decisions under the RMA and flood protection schemes under the Soil Conservation and Rivers Control Act 1941.

Regional councils and local territorial authorities have operational and policy responsibilities relating to climate change including in the context of flood risk management and coastal management under the RMA. The RMA requires local government to consider the effects of climate change and thus incorporate climate change into decision-making. A 2004 amendment to the Resource Management Act (RMA, 1991) requires decision makers to have particular regard to the effects of climate change (Manning et al., 2015; MfE, 2008a). Recent amendments to the RMA also require recognition of and provision for the management of significant risks from natural hazards as a matter of national importance. However, while 36 councils reported in 2015 that climate change was factored into water assets decision-making, approaches vary significantly (Water New Zealand, 2015). Consideration of natural hazards in stormwater and wastewater management under infrastructure strategies is included in the Local Government Act 2002 section 103B.

6.2 Aotearoa New Zealand adaptation: known issues likely to be exacerbated by climate change

Information gaps

Because no one central government agency has oversight of wastewater and stormwater management, Aotearoa New Zealand has only recently begun to build a national picture of water networks. The National Infrastructure Plan in 2011 identified New Zealand's water network as having the lowest ranking of all infrastructure sectors analysed (NIU, 2011). Water's investment analysis, funding mechanisms, and regulation were found to be ineffective or non-existent. Coordination, accountability and performance, and resilience were under developed. Since then it has been acknowledged that water assets need to be considered at a national level. Local Government New Zealand (LGNZ) has begun a series of projects to fill this information gap including information on: financial management; age, condition and performance of the network; setting, delivering and measuring levels of service; planning capabilities and tools; governance models; and service delivery mechanisms. However, responses are varied and there is no consistency of reporting across councils. For example age and deterioration of assets is a likely issue, but condition grading approaches vary across Aotearoa New Zealand (Water New Zealand, 2015). This makes national understanding and assessment of pipeline conditions difficult, and as

Case Study: Canterbury

During the Canterbury Earthquake Sequence the land elevation in some urban areas of Christchurch City Council and Waimakariri District Council subsided by up to 1 metre. This mimicked the impact of several decades of sea level rise by lifting water tables and reducing the gradient on stormwater and wastewater drainage systems. The operating costs for these stormwater and wastewater systems have increased as gravity fed systems been replaced with low pressure systems to accommodate the lost gradient.

In July 2017 Christchurch City Council declared a state of emergency when the city and its upper catchments were exposed to over two months of rain in two days. Floodwater began to infiltrate the city's wastewater network causing sewerage overflows throughout the city. When this combined with a storm surge of approximately 40 centimetres and a spring tide, the Heathcote River, unable to drain to the ocean, burst its banks and flooded city streets. Several wastewater pump stations were flooded and the entire city was asked to restrict activities that produce wastewater. Dozens of houses were flooded with contaminated water and temporarily deemed unsafe for occupation (Christchurch City Council, 2017).

The Canterbury Earthquake Sequence also raised questions concerning local government's obligation to continue to provide services to areas severely impacted by natural hazards. Following major earthquakes in 2010 and 2011 the Aotearoa New Zealand government purchased thousands of private properties within urban areas heavily damaged by liquefaction. However, a small number of property owners declined the government buyout offer and instead continued to reside in the damaged areas. A recent legal opinion obtained by the Christchurch City Council and Waimakariri District Council indicates that these owners retain their legal rights in relation to their land, including access to stormwater and wastewater services provided to other households. The legal opinion noted that while there are provisions which theoretically provide a legal path to withdraw stormwater and wastewater services, councils may find it difficult to meet the necessary criteria (Simpson & Grierson, 2014).

such it is hard to get a complete picture of how climate change may affect infrastructure in different ways in different places. Implications include the need to review all assets used currently.

Funding constraints

Services tend to be funded by territorial authorities through local rates and development contributions, sometimes supported by central government subsidies (NIU, 2010). The Assistant Auditor General of Aotearoa New Zealand recently warned that inadequate re-investment in stormwater and wastewater systems could undermine service levels and will transfer costs to future generations (Cropp, 2017). In 2014 the Auditor General wrote that while local governments' decision making and asset management appears sufficient in the short and medium term, they will face challenges in the long term (Office of the Auditor-General, 2014). Only in some regions are water services metered and charged volumetrically. There is a wide variation in the unit cost of service delivery. For example Water New Zealand reported a range from $0.50 to $2.80 per cubic meter of wastewater nationally (Water New Zealand, 2015). Further, the sector has distinct segments facing funding challenges. Of particular concern are those councils needing to cater for growth, and those councils facing static or decreasing rating bases (NIU, 2010). Financing of replacement and renewal of assets was also noted as a concern in a recent Castalia report commissioned by LGNZ. This states that a high level of investment is required to maintain existing infrastructure assets, let alone to renew or replace them (Castalia, 2014); further, this is likely to increase with climate change impacts.

Temporal Misalignments

Some climate change impacts, such as sea level rise, are already visible. Other impacts, such as the warming of oceans which influence storm tracks and intensity may have a lag of several decades. The on-going impacts of climate change will continue for centuries.

Our regulatory framework comprises laws with varying time jurisdictions. Policy 25 of the New Zealand Coastal Policy Statement 2010 requires local government decision makers to consider the impact of climate change on coastal hazards over a horizon of at least the next 100 years, whereas the Building Act governs buildings over a 50 year timeframe. The RMA provides for consents of up to 35 years. These varying time jurisdictions create issues for the water community, though it is unclear how best this could be addressed.

6.3 Techniques and Tools to support Decision Making

A number of tools can be used to assess the ability of decisions to meet stated objectives that will help Aotearoa New Zealand better adapt to climate change. Many of these can also help engage a local community with wastewater and stormwater issues. Decision support tools are included in this document because they can help avoid conventional analysis that reinforces variations of business as usual, whereas what is needed is a critique of business as usual.

Multi Criteria Analysis (MCA) is a common tool whereby experts and representatives of the local population can assess the economic, social, cultural, and environmental impacts of options and thus assign values and preferences to them in a decision making process. This enables prioritization of adaptation efforts (Johnston et al., 2014).

Three other decision-making frameworks used in Aotearoa New Zealand that are relevant for assessing stormwater and wastewater systems include the Treasury Living Standards Framework, the Mauri Model Decision Making Framework and the Dynamic Adaptive Policy Pathways planning approach.

The Treasury Living Standards is a framework for incorporating a broad range of material and non-material factors which impact on well-being (such as trust, education, health and environmental quality) into policy making.

The integration of Māori knowledge is a significant challenge for scientists and engineers. This framework can better communicate Iwi considerations in the planning process while adapting to climate change (Challenger, 2013). The Mauri Model acknowledges Mātauranga Māori (indigenous knowledge) insights and asks how cultural values can be better acknowledged and engaged (Morgan, 2010). The Mauri Model Decision Making Framework (DMF) is a significantly advanced approach to decision support. It incorporates sensitivity analysis that includes the impact of worldview bias (Faaui et al, 2017).

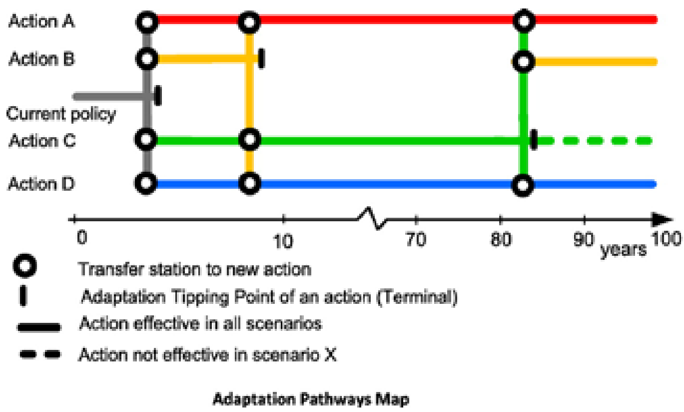
The Mauri Model DMF is made up of two parallel assessments: one using world view prioritisation of well-being criteria, and the other using absolute sustainability assessment (Morgan, 2010). The Mauri Model DMF has been identified in an Aotearoa New Zealand study as an exemplar for sustainability indicator sets (Challenger, 2013) and is readily adaptable

to climate change impact analysis (Ubels & Morgan, 2016). The DMF facilitates recognition and respect of Mātauranga Māori alongside mainstream science, seamlessly integrating quantitative and qualitative data to provide a more complete understanding of the problem.

Dynamic Adaptive Policy Pathways (DAPP) provides a framework well suited to assessing changing risk over long time frames and relevant for climate change impacts assessment. This describes a sequence of policy actions over time to achieve a set of objectives under uncertain and dynamic conditions. It requires that users have understanding of different adaptation options over time, and how they interact. An example of the DAPP tool is shown below.

As shown in Figure 1 (Haasnoot et al., 2013), following the grey line of current policy, leads to targets being to be missed after around four years. Four options emerge. Of these actions, A and D can hit targets over a long time period under different scenarios, while action B will hit a tipping point in another five years when another shift will be required. This allows policy to adapt to different circumstances at different times.

Figure 1: Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013)



The DAPP method supports decision making under uncertainty by helping to avoid future expensive path dependency that creates lock-in and thus inability to change course as the climate changes.

Given the long lifespans of infrastructure, it is particularly prone to path dependency issues.

A real option is the right but not the obligation to invest resources at a future date to expand, delay, abandon or redeploy the use of an existing asset. Like financial options, the value of real options are estimated by computing the time to expiry, the variability of outcomes, and the value of those potential outcomes. By avoiding deterministic assumptions, real options analysis accommodates the uncertainty of future climate scenarios (Kim et al., 2017). Real options analysis provides a mechanism to quantify the value of DAPP pathways at each node, and explicitly prices the value of "keeping options open".

Case Study: Auckland

Like South Dunedin and Christchurch, recent flood events in Auckland have highlighted vulnerabilities with the city's stormwater and wastewater systems. The "Tasman Tempest" earlier this year made March 2017 the wettest month since record keeping began in the 1950s. Water managers in Auckland found that social media has changed how communities learn about and respond to stormwater and wastewater failures. Just as escalating climate hazards are increasing the stressors on stormwater and wastewater systems, social media is facilitating immediate dissemination of citizen-sourced information on the performance of those systems.

The conversations revealed that the way current decisions are made may not be effective in enabling adaptation to occur under conditions of uncertainty.

The type of decision support tool appropriate for use depends on the level of uncertainty. Cost Benefit, Multi-Criteria Analysis, the Treasury Living Standards Framework, and the Mauri Model MDF can be used for understanding complex, but non-path-dependent aspects.Tools such as Real Option Analysis, Robust Decision Making (Lempert et al., 2006; Lempert et al., 2003) (which uses exploratory modelling, scenario discovery, and trade-off analysis to decide on actions that result in robust strategies), Scenario Analysis, and DAPP are designed to explicitly consider path-dependency and uncertainty and are more likely to result in successful adaptation by enabling short-term decisions to be made now that can be adapted over time.

7. CONCLUSIONS: HIGH-PRIORITY RESEARCH QUESTIONS

Our high priority research questions are listed below as an integrated suite of research. The first priority is to better understand the risks to our stormwater and wastewater systems, including the cascading indirect effects that we may not yet be aware of. This evidence base will allow us to better understand what is at risk, where, and why. This, in turn, provides a foundation for our next two research questions to consider the most appropriate adaptation response and solutions that may help reduce these impacts. We also need to incorporate these elements within our decision-making frameworks, so the final question will investigate the best way in which these decisions can be implemented. Together these four questions can link the knowledge gaps regarding the scientific impacts of climate change to policy and practice.

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

- How significant are those impacts?
- How will those impacts be distributed across different groups?
- How will those impacts manifest in different contexts and locations?
- What guiding principles could be developed for local government decision makers to apply this information?

Question Two: What adaptation opportunities are currently being missed within redevelopment of brownfield sites and retrofits of existing assets?

- What legal requirements constrain these options?
- How do funding mechanisms constrain these options?
- What other barriers exist?
- What benefits could be realized (or other problems addressed) through redevelopments and retrofits?

Question Three: What solutions are available for Aotearoa New Zealand to reduce our dependency on traditional wastewater and stormwater infrastructure and delivery mechanisms given climate uncertainty and intergenerational affordability?

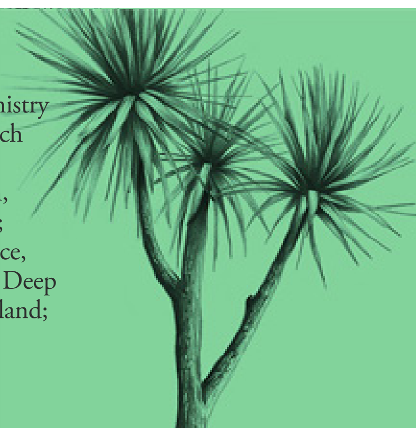
- Are there neglected or under-utilized low tech solutions that could be applied? What are the barriers to their widespread adoption?
- What are the emergent technologies that could be applied to Aotearoa New Zealand? What are the barriers, if any, to their widespread adoption?
- What benefits could be realized, including improved Mauri?

Question Four: How can we improve stormwater (flood) risk management under changing climate conditions over long timeframes?

- Review international and Aotearoa New Zealand literature for examples of how evolving decision frameworks and practices that address uncertainty and changing risk over long timeframes have been implemented for SW infrastructure and flood risk. How are adaptation measures for infrastructure in this space being evaluated in that literature?
- What evidence is there on how effective long term decision making processes for stormwater system adaptation can be implemented, and on how those who are most successful have overcome known institutional, regulatory, and social barriers?

APPENDIX 1: DIALOGUE PARTICIPANTS

Adolf Stroombergen, Infometrics; Emily Harvey, M.E. Research; Sue-Ellen Fenelon, Ministry for the Environment; Suzi Kerr, Motu Research / Deep South; Sally Owen, Motu Research / Deep South; Kepa Morgan, Ngāti Mākino Iwi Authority; Rob Bell, NIWA; Christian Zammit, NIWA; Richard Ward, New Zealand Treasury; Liam Foster, Opus; Zeb Worth, Opus; Gavin Palmer, Otago Regional Council; Trish Hall (facilitator), Thought Partners; James Hughes, Tonkin Taylor; Frances Charters, University of Canterbury; Judy Lawrence, Victoria University of Wellington; Susan Livengood, Victoria University of Wellington / Deep South; Belinda Storey, Victoria University of Wellington; Noel Roberts, Water New Zealand; Mark Bishop, Watercare; Simon Markham, Waimakariri District Council; Blair Dickie, Waikato Regional Council; and Iain White, Waikato University.



APPENDIX 2: LONG LIST OF FUTURE RESEARCH QUESTIONS

Risk under Climate Change

A. Which towns and cities in Aotearoa New Zealand are likely to face increased frequency of medium sized events, extreme rainfall, coastal inundation, or drought threats to their stormwater and wastewater systems? How quickly will these hazards escalate? What are the direct physical impacts of those hazards on receiving environments?

B. What are the strongest dependencies between the three waters in Aotearoa New Zealand and how could these dependencies change under climate change?

C. What is the impact of rural and conservation land use on urban stormwater and wastewater?

D. What is changing in the receiving environment that will determine the capacity of those environments to successfully support upstream stormwater and wastewater adaptations?

Potential Adaptations

E. How will climate change affect the Annual Exceedance Probabilities of events (e.g. the 1 in 100 year return period used as the design criteria for many wastewater systems) and how do we ensure future climate projections are incorporated into the default design criteria for new and existing stormwater and wastewater systems?

F. What alternative ownership models could be developed to enhance the resilience of stormwater and wastewater systems? How do existing ownership models affect decision making on stormwater and wastewater? Under what circumstances would more decentralized stormwater and wastewater systems enhance resilience?

G. What are the major co-benefits of stormwater and wastewater adaptation and how can these be quantified? What are the unintended consequences of stormwater and wastewater adaptation?

H. How can we use whole catchment and system understanding to better evaluate stormwater and wastewater system adaptations?

I. What are the opportunities for resource recovery? How do we encourage water conservation and protect water quality within stormwater and wastewater adaptations?

Engagement and Decision-Making

J. How can public decision makers best communicate to local communities the likely and actual consequences of stormwater and wastewater service failures (particularly given the prominence of citizen reporting)?

K. What are the best tools for incorporating uncertainty on climate change impacts on stormwater and wastewater systems into public and private decision making?

L. What are the possible physical, economic and cultural trigger points which could influence decision making on stormwater and wastewater systems (including slow onset events and the cumulative effects from small to medium events and opportunities to influence long term decisions such as major investments in stormwater and wastewater infrastructure)? How significant would future impacts need to be to influence current decision making?

M. What type and scale of service failures does Aotearoa New Zealand currently tolerate (e.g. formally, through explicit exemption or the absence of a legal prohibition and informally, through lax enforcement and/or inadequate penalties) and how might these tolerances change with escalating climate hazards?

N. How might existing funding mechanisms need to change to address climate impacts on stormwater and wastewater? Are there alternative pricing models which could incentivize adaptation?

O. How can indigenous ways of knowing provide new understanding of climate change problems with stormwater and wastewater to inform climate change response?

P. How could regulatory and institutional mechanisms be realigned to address the needs of stormwater and wastewater systems under climate change?

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