A PROACTIVE APPROACH TO MANAGING A SMELLY AFTERTHOUGHT

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ABSTRACT

With continued growth projected for New Zealand's urban centres, a corresponding increase can be expected in the quantities of sewage flowing through urban wastewater networks, and the odour emanating from these. Sewer odour is not only a nuisance, but also an indicator of greater issues within the reticulation system. Corrosive by-products of anaerobic digestion instigate a chain of chemical reactions, attacking and weakening the walls of concrete sewers, thereby increasing management and operative costs for local councils. Leaks and ground contamination additionally pose a greater health risk to the wider public.

Across New Zealand, odour management has largely been dealt with in a reactive manner, which is an expensive and short-sighted approach. Monitoring is carried out fairly infrequently, often triggered by public complaints occurring when H_2S concentrations are elevated which often mislead the need for control and result in the application of quick fix solutions to help mitigate odour levels. A common solution across the country has been to install odour treatment devices in proximity to the site of the odour issue. The units can vary in complexity and process but the basic principle is to draw in foul air, treat it, and release clean air. At a capital cost in the magnitude of several million dollars to procure and install, and accompanying high ongoing opex costs, installing odour units tends to be a superficial solution which does not resolve the root cause of the issue, and can in some instances worsen the overall situation due to the impact on sewer air flow paths.

This paper presents a proactive strategy for managing odour and corrosion in sewer networks, developed as part of the University of Queensland's Sewer Corrosion and Odour Research (SCORe) project which was completed in 2013 carried out in conjunction with Australia's major water utilities. The strategy consists of first creating an accurate representation of the sewer network and simulating in-sewer processes using an in-sewer process model developed by the SCORe project. The model is able to predict "hotspots" of odour and corrosion areas within the network and evaluate various methods of control such as ventilation and chemical dosage to determine optimal locations and dosage quantities across the entire sewer network. The use of this tool has helped Australia's water utilities to devise strategic protocols and programme of works to

manage network risk and prolong the design life of network assets, thereby minimising the cost of corrosion and odour control.

The full paper will present two case studies for Sydney Water Corporation (SWC) and South Australia Water (SAW), who with the use of this tool are managing network odour and corrosion risk in a more proactive manner. It will discuss how SWC and SAW have used this tool to develop:

- Network odour and corrosion risk profile.
- Network corrosion and odour strategies and future programme of works.
- Guidelines, standards and costing tools for effective management.

Furthermore, it will discuss how this tool can be implemented in a New Zealand context across key urban centres, the potential shortfalls, and overall gains.

KEYWORDS

Odour, corrosion, sewer networks, risk management, master-planning, modelling.

PRESENTER PROFILE

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1 INTRODUCTION

Urban sewer networks receive wastewater from both domestic and industrial sources, and in the case of combined networks also receive stormwater flows. Population growth in economic centres often results in urban sprawl with the wastewater networks having to extend further and wastewater having a longer retention period before receiving treatment. As a result, wastewater becomes increasingly more concentrated in contaminants with the long retention times often resulting in a greater tendency for wastewater to be travelling under septic conditions which increases in turn increases the likelihood of microbially induced corrosion (MIC) and odour generation (Cesca, et al., 2015) (Wells, Melchers, & Bond, 2009).

MIC is a major cause of sewer deterioration and globally requires significant annual rehabilitation expenditure. Advanced corrosion can lead to unexpected catastrophic failure resulting in service interruption, environmental contamination, potentially extensive damage to surrounding roads and pavements and health and safety impacts to the larger public (Wells, Melchers, & Bond, 2009). Global rehabilitation expenditure of corroded networks is estimated to be in the magnitude of billions of dollars (Wells, Melchers, & Bond, 2009), therefore there are huge incentives to improve understanding of in-sewer processes and improve management practices.

2 MECHANISMS OF ODOUR GENERATION & CORROSION IN SEWERS

Sulphur-related compounds are the leading contributors of corrosion and odour generation within concrete sewer networks. Aqueous sulphur-related compounds in the wastewater most likely originates from domestic detergent use (Mahmood, Zheng, Cai, Yousuf, & Hassan, 2006) and enters the network in the form of sulphides, sulphates, thiosulphates and elemental sulphur (Cesca, et al., 2015). The corrosion and odour generation cycle generally begins at the depletion of dissolved oxygen within travelling sewage, which can be attributed to a lack of ventilation and long hydraulic retention times, resulting in anaerobic conditions. Sulphate-reducing bacteria present within the sewage anaerobically digest sulphates (SO_4^{2-}) in wastes into sulphides (S^{2-}).

$$SO_4^{2-} + anaerobic\ bacteria\ \longrightarrow S^{2-}$$

As sulphides rise to the wastewater surface, reactions at the liquid/gas interface and release of hydrogen sulphide (H_2S) in vapour form; the source of the sulphurous "rotten egg" odour associated with sewage.

$$S^{2-} + 2H^{+} \longrightarrow H_2S$$

Vaporous H_2S is further oxidised to sulphuric acid (H_2SO_4) by aerobic bacteria at the sewer walls, corroding the concrete pipe surface.

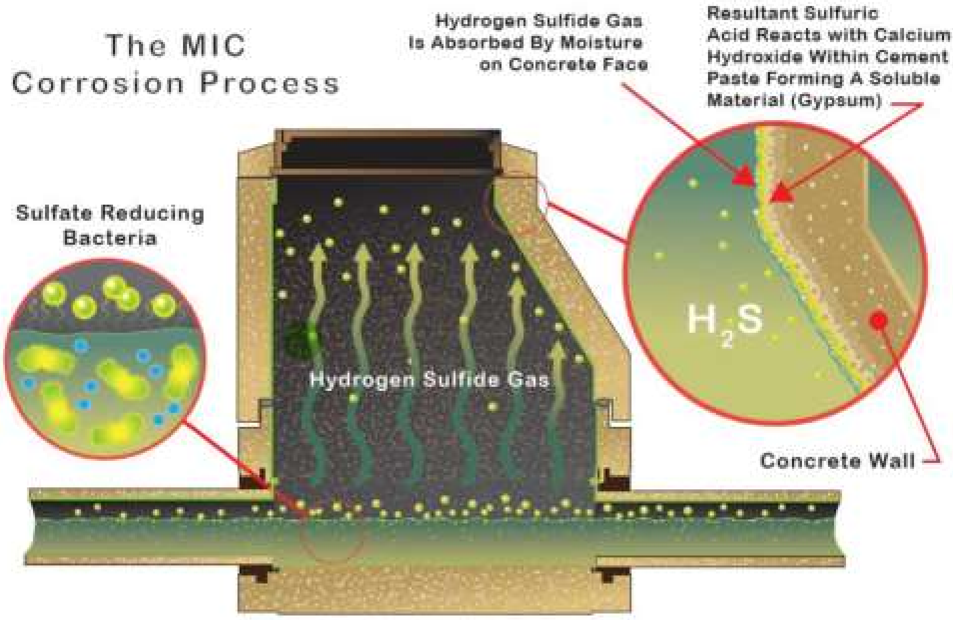
$$H_2S\ +\ 2O_2\ +\ aerobic\ bacteria\ \longrightarrow H_2SO_4$$

This process is known as microbially induced corrosion (MIC). **Error! Reference source not found.** is a schematic representation of the odour generation and corrosion process within a sewer pipe. The rate of corrosion in the sewer is influenced by the following factors:

1. The concentration of sulphides within the sewage
2. Sewage pH
3. The rate of H_2S generation at the gas/liquid interface
4. The vaporous concentration of H_2S
5. Temperatures within the sewer
6. Relative humidity in the sewer vapour space

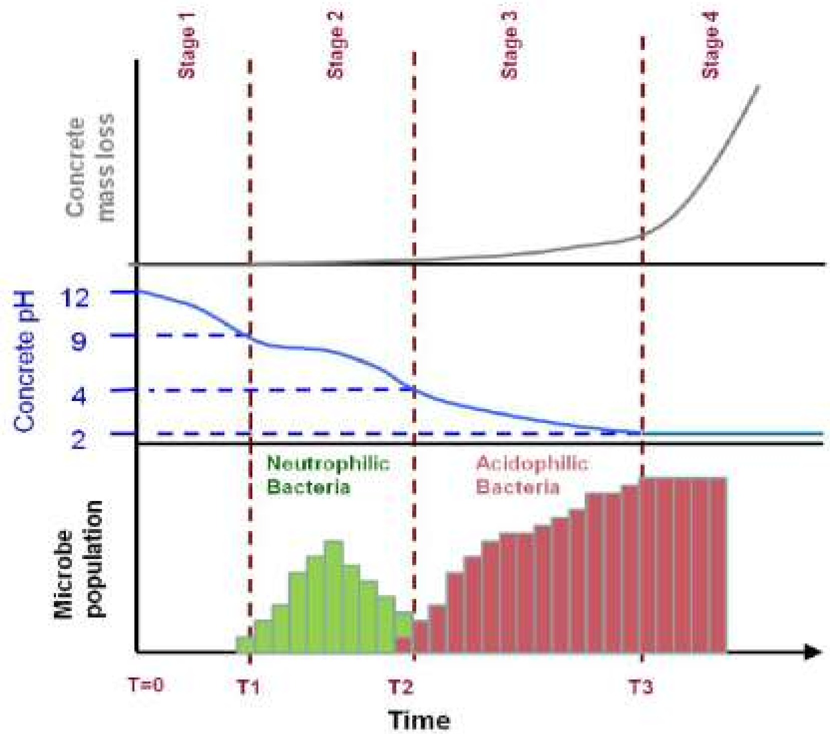
Over time, as the acid eats away at the concrete pipe wall, it can greatly reduce the design life of the asset, increasing the potential for structural damage, infrastructure collapse and contamination of surrounding areas due to sewage release (Wu, Hu, & Liu, 2018).

Figure 1: MIC Process Schematic (Grace, Kay, & Goff, 2018)



As corrosion advances in the concrete sewer wall, it does not follow a strictly linear pattern with constant rate of corrosion and mass loss taking place over time. Instead, as the concentration of sulphuric acid increases at the concrete wall face, the concrete pH decreases leading to accelerated disintegration of the concrete wall as seen in the relationships of concrete mass loss, microbe population and concrete pH in **Error! Reference source not found.**.

Figure 2: Acceleration of microbial corrosion of concrete sewer pipe (Wells, Melchers, & Bond, 2009)



In addition to H_2S, organic matter will undergo various anaerobic decomposition reactions to produce ammonia, carbon dioxide, methane and a variety of inorganic sulphates and sulphides (such as mercaptans, thioethers and sulphides).

Where there is corrosion from vaporous H_2S there will also be odour. Odour can escape from sewers via network vents and manholes into the atmosphere. H_2S is a colourless gas which can be detected by humans typically as a rotten egg odour at concentrations as low as 0.01 ppm and is fatal in higher doses. Table 1 summarises the impacts to human exposure of H_2S across low to high concentrations (Institute of Environmental Science and Research, 2019). As indicated by Table 1, excessive odour generation within sewer networks is not only a nuisance but also a potentially massive risk to public health, especially to those involved in routine maintenance and infrastructure related activities.

Table 1: Human Health Impacts of H_2S Exposure (Institute of Environmental Science and Research, 2019)

H_2S Concentration (ppm)	**Symptoms/effects**
0.01 – 1.5	Noticeable rotten egg odour
20	Fatigue Loss of appetite Headaches Memory Loss
150	Loss of smell (olfactory paralysis)
500 - 700	Staggering Serious damage to the eyes within 30 mins of exposure Death after 30 – 60 minutes Respiratory issues
1000+	Nearly instant death

3 RECENT DEVELOPMENTS IN SEWER ODOUR AND CORROSION MODELLING TECHNOLOGY

Presently there are a handful of odour and corrosion control measures being routinely used by New Zealand's water providers such as:

- Improving sewer design to limit hydraulic retention times and limit points of turbulence
- Forced ventilation
- Extraction and treatment of odour via odour treatment units.
- Chemical dosing to control aqueous sulphide concentration

The control measures listed could be effective for a limited periods, but as wastewater composition and the sewer network configuration changes over time, the ongoing costs of haphazard solutions can become unaffordable for water providers. A more strategic approach to mitigation as developed by the Australian Sewer Corrosion & Odour Research (SCORe) project could be a useful approach to solving odour and corrosion issues in New Zealand.

In 2008, the University of Queensland's Advanced Water Management Centre led a group of Australian water utilities, universities and consultancy partners in extending emerging research in sewer science and empowering utilities to make better decisions in managing corrosion and odour in their networks. The $20 M SCORe project was completed in 2013 and, produced a new and innovative set of tools listed below for optimal management of corrosion and odour problems in sewers (Nguyen, et al., 2015).

- Quantitative relationships between concrete corrosion rate and the gas phase concentrations of H2S, water, oxygen and other influencing factors
- Models predicting corrosion rate and the remaining life of sewer pipes with various degrees of corrosion, and the potential risk of sewer failure, under given environmental conditions
- Guidelines for the use of pipe coating materials
- A database of odorants from sewers, and their removal by various treatment technologies
- Guidelines for sewer ventilation
- Algorithms for the on-line control of chemical dosage for sulphide control
- New products for sulphide control in liquid phase
- Enhanced model for the prediction of sulphide generation and emission in sewers
- A model-based decision support tool (University of Queensland Advanced Water Management Centre, 2017)

The use of the SCORe projects tools and research has since been used by Australia's water utilities for planning and strategizing, to evaluate different measures of control and furthermore as an operational tool to optimise the use of control measures to mitigate corrosion and odour problems (Nguyen, et al., 2015).

In most cases it has resulted significant savings of sewer operation and maintenance costs to a number of Australian water utilities.

4 OUTCOMES OF ODOUR AND CORROSION MANAGEMENT IN AUSTRALIA

Sydney Water Corporation (SWC) and South Australian Water (SAW) are state-owned water entities servicing the greater Sydney and the South Australian region, respectively. Both entities utilised the knowledge and outcomes of the SCORe project to implement more system-wide approaches to managing odour and corrosion in their assets. This section details the common approaches of both entities in developing system-specific odour and corrosion management strategies.

Both SWC and SAW have common objectives in odour and corrosion management which are to:

- Ensure the network assets are meeting their intended design life
- Minimise whole-of-life network costs
- Improve network safety and reduce risk of adverse impacts experienced by stakeholders

At the master-planning stage, clear performance indicators for control strategies were defined to clarify what successful implementation of strategies was defined as being. SAW had the following performance indicators:

- For chemical control strategies:
  - Dissolved sulphide ≤ 0.5 mg/L
  - H_2S gas phase ≤ 5 ppm (with 95th percentile of <10 ppm).
- For air phase control strategies:
  - Odour released from the treatment system is less than 1,000 odour units (ou)
  - Air extraction system is sufficient to prevent air pressure surges in the sewer.

The methodology adopted by SWC and SAW for their respective strategies was very similar; both entities had an initial phase of gap identification and existing data review. In this phase, SAW and SWC reviewed existing network information available such as wastewater quality parameters for their systems, existing network physical and hydraulic models, and identified the data to be acquired for input into their individual sewer modelling tools.

Field data and sampling plans were drafted by both entities; SAW's data collection plan included the following parameters:

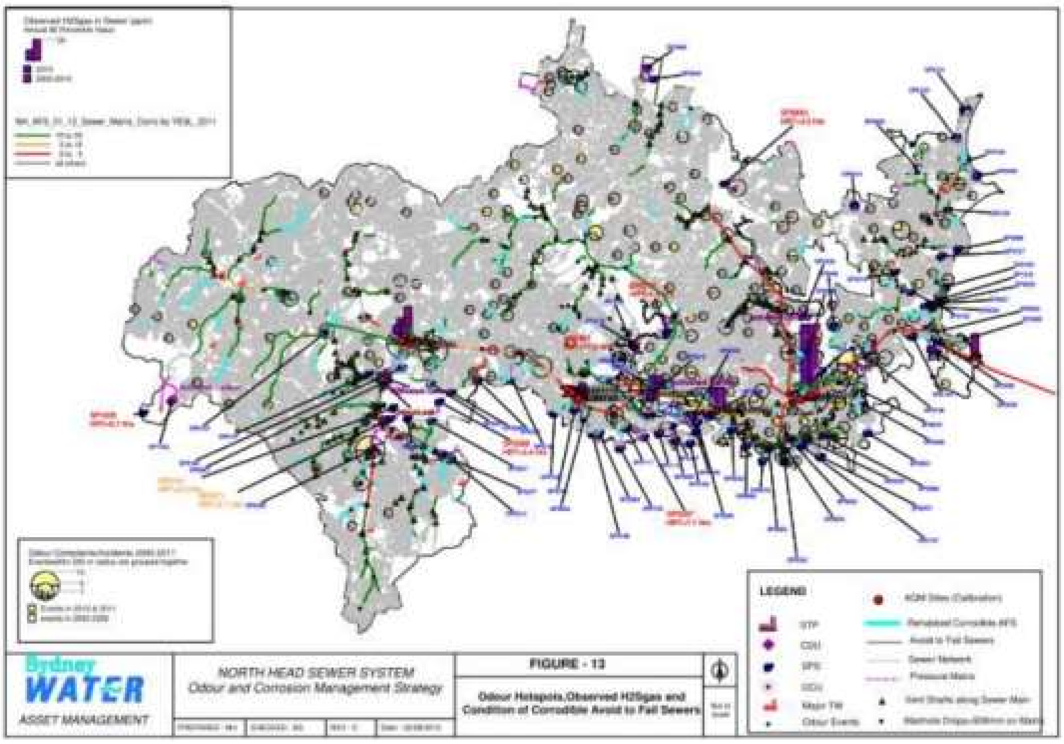
- Wastewater quality parameters: temperature, DO, COD, pH and alkalinity

- Speciation of sulphur in the aqueous phase, i.e. quantities of sulphide, sulphate, thiosulphate and elemental sulphur
- Sewer headspace measurements: air velocity, temperature, relative humidity

Data was manipulated to develop appropriate inputs to the SWC and SAW modelling tools which in a planning capacity could model the temporal and spatial variations in sulphide and various other physical, chemical and biological processes occurring within the sewer. The models would also simulate mass transfer between the liquid and gas phases which additionally develops an indicative corrosion rate relationship inside the sewer.

The models were then calibrated and compared against field measurements and operational data from CCTV inspections and customer complaints to ensure an accurate representation of the network. The resulting final model helped to identify hot spots of H_2S generation with accurate results of simulated and measured concentrations of H_2S and other parameters. **Error! Reference source not found.** is an image of the SWC model results of corrosion and odour hotspots in the central Sydney catchment.

Figure 3: SWC Odour Hotspot Modelling Results (Gonzalez, et al., 2017)



Solution optioneering was the final step carried out and modelled by both SAW and SWC to test the effectiveness in achieving the chosen parameters. SWC had shortlisted a "hierarchy of controls" (Gonzalez, et al., 2017) which were the most effective odour control measures that are known to provide immediate improvements. The expected impact of the measures listed below would be modelled in the SWC tool to evaluate the options drafted.

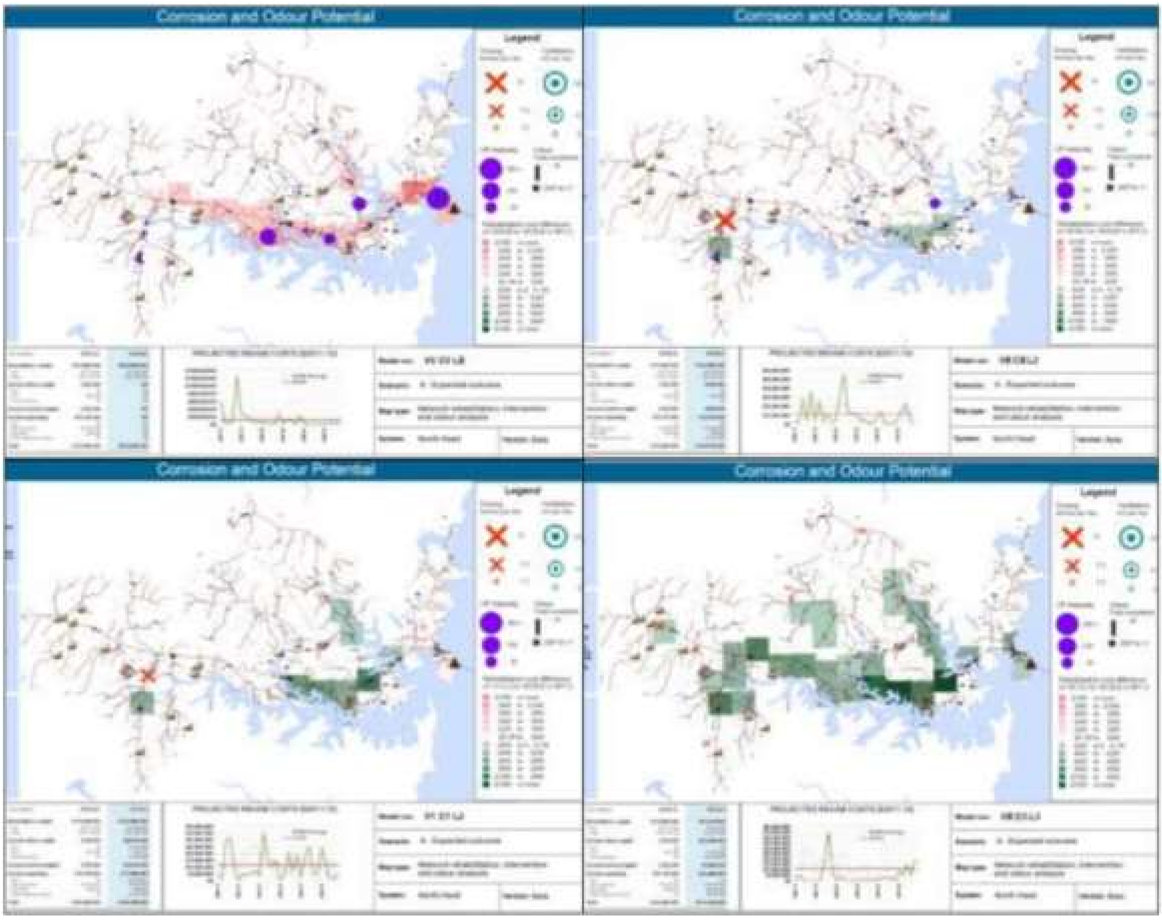
- Source control – limiting the discharge of industrial and commercial customers to < 600 mg/L BOD, pH > 7.0 and temperature < 30°C.
- Limiting hydraulic retention time (HRT) – sewer design and operation
- Limit sulphide generation – through dosing biocides, high scour velocity and flushing
- Limit sulphide transfer into the gas phase – reduced turbulence, pH adjustment dosing (e.g. $Mg(OH)_2$), precipitation dosing (e.g. iron salts), oxidative dosing (e.g. $Ca(NO_3)_2$ or O_2)
- Corrosion resistant coatings and / or materials
- Sacrificial coatings (e.g. $Mg(OH)_2$)
- Forced ventilation with foul air treatment such as:
    - Activated carbon filtration
    - Biotrickling filtration
    - Wet chemical scrubbing

Error! Reference source not found. shows the results of the SWC odour and corrosion tool model for four mitigation options, each composed of different odour control methods including ventilation, odour treatment unit installations, and chemical dosing to varying extents. The results are shown as maps of the network. The first map can be seen to have patches of red across the network, red indicating that the rehabilitation costs will be higher than the current network management practice. Where the colour is green, the rehabilitation costs will be lower than the current network management practice. The darker the colour, the larger the difference compared with the current network management practice.

The Odour Potential of certain areas is also mapped **Error! Reference source not found.** as purple circles, indicating the number of people potentially affected by odour emissions from network vents; it is the impact of the modelled H_2S concentration against the population known in that specific location.

As can be seen by the larger, deeper green coloured squares in **Error! Reference source not found.**, Option d (lower right) was the most effective solution as it was identified that in this case having multiple dosing points in the system would give a better outcome than the existing main single dosing point, without increasing the amount of chemicals dosed. The extra capital and operational costs for additional chemical dosing facilities would be readily recouped from averted sewer rehabilitation costs.

Figure 4: SWC Odour and Corrosion Mitigation Optioneering (Gonzalez, et al., 2017)



The solutions were then costed over a 30-year design period for operating and capital costs, and the net present value was calculated for the design period. The estimate included the cost of:

- Rehabilitation of the sewer pipes
- Installing new control measures
- Opex new and existing corrosion and odour measures

MCA analysis was also carried out for more robust decision making.

The use of a modelling tool in conjunction with a controls hierarchy list aided decision-making for both SWC and SAW to identify the best achievable outcome for the asset, public, and the utility.

5 APPLICATIONS IN A NEW ZEALAND CONTEXT

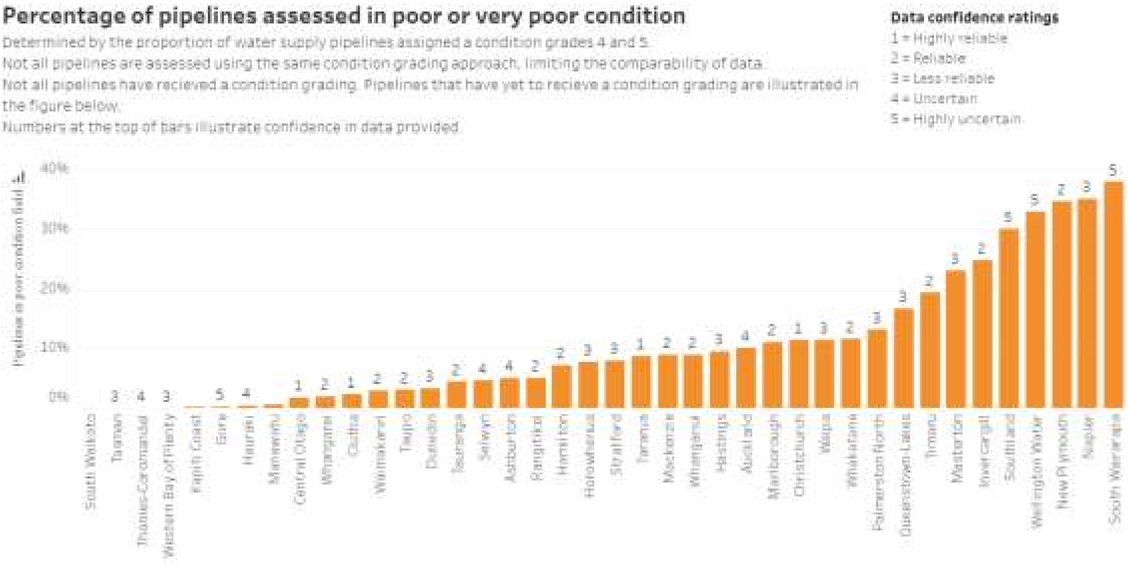
5.1 A CASE FOR CHANGE

Extending 27,057 kilometres at an estimated value of $14.5 billion (Water NZ, 2020), New Zealand's wastewater network is its most expensive water infrastructure asset. In recent years there have been a slew of network incidents in urban centres, most notoriously in Wellington. Wellington has been showcasing symptoms of chronic under-investment in its wastewater network for a number of years. A record number of 2,096 wastewater, water supply and stormwater network incidents occurred in 2020 – over 40 per week (Stuff, 2020). The most disastrous incidents have resulted in sinkholes forming in inner city roads due to collapsed underground stormwater infrastructure, raw sewage overflowing from manholes in the inner city streets and sewer and water supply pipes bursting after years of heavy corrosion damage and insufficient renewals programmes.

As Wellington has grown and sprawled its wastewater network has been underfunded, damaged and poorly understood (Stuff, 2020). Recent reporting from Wellington City Council indicates that only a third of Wellington's 2,653 km wastewater network has been assessed in the previous 15 years. It is not unreasonable to conclude that many of the aforementioned incidents can be traced back to corrosion issues within the sewer networks, lack of understanding of the biological and chemical processes that take place and a lack of consistent network assessments and repair programmes.

Data released from Water NZ's National Performance Review for 2019/2020 provides comparison of drinking water, wastewater and stormwater provision in New Zealand. **Error! Reference source not found.** is a bar chart comparison of the percentage of wastewater pipelines considered to be in poor condition in regions across New Zealand. With an estimated 35% of wastewater pipelines assessed as being in poor condition, Wellington's sewer network is the worst of all the urban centres in New Zealand, trailing behind both Auckland and Christchurch which have an estimated 10% and 15% of their wastewater pipelines in poor condition, respectively.

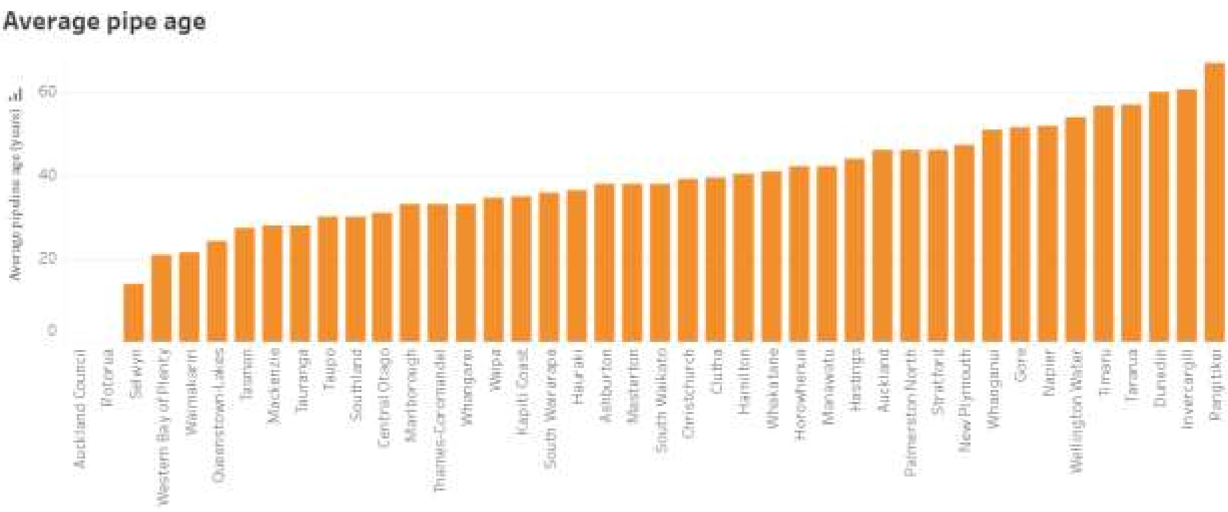
Figure 5: Condition of poor pipelines in New Zealand (Water NZ, 2020)



Another concerning factor is the lack of confidence in the data provided for urban centres. Auckland and Wellington have reported *uncertain* and *highly uncertain* confidence in data respectively, which is indicative of a lack of rehabilitation programmes, regular monitoring and inspections taking place which infers that the actual state of wastewater infrastructure is likely to be underestimated and worse than reported.

Average age of network pipes as charted in **Error! Reference source not found.**, is another parameter that is symptomatic of network health. As seen in **Error! Reference source not found.**, the median age of wastewater pipes in New Zealand is approximately 37 years. The average age of Wellington's wastewater pipes extends close to 20 years beyond the median age at ~55 years, which reinforces the concerns stated earlier in this section.

Figure 6: Average age of wastewater pipes (Water NZ, 2020)



The implication in the data captured in **Error! Reference source not found.** and **Error! Reference source not found.** is that wastewater network management has fallen in level of priority for New Zealand's major water providers. A major attributor to this being that local councils have diverted the investment needed to fund more urgent infrastructure to better position urban centres for growth. Wellington's network issues can serve as an example for the rest of New Zealand of the havoc that network deterioration and lack of regular maintenance and investment results in. It is reasonable to expect that if Wellington, as a significant urban centre where the failure of critical services like sewers brings compounded impacts, that management of odour and corrosion could be in even greater need of improvement in other parts of the country where the stakes are lower.

Elsewhere in New Zealand both network odour and corrosion issues are being dealt with in a reactive manner. In Christchurch, there has been significant investment in localised odour treatment units and extraction systems as a form of odour mitigation throughout the city. Christchurch has a flat sewer network with very long retention times, wastewater travelling through the network becomes septic under anaerobic conditions resulting in the generation of odour and accelerating corrosion downstream and at areas of high turbulence within the system. The odour units extract odorous air from trunk mains, treat to remove the H_2S present and exhaust treated air into the atmosphere. The units are often complicated systems that require high capital investments for the individual units, associated land acquisition placement and installation of extraction infrastructure increases the estimated investment to be in the range of millions. Annual operating costs also range in order of tens of thousands for monthly maintenance visits from operations personnel and replenishment of any solutions and/or material needed for the treatment systems.

Figure 7**Error! Reference source not found.** is a map of southwest Christchurch showing proposed (blue dots) and existing (yellow dots) odour treatment units servicing several sewer trunk mains. The investment seen in this image alone is likely to be in the magnitude of tens of millions of dollars. An alternative approach would be to develop a strategy to treat the issue at its root cause, using modelling of corrosion and odour generation within the network and targeted optioneering for highlighted hot spots. This way investment is optimised and the overall best value solution can be identified and implemented.

Figure 7: Proposed (blue) and existing (yellow) odour treatment units in Christchurch

5.2 A HIGH-LEVEL STARTING POINT

As part of the impending three water reforms, the 67 councils currently responsible for managing water services across New Zealand will be amalgamated into four large water entities (Stuff, 2021). Local councils, to date, have been responsible for the challenging task of:

- Provision of three waters services and additionally
- funding infrastructure deficits
- complying with safety standards and environmental expectations
- building resilience to natural hazards and
- accounting for climate change and supporting growth

The intention is that by creating singular entities for the management of water services and a comprehensive, system-wide reform will achieve lasting benefits for the local government sector, our communities, and the environment. The entities will be able to fund investments on their own accord, which will be crucial to their ability to invest in upgrades to New Zealand's ailing water networks. They'll also be able to make efficiencies that much smaller councils cannot, saving money in the long term and improve network resilience.

In regard to managing odour and corrosion, as a starting point, the four future water services providers could adopt a similar approach to SWC and SAW in master-planning for mitigation of their wastewater networks. Prior to developing system-specific odour and corrosion management strategies, a high-level entity-wide implementation structure could be similar to the following:

1. **Condition assessment of the current state of the network**: It is crucial to fully understand the state of the existing network, the extent of deterioration, estimated associated costs to replace and the costs to maintain infrastructure

2. **Define the objectives and timeline**: What exactly is it that the provider wants to achieve through this effort and what is a realistic timeframe for implementation
3. **Develop a masterplan for works required**: The future entities should undertake a master-planning exercise for odour and corrosion for their boundary of influence. It will help to consolidate and ensure a standardized approach across the entity boundaries and could involve establishing guidelines and framework for managing odour and corrosion
4. **Implementing a risk based approach**: Risk assessments are a key tool in decision-making that integrate with the strategic planning process and help to clearly articulate the incentives for change in wastewater network management
5. **Defining roles and responsibilities**: Define who will be responsible for driving, planning, approving and monitoring the portfolio of works

The capital cost in developing an entity-wide standardized structured approach and investment in modelling technologies and programme of works for odour and corrosion mitigation is expected to be significant. However, the long-term benefits of achieving common objectives such as achieving asset design life, lowering overall lifecycle costs and increasing overall system safety and lowering risk would be a sustainable and beneficial outcome for all stakeholders.

6 CONCLUSIONS

Sewer odour and corrosion issues can significantly impair and deteriorate wastewater network performance. Sewer and corrosion science knowledge and tools from the University of Queensland Advanced Water Management Centre's SCORe project have been employed by Australian water utilities such as the Sydney Water Corporation and South Australian Water to transform the management practices of their sewer networks.

A similar five-step approach can be applied in a New Zealand setting to plan for improved network, achieve design life of assets, and realise lower lifecycle costs. This can but achieved through a five-step approach:

1. Condition assessment of the asset network
2. Definition of objectives and timeline
3. Master-planning works required
4. Risk based approach to prioritising works
5. Clearly defined roles and responsibilities

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