CLIMATE CHANGE PRESSURES IN THE WASTEWATER SECTOR AND ADAPTIVE PLANNING

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ABSTRACT

Ministry of Environment (MfE) is leading policy work related to the development of a proposed new national environmental standard for wastewater discharges and overflows. To inform their work MfE engaged a joint consultant team of GHD, Beca and Boffa Miskell to provide a summary of the current state of the wastewater sector in New Zealand including details on current and emerging issues for wastewater management.

This paper outlines a portion of this study which explored the current climate change regulatory requirements and the current tools to estimate greenhouse gas emissions, in conjunction with the primary risks facing wastewater treatment plants (WWTPs) in New Zealand with regards to current climate change predictions and the likely direct and indirect impacts these changes may have.

The wastewater sector is vulnerable to the direct and indirect impacts of climate change, including coastal inundation and erosion, changing patterns in precipitation, and drought frequency. Analysis of the location of WWTPs in New Zealand identified 5% are located within 5 km of coastlines highly sensitive to inundation and 14% are within 5 km of a segment of coastline highly sensitive to erosion. A significant number of WWTPs are also located in flood hazard areas, such as in the Waikato, where 32% of Plants are within a flood hazard zone and 41% within 1 km of these zones.

The localised impacts of climate change, particularly indirect impacts, are difficult to quantify and predict. From interviews with a representative selection of Local Government Authorities in New Zealand it was clear that there is a considerable journey ahead to prepare the wastewater sector to respond to the implications of climate change. This paper summarises feedback from service providers and describes what climate change implications interviewees identified were priorities for them, and the key knowledge gaps and hurdles perceived.

Consideration is given in this paper to the greenhouse gas emissions from WWTPs, and the associated New Zealand carbon reduction policies. The paper also describes the emergence and use of adaptation planning for the wastewater sector and potential to improve its resilience to climate change. By drawing on international, and emerging domestic case studies, adaptive planning is explored and its applicability for implementation in New Zealand as a best-practice approach.

KEYWORDS

Climate change, climate change resilience, adaptive pathways planning

PRESENTER PROFILE

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INTRODUCTION

Ministry of Environment (MfE) is leading policy work related to the development of a proposed new national environmental standard for wastewater discharges and overflows. This work is being progressed as part of a package of reforms to the Three Waters regulatory system, which was agreed by Cabinet in July 2019.

To inform their policy work on wastewater, MfE required detailed information on the operation and performance of wastewater treatment plants (WWTPs) and the wastewater sector in New Zealand, including identification of climate change risks and adaptation and mitigation opportunities in response to these risks, to ensure that any future policy and regulatory interventions are appropriately designed and underpinned by strong data and evidence. Accordingly, MfE engaged a joint consultant team of GHD, Beca and Boffa Miskell to provide a series of reports describing the wastewater sector in New Zealand including details on current and emerging issues for wastewater management (GHD et al., 2020). This paper draws on the outcomes of the climate change section of the package of work, where consideration was given to the anticipated impacts of climate change on the wastewater sector in New Zealand, including the impacts of carbon reduction policies.

The predicted outcomes of climate change have been widely researched and reported in the international and national context (Ministry for the Environment, 2018) as have the impacts of greenhouse gases (GHG). Following the 1992 United Nations Framework Convention on Climate Change there has also been a steady increase in global and national development of climate change response polices and legislation. Considering this, the work undertaken on behalf of MfE focused on the key climate change pressures facing the wastewater sector in New Zealand and identifying, through an interview process, the level of readiness, areas of concern and perceived challenges the wastewater sector is going to face developing response strategies.

BACKGROUND

New Zealand, influenced by international GHG emission targets and by global pledges made under the Kyoto Protocol, Paris Agreement and United Nations Framework Convention on Climate Change (UNFCCC), has developed the Zero Carbon Amendment Act (ZCAA), which outlines the domestic emission targets for 2050 and requires the creation of an Emission Reduction Plan. The requirement to develop an Emission Reduction Plan will impact the wastewater sector through the development of sector-specific policies and multi-sector strategies which will include reducing emissions, increasing removal efficiency, and adapting to the effects of climate change. These sector specific policies will require the wastewater sector to monitor GHG emissions and their progress towards the sector and national set targets. It has been acknowledged however there are several uncertainties in the estimation of GHG emissions from wastewater collection and treatment systems (de Haas, 2018). To manage the requirements of the Emissions Reduction Plan, the wastewater sector in New Zealand will need an appropriate and consistent approach to GHG testing, measuring, and reporting. GHD et al. (2020) investigated the current guidelines for reporting GHG emissions and its applicability to meet this need, as detailed in the GHG emissions section below.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to provide comprehensive summaries regarding the drivers of climate change, predicted future risks and implications of climate change, and how adaptation and mitigation can reduce climate change risks. The objective of the IPCC is to provide scientific information for use by governments at all levels to help develop climate related policies. In New Zealand entities such as the Ministry for the Environment and the National Institute of Water and Atmosphere (NIWA) use the IPPC climate model simulations to develop climate change predictions specific to New Zealand. Currently, using the Fifth Assessment report of the IPPC, the Climate change predictions for New Zealand have been developed out to 2120 and are reported in the Climate Change Predictions for New Zealand Report (MfE, 2018). This report details expected patterns of change, changes to temperature, pressure systems and wind, evapotranspiration, drought conditions and other variables.

The climate change prediction information for New Zealand continues to expand from there with the likes of NIWA and other organisations creating climate adaption platforms, regionally specific climate change predications, climate change scenarios specific to certain variables, such as sea level-rise, and guidance reports and fact sheets. To understand the climate change risks and implications which are of most concern to the wastewater sector in New Zealand GHD et.al (2020) conducted a series of interviews with a selection of seven representative local government authorities. The interview process highlighted sea level rise, storm surges, changes in precipitation patterns, flooding, increase in temperatures, and drought frequency were the climate change risks acknowledged as putting pressure on, or are anticipated to put pressure on the wastewater sector. These pressures are expanded on in the climate change implication section below.

GREENHOUSE GAS EMISSIONS

Emissions, because of anthropogenic activities, are increasing the concentration of atmospheric GHG globally. The types of GHG emissions associated with the wastewater sector are categorised as direct or Scope 1 emissions, indirect or Scope 2 emissions, and indirect emissions that are expected to be reported elsewhere as direct emissions also referred to as Scope 3 emissions. Wastewater treatment plants and the wastewater sector have been identified as contributing to the emissions of GHG in the atmosphere (Parravicini et al., 2016), with direct, Scope 1, GHG emissions from wastewater contributing an estimated 1.6% of total global emissions (IPCC, 2014). The GHG emissions from the wastewater sector will vary by country and region according to the extent of wastewater collection, as well as the level and type of wastewater treatment. In addition to the direct wastewater emissions, emissions associated with the energy consumption at wastewater treatment plants, Scope 2 emission, need to be considered. In Australia the contribution of GHG emissions from energy consumption in the wastewater sector are estimated to be approximately 0.6% of the electricity sector emissions, and approximately 0.2% of the national GHG inventory (Australian Government, 2018). The emissions due to energy use associated with wastewater pumping are likely be of a similar order, depending on location, topography, and nature of the sewer collection systems (Cook et al., 2012). Methane emissions from sewers are highly variable, and potentially a significant additional source of global GHG emissions, but typically have not been included in GHG reporting protocols (Liu et al., 2015).

Internationally there are multiple methods for how emissions are estimated. The method for estimating Scope 1 (CH_4 and N_2O) emissions associated with domestic wastewater treatment (or handling) is described in the New Zealand detailed guide to measuring emissions for organisations (Ministry for the Environment 2019). GHD et al. (2020) provided a detailed description of the scope of GHG emissions generated by the domestic wastewater sector in the New Zealand context and compared it with the approach taken by the Australian Government. The overall contribution of the wastewater sector to emissions at a national level was examined and the assessment considered emission calculations based on a population data set and relative contribution by treatment plant type.

The results of the GHG emissions assessment (GHD et al., 2020) have not been replicated in this paper, giving room to focus on the key findings of the assessment. Wastewater treatment plant Scope 1 emissions are likely to be among the dominant type of GHG emissions. However, efforts to reduce GHG emissions from WWTPs treating predominantly domestic wastewater need to be tempered by an understanding of the relatively small contribution that this sector makes to the national greenhouse inventory, indicatively less than 0.5% in New Zealand (GHD et al., 2020).

The current MfE 2019 guidelines for reporting GHG emissions from wastewater treatment is reasonably straightforward and aligned with similar protocols around the world but is relatively simplistic as it was authored to provide basic estimates for small-scale waste generators, not WWTP-scale waste processers. In addition, at present, a significant proportion of New Zealand's population is served by wastewater that is treated and disposed of using septic tanks, largely in rural areas. Cumulatively, these systems contribute about 40% of the domestic wastewater emissions according to the national greenhouse inventory and therefore further investigation into improved methods to measure and account for septic tank emissions in the New Zealand context would be useful.

These current challenges emphasise that capital expenditure on WWTP asset renewal programs in New Zealand that have a focus on GHG reduction must therefore consider the overall justification for such expenditure, in conjunction with other, sometimes interdependent factors such as improvement in treatment efficiency to enhance the water quality of treated effluent.

A series of interviews with Local Government water service providers was conducted to determine, among other things, their appreciation of GHG emissions and the need to monitoring and report on these emissions. Further details regarding the interview outcomes are reported in the sections below. With respect to GHG in particular it was identified that some smaller service providers have started their climate change response by first building an understanding of their

GHG emissions. The interview processes highlighted that an appropriate and consistent approach to GHG testing, measurement and reporting that meets the industry's needs is yet to be confirmed in New Zealand, as discussed in more detail in GHD et al. (2020). This can pose an issue when considering future measurement methods and strategies to manage GHG emissions across a sector which operates a range of treatment technologies at a range of scales across the country. A one size fits all approach may not be desirable.

POTENTIAL DIRECT AND INDIRECT CLIMATE CHANGE IMPLICATIONS

Direct implications of climate change are effects on the functionality and operation of the wastewater sector. Direct implications can be caused by single or multiple climate change drivers, and each driver can have various impacts or cascading effects on wastewater sector infrastructure and the wider environment (Hughes et al., 2021). Indirect implications of climate change on the wastewater sectors may include impacts on the quality of influent and effluent and the predicted reduction of water use for conservation purposes. The indirect implications of climate change on the wastewater sector can be more difficult to pre-empt and are extensive.

POTENTIAL DIRECT IMPLICATIONS IN NEW ZEALAND

The key direct climate changes implications expected to influence the wastewater sector in New Zealand are sea level rise and storm surges, precipitation patterns and flooding, and increase in temperatures and drought frequency.

The Stocktake Report, from the Climate Change Adaptation Technical Working Group (2017), predict sea level rise to increase in New Zealand by 0.2 – 0.4 m by 2060, and 0.3 to 1.0 m by 2100. In addition to rising sea levels, sea level variability in terms of storm surges is likely to increase because of climate change (Hallegatte et al., 2011). Storm surges are the temporary rise of sea level in a coastal area because of low atmospheric pressure and sea-level gradients set up by strong winds. The influence of tidal activity during a storm surge will affect the intensity of the event (Bell et al., 2000).

New Zealand has over 15,000 km of coastline and approximately 75% of all residents live within 10 km of the coast (Hopkins et al., 2015). A considerable volume of infrastructure is therefore located in coastal areas. In 2012, NIWA developed a coastal sensitivity index (CSI), to understand the sensitivity of the coastal margin of New Zealand to climate change. The CSI developed shows relative potential future sensitivity to two variables; coastal inundation and coastal change, referred to herein as coastal erosion. The CSI for both variables was developed by assigning, to each segment of coast, a score, and weight regarding the relative way the geomorphic and oceanographic attributes are likely to be affected by climate change (Goodhue, et al., 2012).

Analysis of the CSI for inundation identified 15 WWTP are located within 5 km of a highly sensitive segment of coastline to inundation, of which 13 are within 1 km, and 74 WWTP were within 5 km of a moderately sensitive segment of coastline. These WWTP will be increasingly vulnerable to coastal inundation and storm surges because of climate change

Analysis of the CSI for erosion identified 45 WWTP are located within 5 km of a highly sensitive segment of coastline to erosion, of which 23 are within 1 km, and 63 WWTP were within 5 km of a moderately sensitive segment of coastline. These WWTPs will be increasingly vulnerable to coastal erosion from sea level rise and storm surges because of climate change.

The primary risk of sea level rise and storm surges for wastewater sectors in New Zealand is damage to infrastructure through inundation, erosion, and corrosion from saline floodwater (Tolkou & Zouboulis 2015, Hummel et al., 2018). In conjunction to structural damage, there is a risk of damage to electrical systems leading to faults at key processing units within a plant, such as sludge and aeration pumping, or complete shutdown of processing at a facility (Blumenau et al., 2011). The degree of damage may initially be small or short lived, depending on the severity of the event. However, damage to infrastructure is costly, whether it is slow degradation or immediate damage. The cost can be associated with the direct and indirect damage. For example, the coastal flood in Thames in 1995, which coincided with the highest tide of the year (storm surge), caused $3-4M worth of damages (Bell et al., 2000). Whereas indirect damage costs can include environmental and wellbeing costs to the local receiving environment or community because of untreated discharge from failed infrastructure (Blumenau et al., 2011, Hughes et al., 2021).

Precipitation projections for New Zealand are highly variable with rainfall expected to increase in the west coast of both Islands over winter and spring and decrease in the east and north during winter and spring (Ministry for Environment, 2018). In the west coast of the South Island, annual mean precipitation is expected to increase by 5% in 2040 and 10% in 2090. In the eastern areas, including Northland and Auckland, projected precipitation could decrease by up to 5% by 2090 (Lundquist et al., 2011). Projections also indicate increases in rainfall intensity and frequency. Lundquist et al. (2011) reported frequency of extreme precipitation events in New Zealand could nationally increase between 7-20%, with a potential 20% increase in very wet daily precipitation extremes in the south west of the South Island by 2090 (Climate Change Adaptation Technical Working Group, 2017, Ministry for Environment, 2018). Projected decreases in the daily precipitation extreme (wet days) in parts of the north and east of the North Island are also expected (Ministry for Environment, 2018).

Increased frequency and intensity of precipitation events means more severe flooding is expected (Tolkou & Zouboulis, 2015). Extreme precipitation and flooding pose a risk directly to infrastructure and the local environment. Flooding can overwhelm a wastewater facility by overloading pipe and pump capacity, and directly damaging infrastructure. For example, in 2010, the WWTP in the City of Norfolk, Nebraska, USA, was flooded and the weight of the water caused the 36-inch pipe, responsible for carrying wastewater into the facility, to collapse (Blumenau et al., 2011). New Zealand wastewater networks located in frequently flooded areas such as those located in Hauraki District or the Edgecumbe plant managed by Whakatane District Council will be vulnerable to similar risks. Increased inflow loads through direct inputs or inflow and infiltration have the potential to overload the collection systems, increase the risk of system overflows and decrease treatment efficiency (Flood & Cahoon, 2011). Damage directly to the facility is not only costly to fix but can directly release untreated waste into the receiving environment, posing a risk for cultural, human and ecosystem health (Hughes et al., 2021).

A portion of the wastewater infrastructure and facilities in New Zealand are in flood zones or flood plains. For example, in the Auckland Region 7 of the 17 WWTP facilities, or 41% of the Regions WWTP, are located within a flood plain and all other WWTP in the Region are within 1 km of a flood plain. Resulting in almost half of the WWTP in immediate risk of increased flooding vulnerability under climate change predictions. Similarly, in the Waikato Region 32% of the WWTP facilities are within a flood hazard zone, 41% are within 1 km, and 20% are within 5 km. Majority of the WWTP facilities are therefore vulnerable to flooding.

General midrange estimates predict temperature changes to increase by 0.8 °C by 2040, and 1.4 °C by 2090, in New Zealand. With wide range predictions spanning from 0.2-1.7 °C by 2040, and 0.1-4.6 °C by 2090 (Ministry for Environment, 2018). The surface temperatures in New Zealand have increased by approximately 0.9 °C since the pre-industrial period and relative to the temperatures observed in 1980-1999, average surface temperatures could increase by 2.1 degrees by 2090 (Lundquist et al., 2011).

Temperature increases may affect drought intensity and frequency in New Zealand. The severity and frequency of droughts may increase, with a possible 50 mm+ increase per year of potential evapotranspiration deficit, in July – June, by 2090 (Climate Change Adaptation Technical Working Group, 2017, Ministry for Environment, 2018). Drought potential could also increase in the western regions of New Zealand from 1 in 20-year return interval to a 5 to 10-year return frequency.

Drought conditions slow the overall flow of water in wastewater systems and can lead to build up of solids in the pipe network, causing blockages or breaches (White et al., 2017). Reduced quantities of water through the wastewater system can also result in reduced quality of the waste, i.e., an increase in contaminant concentrations (Tran et al., 2017). The increase in drought frequency in New Zealand is not an immediate challenge for the wastewater sector regarding direct implications and could in fact be beneficial in terms of behavioural change and reduced per capita water consumption. However, adaptive planning measures will be required to manage the upkeep of infrastructure, especially concerning reduced flows, and the indirect implication reduced wastewater quality could have on the receiving environments and overall treatment process.

POTENTIAL INDIRECT IMPLICATIONS

The indirect implications of climate change on the wastewater sector can be more difficult to pre-empt and are extensive. Indirect implications can include treatment process efficiencies and energy usage, increased sensitivity of the receiving and surrounding environment, tight controls on discharges and plant management, increased demand for storage capacity, reduced availability of land in vulnerable locations, and influent and effluent quality management.

The relationship between climate change pressures and the implications these have on the wastewater sector are not singular or linear, therefore, an example of an indirect implication and tension caused by differing requirements on the wastewater sector includes the need to treat to a level that reflects the sensitivity and values of the receiving environments and maintaining and improving plant process efficiency while reducing energy consumption and greenhouse gas emissions.

Increasing temperatures and rising sea levels are already posing a threat to many of the freshwater and estuary ecosystems in New Zealand (Jenkins et al., 2011). The indirect implication of this for the wastewater sector is the controlling limits on discharge quality and quantity are likely to become more restrictive, catering to the increasing sensitivity of the receiving environments. A direct implication of increasing drought severity is reduced base flows and increased contaminant loads (White et al., 2017). Under persistent dry climatic conditions, the lack of base flow and precipitation can cause a higher concentration of contaminant built up, having an indirect impact on the receiving environment where wastewater facilities discharge directly to the receiving environment (Senhorst & Zwolsman, 2005). Likewise increased flooding, storm and inundation risks puts pressure on the infrastructure and overflow capacities of treatment plants. Uncontrolled release from a wastewater plant, or infrastructure because of such events, may also have an adverse and indirect impact on the receiving environment, through addition of contaminants (Senhorst & Zwolsman, 2005, Tolkou & Zouboulis, 2015). Tighter restrictions on the discharge quality and quantity from wastewater facilities, subsequently puts indirect pressure on efficient plant processing and infrastructure maintenance. As a compounding factor the wastewater sector is then faced with the additional challenge of reducing greenhouse gas emissions and energy consumption.

The exact impacts of climate change, particularly indirect impacts, are difficult to quantify and predict, as highlighted through the sector interview process undertaken. This challenge has led to the increasing global acceptance of adaptation planning in the wastewater sector and its resilience to climate change.

FACING CLIMATE CHANGE IN THE NEW ZEALAND WASTEWATER SECTOR

Majority of the wastewater facilities and associated assets in New Zealand are considered old and suffer from historical under investment therefore, some Regions require significant upgrades to the current facilities to assist with resilience to population growth and climate change pressures. It has been observed in New Zealand that wastewater facility upgrades are driven by the level of service required by the local area and the quality of the existing infrastructure. Followed by the secondary driver, implications from climate change pressures.

Interviews were conducted with seven representative Local Government authorities in New Zealand to understand the keys climate change risks faced by each authority, if they have climate change strategies in place, and what they perceived as the key concerns and gaps in the sector regarding climate change response. The synthesised results of the interviews are summarised in table 1, the full responses are reported in GHD et al. (2020).

Table 1: Consolidated key findings from wastewater sector interviews

Questions	Consolidated responses
What do you consider are the key climate change associated risks that face your wastewater treatment facilities?	- Changes in rainfall, precipitation frequency and intensity, - Sea level rise and coastal inundation, - Storm events and drought, - Flooding, river rise, - Rising groundwater tables and associated salinity in coastal areas, and - Cumulative effects of climate change, growth, and changes to disposal requirements.
Is there adaptive capacity at the current sites that enable them to be resilient in the face of climate change?	- Mixed responses of yes and no. - Some participants indicated land had been purchased or additional land was available for expansion. - One participant indicated some plants are considered secure and have potential for adaptive capabilities, but this is more challenging for the low-lying plants. - One participant indicated there was adaptive capacity at one of their plants, but they had not considered it for their other facilities. - Another participant indicated some planning adaptive capabilities using a dynamic adaptive planning approach, and through operational set up.
Do you have, or are you in the process of developing, a climate change policy or strategy	- Two participants said no. - Three participants said they were at various stages of establishing a climate change action plan and/or strategy. - Two participants have policies or strategy documents in place
Do you monitor and report greenhouse gas emissions in relation to your WWTPs	- Three participants said no, two of which acknowledged it was currently a gap and to be implemented in the future. - Four participants said yes, with at least two participants in this group having done monitoring for over a year, and one of these participants is already using the results to feed into emission targets.
Do you have key concerns or questions you would like raised with regards to climate change and climate change response in the wastewater sector of New Zealand	- Key concern is there needs to be good clear guidance on environmental preference at a National level i.e., clear objectives and outcomes sought and clear areas of focus. - There is no industry standard for design (i.e., do you design and plan for a 1 in 10-year flood or 1 in 100-year flood?) - Traditionally three waters are addressed individually but in the climate change space there is a lot of overlap and interaction therefore there should be a collective lens applied when addressing this issue. - There is a desire from the community to see smart and environmentally focused options but meeting these expectations is difficult due to funding. Rating base is small, and communities are diffuse which makes it difficult to consolidate effort and fund infrastructure improvements - From an asset management perspective there is a want for the Central Government to consider specific communities not just a general approach. There is also a want for guidance with flexibility.

Questions	Consolidated responses
	- What does a climate change response look like for communities and how does it affect specific communities in each region. - An area of key concern is that the current method for monitoring emissions factors has some shortcomings and does not consider treatment processes or upgrade. - The Three Water Reforms indicate the industry will be pushed into tighter controls and moving away from things like oxidation ponds, especially in challenging in some geographical areas. There are concerned about the funding needed to carry out such upgrades in the future.

From the interviews it has become clear there is a considerable journey ahead to prepare the wastewater sector to respond to the direct and indirect implications of climate change with most interviewees expressing they had treatment plants that were vulnerable or at risk of implications due to climate change variables. The interview process identified that the organisations are at differing stages with some well underway with climate change strategies and response and others who have not started to draft or consider plans. A similar observation was made about the management of greenhouse gases, some organisations are monitoring and working towards reducing these whereas other do not monitor greenhouse gas emissions at this time.

The interview process identified the following knowledge gaps and hurdles perceived by the participants:

1. There is an overall budget and cost issue, where upgrades, resilience and adaptation are required but comes at a cost above and beyond what the organisation can afford or secure through funding. This is especially pertinent for those with small rating bases and dispersed communities.
2. The rate of change is unknown with many of the climate change variables and more regional specific data and monitoring is required now to aid in the understanding and future planning.
3. The risk, vulnerability and financial circumstances of service providers vary significantly and thus they are facing different challenges. Therefore, national level guidance and policy needs to be flexible enough to enable location specific responses to be developed whilst also providing a nationally consistent general approach in terms of outcomes sought, policy and objectives set and overarching rules, regulations, and standards

ADAPTIVE PATHWAY PLANNING

Use of adaptive planning pathways is an emerging concept globally. Adaptive planning, dynamic adaptive planning pathway, or planning with the use of adaptive pathways is the concept of planning for a range of future uncertainties and developing flexible long-term strategies that allow for adaptive responses to different plausible futures or outcomes. With the interview process highlighting the general want for flexibility and location specific responses associated with national climate change practices the use of adaptive pathway planning is emerging in the New Zealand wastewater sector. The adaptive planning concept is popular in the water sector internationally and is fast becoming a best-practice approach as the challenges of facing climate change, demand, and population growth increase.

The adaptive planning approached was pioneered in the UK, relating to the Thames Estuary 2100 Plan, and the Netherlands, relating to the Delta Program. It is also fast-growing traction in the United States of America and Australia. In America the adaptive planning approach in the wastewater sector has been described as having three categories: protection, accommodation, or relocation. Where the protection approach consists of building infrastructure to prevent future damage to a facility. The accommodation approach is designed to be flexible and accommodate possible risks, such as elevating a plant to allow for temporary site flooding, and the relocation approach is designed to move a facility into a lower risk area (Hummel et al., 2018).

Across Australia the adaptive planning approach in the water sector has attempted to embrace future uncertainty by exploring the impact of multiple outcomes, with some organizations putting focus on the overall strategy and long-term plan for adaptability, not individual assets, or fixed outcomes. For example, Melbourne Water have created an Adaptive Pathways Planning Guideline in 2017-18 and specific plans such as the Western Treatment Plant Adaptation Plan 2018. The Western Treatment Plant Adaptation Plan is a multi-year work plan that enables Melbourne Water to complete a 100-year adaptation plan for the plant to understand the options available, interaction between actions and identify knowledge requirements to face change and future uncertainty in a coastal environment.

Throughout the wastewater sector in New Zealand the application of adaptive pathway planning is already being considered (Kool et al., 2020), and implemented by some organisations, including Watercare (GHD et al., 2020). Watercare is currently implementing an adaptive planning approach at a regional strategy level and is also applying this approach when planning specific upgrades to wastewater treatment plants and other assets with a long-life span. As a part of their Climate Change Strategy Watercare has begun implementing adaptive planning pathways to aid them in taking a holistic approach that considers climate change as well as other pressures on their infrastructure.

Overall adaptive pathway planning for the wastewater sector helps to improve its resilience to direct and indirect climate change implications and can, and has been, implemented in New Zealand to aid with future planning. There is also opportunity for GHG emissions to be built into the adaptive pathway planning approach.

CONCLUSIONS

A review of the climate change risks facing the wastewater sector in New Zealand has identified sea level rise, flooding and increased storm intensity are the key direct climate change implications facing the sector, with indirect climate change implications such as network inflow and infiltration, the tension between increased levels of treatment, energy usage and GHG emissions also being identified. Through an interview process with a selection of representative Local Government authorities it was identified most service providers are at an early stage in understanding the relative risk of their wastewater infrastructure to climate change factors and therefore developing an adaptation response.

Prior to being interviewed most service providers had begun to consider and/or measure GHG emissions and energy efficiency measures. A review of the current GHG emission guidelines for reporting identified the guidelines are straightforward and align with similar protocols internationally, however these is a need for further development to refine the estimates from small-scale waste generators and septic tanks in New Zealand.

Almost all the service providers interviewed noted that wastewater infrastructure is historically underfunded and would find it difficult to fund their own research to build understanding and to respond to the climate change related priorities identified. The sector would benefit from a more consistent guidance and assistance in terms of policy direction and objectives but noted that flexibility would be required to allow for varied vulnerabilities, levels of risk and ability to respond to them. Adaptive pathway planning is the concept of planning for a range of future uncertainties and developing flexible long-term strategies that allow for adaptive responses to different plausible futures or outcomes. With adaptive pathway planning emerging as a best practice approach internationally, the adaptive pathway planning approach could help improve the resilience of the wastewater sector in New Zealand to direct and indirect climate change implications.

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