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Wastewater Renewals Framework – Gravity Pipelines

A Quake Centre collaborative project with IPWEA and Water NZ.

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Wastewater Renewals Framework – Gravity Pipelines

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Foreword

The contribution of wastewater management to New Zealand's public health and environment cannot be underestimated. The first wastewater systems in the country were installed in 1880 in Christchurch (Dann, 2017) and were followed by a significant drop in water-borne disease (Rice, 2017).

Since then wastewater networks have been installed in all New Zealand urban centres. However, these systems are getting older. With many systems being installed in the 1960's or earlier, they are beginning to reach the end of their expected lives and significant investment in asset renewal may be required. The replacement value of New Zealand's wastewater networks is significant, being estimated to be 15.8 billion (LGNZ, 2014).

This document is intended to be a resource to assist public sector organisations make evidence-based decisions on the renewal of gravity wastewater pipelines. The document provides guidance for asset managers on the renewals process and discusses how to communicate issues related renewals planning to decision makers such as senior management or councillors, finance staff and auditors. The questions that decision makers should expect asset manager to address when proposing renewal plans are summarised.

While this document is focused on the renewal of gravity wastewater pipelines, the concepts and recommendations provided in this document are generally applicable to potable water and stormwater networks.

The document has been produced in response to the findings from the Auditor General that the "evidence base for good decision-making and learning is not consistently available. However, it needs to be" (Controller and Auditor General, 2014).

An extensive investigation was undertaken to establish how organisations of varying sizes undertake renewal planning and the commonly encountered issues and challenges.

The Renewals Framework developed in this document provides a structured process that organisations can use to plan renewals. The Framework shows how organisations can use existing data in a meaningful way. Importantly, the Framework can be scaled and modified to suit the needs of an organisations.

The Renewals Framework draws on processes and information described in the International Infrastructure Management Manual, New Zealand Asset Metadata Standards (NZAMS) and the University of Canterbury Pipeline Renewal Programme. While this document is closely aligned to the NZAMS, the advice provided can be applied independent of the NZAMS.

I believe this document advances the knowledge of renewal planning at a national level. Furthermore, it allows consistency in decision making both geographically and in scale of organisations.

I wish to thank the organisations who participated in the development of this document, providing valuable insights as well as case studies.

A special thanks also to Watercare Services Ltd who provided both funding and data sets. This project would not be possible without their help.

Greg Preston
Manager, Quake Centre (based at the University of Canterbury)

Executive Summary

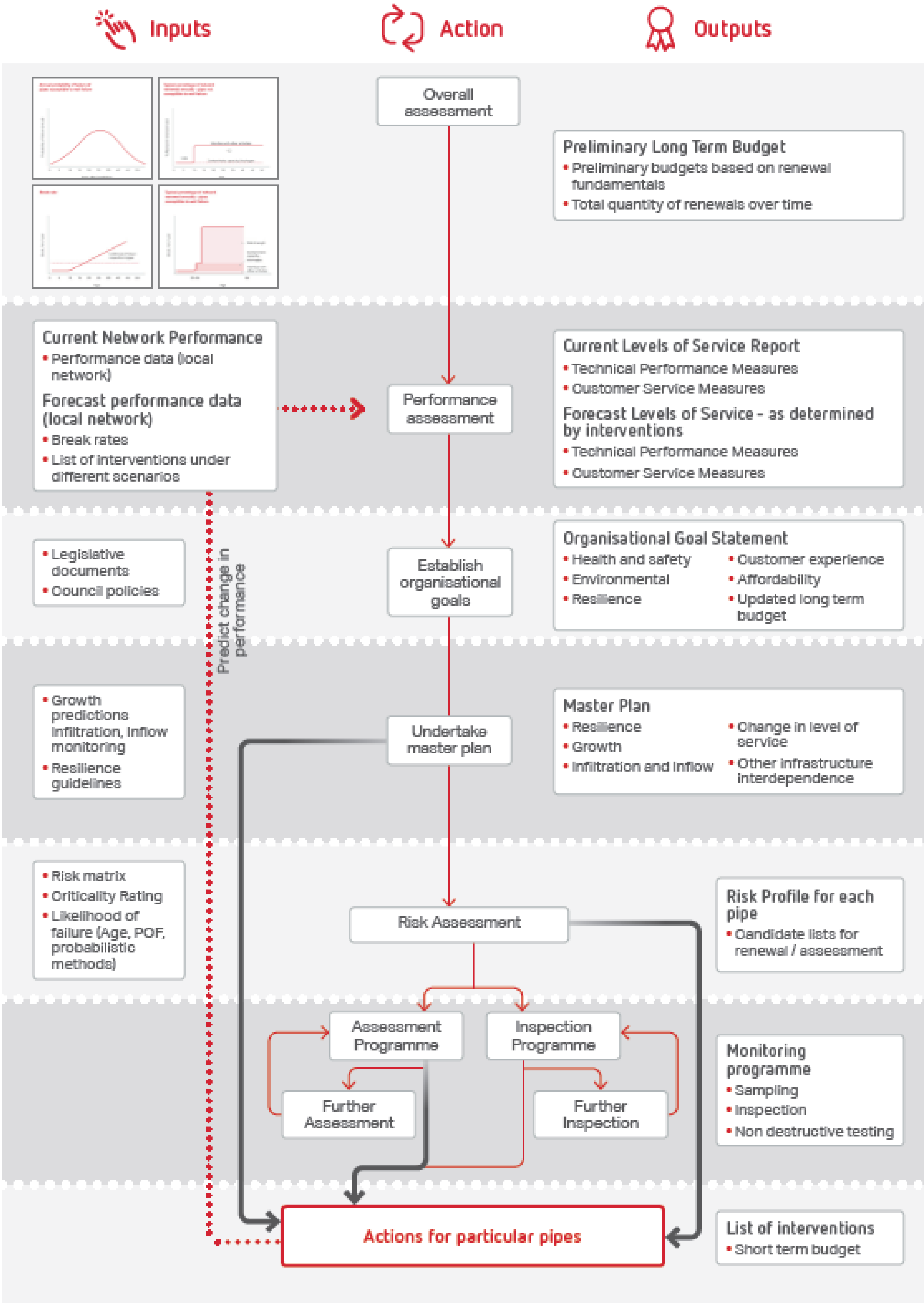
The Renewals Framework described in this document will assist asset managers undertake renewals planning of gravity wastewater pipelines from the 1-3 year horizon to the 30+ year horizon, and to communicate renewal decisions to decision makers. The output from this process is a works programme with forecasts of:

- Budgets
- Level of service predictions
- Risk & resilience profiles
- Monitoring and Condition Assessment programmes

The process involves:

1. Overall Assessment - Estimating the preliminary least cost budget, made up of:
    a. Baseload of renewals required for general containment, capacity and blockages and due to interfaces with other works such as road renewals. Indications are that between 0.2% to 0.4% of the network is renewed annually for these reasons and this is largely unrelated to the age of the network.
    b. Replacement of pipelines that are vulnerable to degradation of the pipeline wall, e.g. asbestos cement pipelines. Once asbestos cement pipelines reach 30 years old about 1.5-2% of these pipelines will fail annually and require renewal.
2. Performance Assessment
    a. Developing Level of Service Statements, identifying those aspects of service that are most important for the community. Develop performance measures and initial targets
    b. Developing a monitoring programme to determine the type and amount of data that should be collected to understand the assets that make up the wastewater network and how they are performing.
3. Master planning to identify specific pipes that are not delivering the required level of service (operational, containment or capacity issues or strength failures during shock events). Consider whether performance is likely to change in the future, e.g. due to growth. This analysis is undertaken at a network level. Identify interventions to address these issues.
4. Risk Assessment, considering the likelihood and consequence of failure to develop a list of candidate pipelines for assessment and to develop a condition assessment programme.
5. Actions on particular pipelines are determined following condition assessment and the earlier master planning.

The framework is summarised schematically in the following figure.



There are however multiple different works programmes that an organisation may adopt. Selection of the works programme depends on financial constraints, level of service improvements and the level of risk that the organisation is willing to accept. Key decision makers and stakeholders must therefore be consulted in the works programme selection. The Framework discusses how to communicate issues related renewals planning to decision makers such as senior management or councillors, finance staff and auditors. In addition, this report contains some key findings which show how condition assessment can be used to plan renewals by considering actual condition and risk of failure of the pipeline. In particular, this document presents revised estimated useful lives which generally extend the estimated useful of piplines thereby narrowing the mismatch between renewals profiles and depreciation.

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Preface

Acknowledgements

This research project was carried out by Opus International Consultants Limited. It was sponsored by the University of Canterbury Quake Centre and funded by Watercare Services Ltd. Their support is gratefully acknowledged.

The research team also acknowledges and is grateful for the contributions of the following organisation who were part of the technical group:

Auckland Council

Christchurch City Council

Citycare Ltd

IDS Ltd

Tauranga City Council

UC Quake Centre

Waimakariri District Council

Waipa District Council

Watercare Services Ltd

WaterNZ

Wellington Water

Abbreviations

AC	Asbestos Cement
CAPEX	Capital Expenditure
CCTV	Closed Circuit Television
DN	Diameter Nominal
EW	Earthenware
GIS	Geographic Information System
IIMM	International Infrastructure Management Manual

IPWEA	Institute of Public Works Engineers of Australasia
LOS	Levels of Service
LTP	Long Term Plan
NZAMS	New Zealand Asset Metadata Standards
OPEX	Operating Expenditure
PE	Polyethylene
POF	Probability of Failure
PVC	Polyvinyl Chloride
QA	Quality Assurance
UC	University of Canterbury

Units

km	kilometres
l/p/d	litres per person per day
m	metres
mm	millimetres

Definition

Intervention	Action undertaken on an asset to facilitate the provision of level of service.
Failure	Failure via the four mechanisms described

Break-out Boxes

This document provides case studies to help users better understand real-world applications of the concepts described in the Framework. This document also recognises that certain elements of the Framework require further work or new elements need to be incorporated.

Case studies and future research opportunities are denoted by the boxes below.

Case Study 0.0	Case studies are used throughout the document to provide real world examples of when the guidance was applied. Case studies are typically sourced from Local Government Organisations who successfully adopted concepts described in the Framework.

Research Opportunity 0.0	The magnifier icon denotes future research opportunities which can supplement this document. A full list of Research Opportunities is included in Appendix 1

1 Introduction

1.1 Scope

The Renewals Framework described in this document will assist asset managers undertake renewals planning of gravity wastewater pipelines from the 1-3 year horizon to the 30+ year horizon, and to communicate renewal decisions to decision makers.

1.2 Objectives

The overarching objective of this Framework is to improve pipeline renewals planning in New Zealand through evidence-based decision-making.

The Framework provides a structured way for answering the key questions that asset managers and decision makers should address when developing renewals plans for gravity wastewater pipelines.

The Framework is scalable in terms of both network size and maturity of data management practices.

This first edition of the Framework describes areas where further research is required to refine renewals predictions, identifying those areas that have the greatest impact on decision-making.

The document is intended to be the start of an ongoing process. It is envisaged that the document will be amended and added to as new renewals planning processes and uses of data are developed.

1.3 New Zealand Metadata Standards

The advice provided in this document is closely aligned to the New Zealand Metadata Standards (NZAMS), however, the advice provided is applicable independent of the NZAMS. This document emphasises the need for and use of data to provide the desired levels of service. NZAMS Volume 1 and Volume 2 provides guidance on levels of service and the collection of data. The NZAMS provides a nationally applicable reference point which is accessible to all organisations hence alignment to it will allow a more consistent renewals planning. The guidance provided in the NZAMS is based on asset management best practice hence much of the guidance will already be used regardless of a formal adoption of the standard. The guidance provided in this document can be practiced without formal adoption of the NZAMS.

2 Background

The Renewal Planning Framework in this document draws together material and processes from the International Infrastructure Management Manual (IIMM), the New Zealand Asset Metadata Standards (NZAMS) project, the Quake Centre/Water NZ/IPWEA NZ's Pipe Renewals Programme and existing practices used in New Zealand. It shows how these processes can be used to make evidence-based decision-making.

2.1 New Zealand context

In 2014, the total replacement value of the 3 waters assets in New Zealand was estimated at approximately NZ$35.7 billion. The wastewater network had the highest replacement value at around NZ$15.8 billion (LGNZ, 2014). Many of these assets are nearing the end of their design lives and might need to be replaced in the next couple of decades.

There is a disconnect between predicted renewals expenditure and the amount that local authorities are depreciating. The Auditor General (2014) identified that during the period between 2007 to 2013, local authorities consistently spent less than they intended on capital works (3 waters and roading), including on asset renewals. If actual spending trends continue to match those forecast, the Auditor General estimates that by 2022, the gap between asset renewals expenditure and depreciation for the local government sector could be between $6 billion and $7 billion (Controller and Auditor General, 2014).

This raises the question, are New Zealand communities in the future going to be faced with significant liabilities to renew assets or is too much money being allowed for depreciation of 3 water assets, thereby diverting funds away from other productive uses.

2.2 Local Government Act – infrastructure strategy

The Local Government Act was amended in 2014 to require local authorities to produce an infrastructure strategy to provide more transparency around infrastructure planning and to help bridge the gap between infrastructure planning and renewals planning. The infrastructure strategy is required to identify significant infrastructure issues that councils are likely to face, the principal options for managing those issues, and the implications of those options. It is required to cover a period of at least the next 30 years.

Infrastructure strategies are required to include:

- indicative estimates of the projected capital and operating expenditure requirements (shown for each of the first 10 years covered by the strategy, and subsequently in periods of five years)

- the significant capital expenditure decisions that the council expects to have to make, when those decisions are expected, approximate magnitude of the costs associated with each decision and the principal options
- assumptions about service levels and asset life-cycles on which scenarios are based
- where assumptions involve significant uncertainty, the nature of that uncertainty and its potential impacts.

Most infrastructure strategies completed in the first round in 2015 took an age-based approach to pipeline renewals planning. They did not consider the implication of different investment strategies on service levels.

2.3 New Zealand Asset Metadata Standards

The Auditor General (2014) observed that the "although local and central government authorities tend to have a lot of data, there is little evident to suggest they use the best data to support decision-making."

The NZAMS Project commenced in 2016 to address this issue. New Zealand Asset Metadata Standard Volumes 1 (New Zealand Treasury – National Infrastructure Unit, 2017) and Volume 2 (New Zealand Treasury – National Infrastructure Unit, 2017) were released in August 2017.

Volume 1 and Volume 2 cover:

- **Volume 1** As-constructed / As-built – describes the data to be captured at the creation of a new asset, at an asset ID (component) level.
- **Volume 2** Asset Management and Performance – describes the decision elements required for making evidenced-based investment decisions.

It is intended that, over time, the industry will develop additional volumes that address:

- **Volume 3** Intervention Methodologies – will describe intervention methodologies to determine the current state and performance of assets.
- **Volume 4** Evidenced-based Investment Decision-Making Analytics – will include analytical methods to predict the condition and performance of assets, to determine when and where to undertake the interventions described in Volume 3 and to assess the implications of adopting alternative investment strategies on cost, risk and level of service.
- **Volume 5** The Management Framework – will cover the overarching legislation & regulation, policies, procedures and guidelines for infrastructure management.

The global asset metadata schema is shown in Figure 2-1. The Renewals Planning Framework developed in this document will form part of Volume 4.

When fully implemented the NZAMS project will enable good information to be built from data that:

- has consistent definitions and metadata, and is high quality
- is used to look at trends and to compare organisations and jurisdictions
- is studied alongside other sets of information to identify wider implications and needs.

However, it may take many years for the project to be fully implemented. Councils are currently asking how they can derive benefits from the project in the short term, what data should they collect on existing assets and what is the purpose of collecting this data.

The Renewals Framework described in this document is one step in providing value from existing data, demonstrating how data can be incorporated into the decision-making process and highlighting which data has the biggest impact on decision making.

Research Opportunity 2.1	**Metadata standards development and application** It is proposed that industry/academic workshops be undertaken to define the pathways for implementing the NZAMS. This includes the process for developing the yet-to-be written volumes 3 and 4 of the Metadata Standards on Intervention Strategies and Analytics. It also includes re-working Volume 2 into a workable and pragmatic document based on Industry feedback.

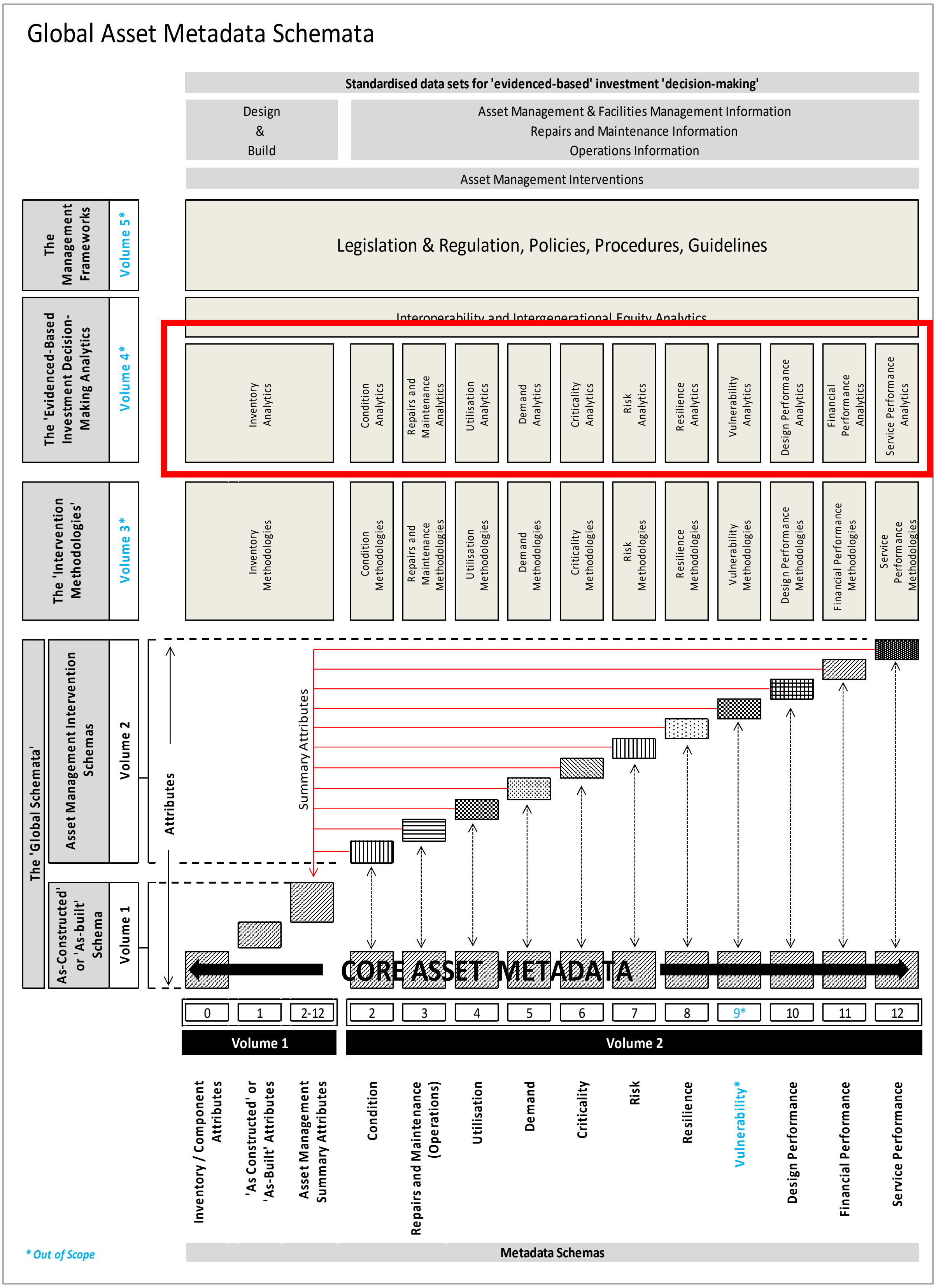


Figure 2-1: Global asset metadata schema

2.4 International infrastructure management manual

The International Infrastructure Management Manual (IIMM) provides guidelines and examples on asset management of infrastructure assets. It describes the overall framework and process. As such it can be seen to be a component of NZAMS Volume 5 of the Metadata Framework, i.e. the Management Framework.

However, the IIMM does not attempt to define specific intervention methodologies or analytical methods. It expects that issues such as the methodology for assessing the condition of pipelines or how to predict the deterioration of pipelines will be covered elsewhere, i.e. NZAMS Volumes 3 & 4.

2.5 Pipeline renewals guidelines programme

The Renewals Framework described in this document is a component of the Pipe Renewals Guidelines Programme being managed by the Quake Centre. This programme concentrates on the analysis of data to improve the understanding of the behaviour of pipelines, the development of analytics to predict future performance and the development of an asset management framework specifically tailored to pipelines in 3 Waters networks, i.e. NZAMS Volumes 3 & 4. A report prepared in 2016 sets out several projects that could be undertaken to achieve the objectives of the program (Quake Centre, 2016).

3 Key Questions for Asset Managers

In developing renewal plans, asset managers should be able address the following key questions:

- How is the system currently performing compared to targets? Refer Section 7.
- How will pipelines deteriorate into the future and how will performance be affected? Refer Section 8.
- What is the most appropriate intervention to undertake given immediate and future considerations, e.g. which pipelines should be repaired, renewed, rehabilitated, upsized or inspected? Refer Section 9.
- What is the most appropriate renewals mix to adopt in the future to optimise risk, cost, level of service and resilience considerations? Refer Section 9.
- How should performance be monitored to determine the current level of performance and assess whether the system is behaving in line with expectations? Refer Section 7.

Having undertaken their analysis, asset managers need to communicate the following to key stakeholders:

Decision makers (senior management, councillors and public)

- What are the key issues influencing renewal of pipelines?
- What options are available to address the key issues?
- At the proposed renewals spend, will the system perform better, worse or the same in the future?
- At the proposed renewals spend, what are the risks and potential consequences?

Operational teams

- What is the basis of the strategy, how is the system expected to behave and what are the key risks?
- What data is required to be collected to inform renewals decisions and why is that required?

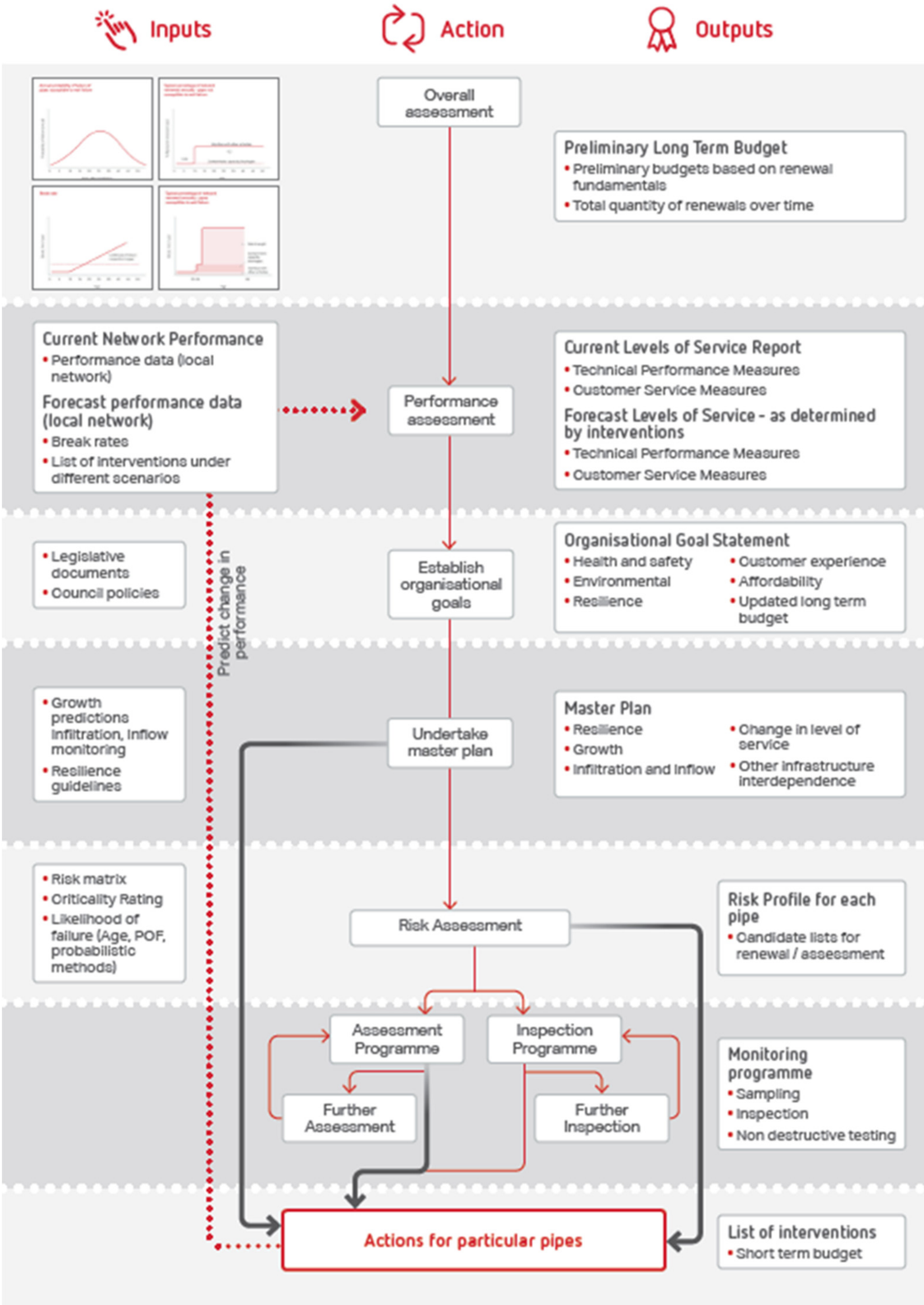
Finance section

- What is the future renewals budget?
- What is the remaining life of the assets and their replacement value (to enable assets to be valued and depreciation rates determined)?

- How will the renewals strategy impact Opex spending and Capex spending to address growth, level of service, public health and environmental impacts?
- How might assumptions and uncertainties affect future budgets?

Auditors

- Are the proposed renewals strategies and financial plans appropriate?
- Is depreciation in line with planned renewals expenditure guidance provided in the Framework?



4 Key Renewal Concepts

4.1 What is pipeline renewal?

Renewal is a form of intervention by which a pipeline is replaced to enable the required levels of service to be provided within risk and economic constraints.

Pipeline renewal is only one of many interventions available to asset managers. Examples of other interventions include repairs, rehabilitation and maintenance. More details are provided in Section 9.

The selection and timing of interventions affects levels of service, risk and maintenance expenditure as well as renewals budgets.

4.2 What is pipeline renewal planning?

Renewal planning involves determining when renewal is the most appropriate intervention.

The generic approach to renewal planning is to identify a list of candidate assets that may require intervention then to undertake performance and/or condition assessment to determine which of those assets require intervention and to determine the most appropriate type of intervention and the timing of intervention.

Renewal planning is undertaken at horizons ranging from 1 year to beyond 50 years as shown in Table 4-1. In the short term, the focus is on identifying specific assets requiring attention and determining specific actions to be undertaken and confirming budgets. The medium term is focused on preparing candidate lists and liaising with other parties to coordinate upgrades, e.g. coordinating renewals works with road upgrades. Longer term, the focus is on establishing strategies for managing assets, developing budgets, determining depreciation rates and developing monitoring programmes. Medium and long-term planning also considers how circumstances, such as growth and levels of service, may change in the future.

Table 4-1 : Renewal planning time horizons, objectives and outputs

Planning Cycle[1]	Comment[1]	Objectives	Outputs
50+ years	Outside 30-year Infrastructure Planning Cycle	Establish strategies for managing assets	Input into Infrastructure Strategy[2]
30–50 years	Outside 30-year Infrastructure Planning Cycle		
11-30 years	Inside 30-year Infrastructure Planning Cycle but outside Long-Term Plan (LTP) 3-year cycle		**Infrastructure Strategy** ▪ Principal options for intervention ▪ Most likely renewals strategy ▪ The significant decisions that will impact on renewals planning and when it is expected that these decisions will need to be made. ▪ Indicative estimates of projected capital and operating expenditure, reported at 5-year periods. ▪ Assumptions about life cycle of significant assets, growth (or decline in demand), increases (or decreases) in level of service ▪ The nature of uncertainties and the potential effects of uncertainties

[1] The planning cycle periods and comments are from Code List 8 of Vol2 of the NZ Metadata standards for Wastewater

[2] Consideration of periods beyond 30 years is not a requirement of the Local Government Act but is good practice for long life assets such as wastewater pipelines.

Planning Cycle[1]	Comment[1]	Objectives	Outputs
4–10 years	Inside 10-year Planning Cycle but outside Long-Term Plan (LTP) 3-year planning cycle	Develop candidate list for renewals. Coordinate with managers of associated assets, i.e., roads.	**Long-Term Plan** ▪ Principal options for intervention ▪ Resilience assessments and improvements ▪ Proposed renewals strategy ▪ Candidate pipelines that may require renewal ▪ Monitoring and assessment programme to identify which candidate pipelines require renewal ▪ Estimates of projected capital and operating expenditure for each year. ▪ Assumptions ▪ The nature of uncertainties and the potential effects of uncertainties
1-3 years	Inside Long Term Plan (LTP) 3-year Planning Cycle	Identify specific assets requiring attention and the specific actions to be undertaken	**Annual Plan** ▪ Work programmes specifying specific interventions to be undertaken on particular pipelines and the timing of these works. ▪ Annual Budget for capital and operating expenditure

4.3 Why renew pipelines?

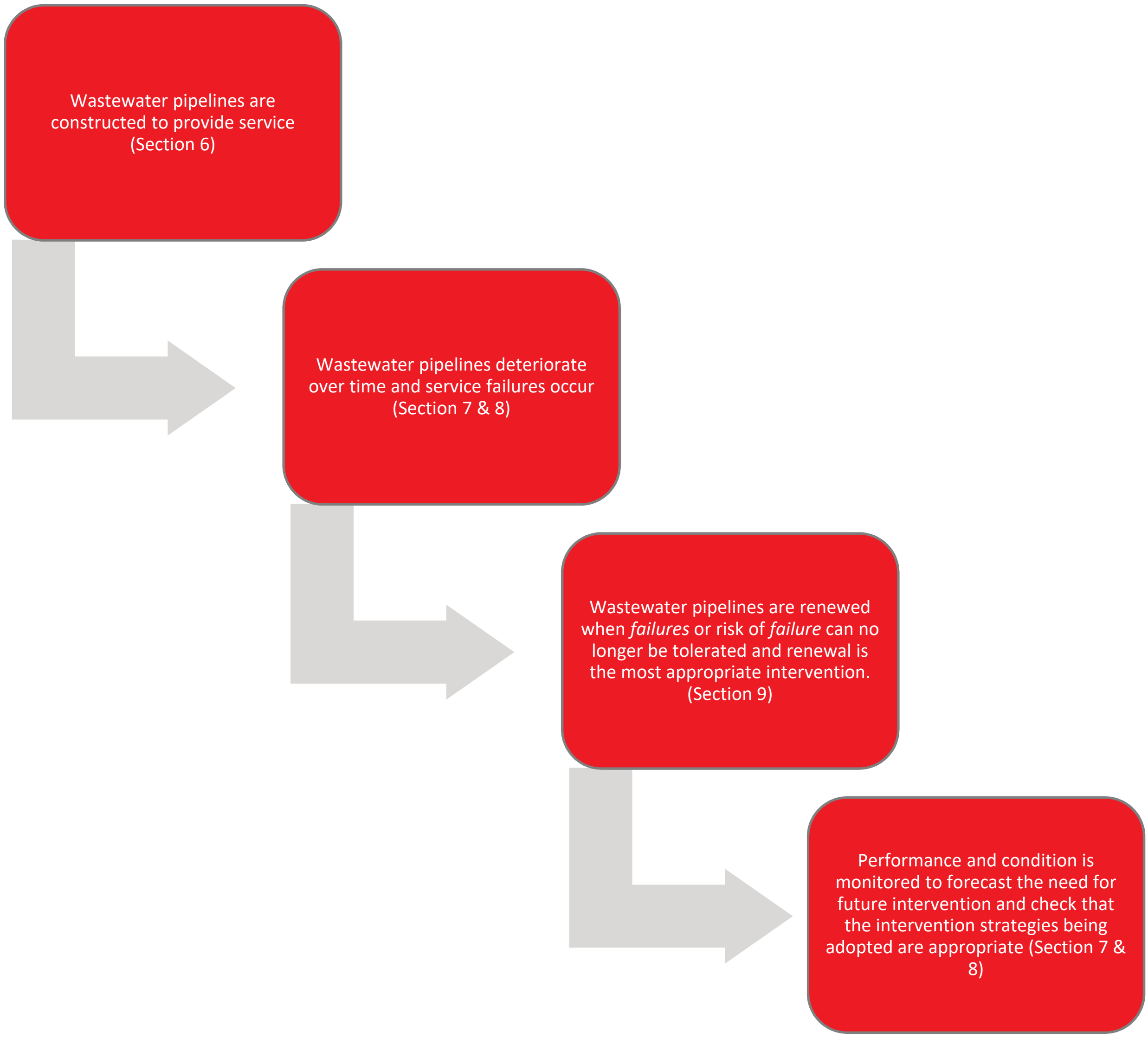


Figure 4-1 : Key renewal concepts

Figure 4-1 provides a simplified model of why pipeline renewal is required. Key concepts are:

- Pipelines are constructed to provide a service. The service required from a pipeline is described in the service attributes included in the NZAMS. The amount of service required to be provided is defined by the levels of service (and related customer and technical measures) that an organisation establishes.

- As pipelines age, they deteriorate. The rate of deterioration is affected by various factors such as pipe material, size and construction methods. This may result in the occurrence of periods when pipelines fail to provide the required levels of service.
- When pipes fail, they can generally be repaired. However, they should be renewed when the rate of failure, or the risk of failure becomes too high.
- The performance of the network should be monitored to forecast the need for renewal or repair in the future and to confirm that the intervention strategies being adopted are having the intended effect.

5 Pipe Renewal Framework

The Framework below provides a systematic approach to pipeline renewal planning. Each module is comprised of several decisions and processes. Some processes cross multiple modules. Each module is explained in greater detail in this document.

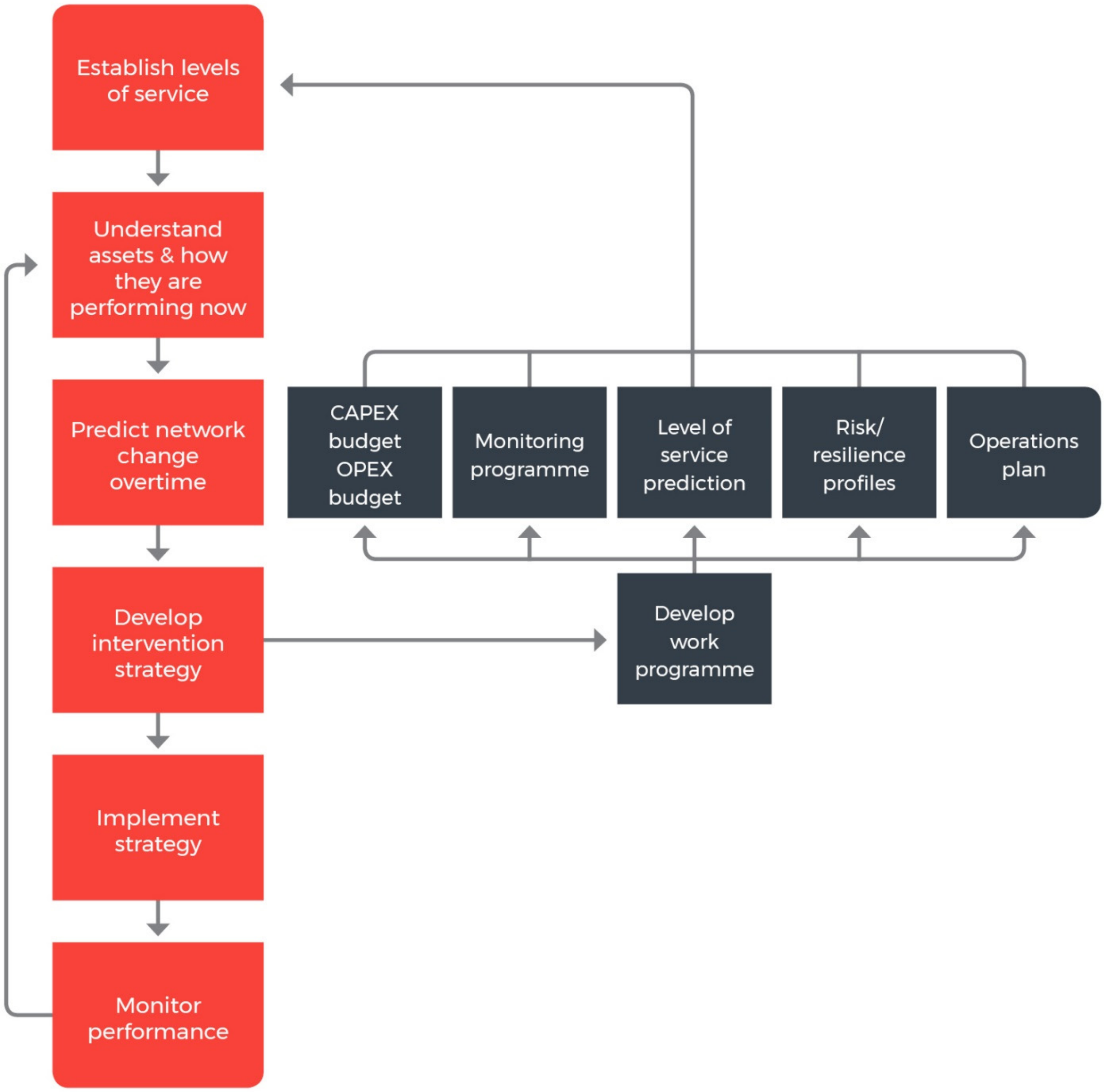


Figure 5-1 Pipe Renewal Framework

6 Establish Levels of Service and Performance Measures

6.1 Introduction

The service provided via wastewater systems benefits public health and the health of the environment within which we live, contributing to the wellbeing of our communities. But this service comes at a cost. Service levels will therefore vary from community to community depending on the circumstances of the community and the level of resources able to be allocated to the wastewater system, given other competing areas of expenditure.

This section discusses service attributes, levels of service and customer performance measures for wastewater systems. Subsequent sections outline how pipe renewals contribute to the performance of the network.

Providing clear line of sight between pipeline renewals, what is measured, and the levels of services provided enables pipe renewals to be concentrated on those areas that have the greatest impact on community wellbeing.

The process steps are:

- Develop level of service statements, identifying those aspects of service that are most important for the community
- Develop performance measures and initial targets

6.1.1 Alignment to the NZAMS

The following sections, and this document in general, are closely aligned to the NZAMS. However, the advice provided is applicable independent of the NZAMS. The levels of service, technical and performance measures advice detailed in the NZAMS generally reflect best practice for management of pipelines. Users will find that some or most of the advice detailed in the NZAMS will already be in use or be applicable to their pipe network regardless of formal adoption of the NZAMS.

6.2 Levels of service framework

Levels of service are the link between higher level corporate objectives and more detailed operational objectives. Levels of service reflect the community's expectations and preferences. They should be aligned to the organisation's vision and community outcomes. The IIMM describes a levels of service framework covering:

- Service attributes – the aspects or characteristics of service, e.g. reliability.
- Levels of service – what the organisation intends to deliver, e.g. service outages and their impact on customers and the community are minimised.
- Performance measures – from customer and technical aspects.

Levels of service and performance measures are used to:

- Inform customers of the current level of service being provided and any proposed changes to level of service and the associated cost
- Measure performance against these defined levels of service
- Develop asset management strategies to deliver the required level of service
- Identify the costs and benefits of the services
- Enable customers to consider the level of service provided within the context of affordability. (IPWEA, 2015)

6.3 Service attributes

The objective of providing wastewater service is to "*facilitate public and environmental health through the removal, treatment and disposal of wastewater*" (New Zealand Treasury – National Infrastructure Unit, 2017).

This objective can be further described using the wastewater service attributes listed below and the level of service statements outlined in Table 6-1 which is an extract from the NZAMS:

- Provision of service
- Health and safety
- Cultural
- Resilience
- Financial

- Environmental
- Governance

6.4 Developing levels of service statements

"Levels of Service are the parameters or combination of parameters that reflect social, political, economic and environmental outcomes that the organisation delivers" (IPWEA, 2015).

Levels of service describe what the organisation intends to deliver. They identify the key organisation drivers that influence asset management and renewal decisions.

Table 6-1 presents the levels of service set forth in the NZAMS for wastewater service. The levels of service presented in the table are applicable to all wastewater services in New Zealand and can be supplemented and modified to meet organisation specific requirements.

Table 6-1 : Wastewater Service Attributes (New Zealand Treasury – National Infrastructure Unit, 2017)

Service Attributes	Levels of Service
Provision of service	
Provision	Supply is provided to the customers that the organisation has deemed it appropriate to service. Under the Local Government Act 2002, organisations are required to consult with their communities and decide which areas will be serviced with reticulated wastewater and what level of service will be provided.
Quantity	Customers are able to discharge the amount and type of wastewater to the level deemed appropriate by the organisation.
Reliability	Service outages and their impact on customers and the community are minimised.
Health and safety	
Public health	Public health risks associated with wastewater are minimised.

Service Attributes	Levels of Service
Safety	Assets are operated and managed in a manner that is safe for network operators and suppliers who maintain the network, as well as the community who live, work and play alongside the network.
Cultural	
Heritage	Our heritage and taonga (treasured resources) are not adversely affected by the operation and maintenance of assets.
Culture	The wastewater system operates in a manner that respects the beliefs of our people and does not negatively affect their ability to participate in cultural practices.
Resilience	
Resilience	The ability of an asset to recover from disruption to deliver the service as intended in its design.
Financial	
Financial sustainability	The assets enable service to be provided in a financially sustainable manner for both the present and the future.
Financial impact on stakeholder	Providing service in a manner that does not have a negative financial impact on stakeholders.
Environmental	
Environmental impact	The asset enables the system to be operated in a manner that minimises environmental impact and nuisance to the community.
Governance	
Reputation	The asset enables the system to be operated in a manner that enables the organisation to maintain a good reputation within the community.
Compliance	Assets are operated and managed in a manner that complies with legislation and regulations.

The service attributes and the level of service statements above apply to all wastewater systems. However, organisations do not necessarily need to focus on all service attributes equally.

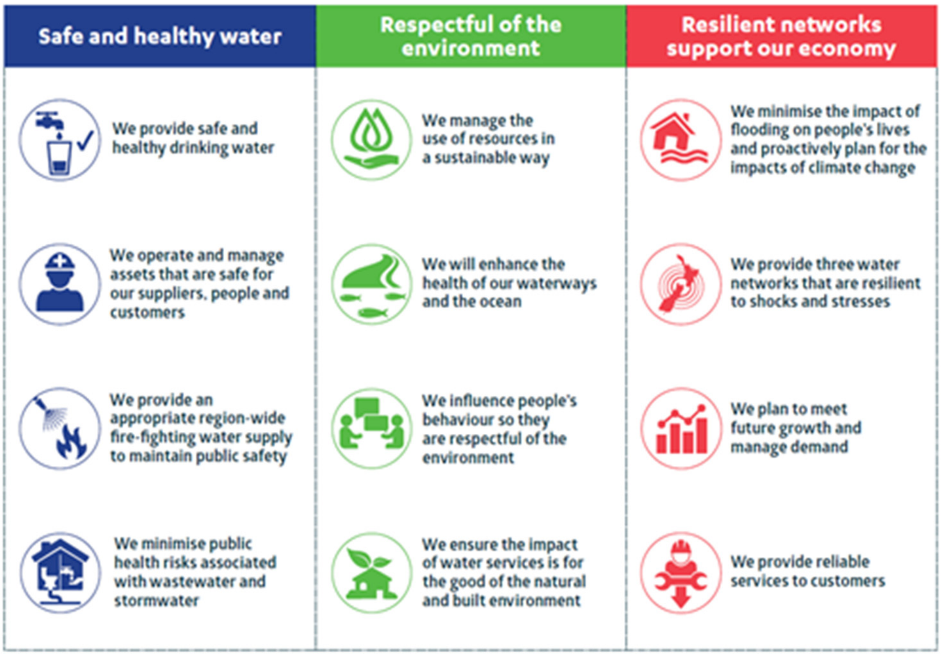
Service priorities will vary between organisations based on the unique requirements and operating parameters of the organisation. Organisations should consult with customers and stakeholders on the service attributes described in the NZAMS and identify those service attributes that have the biggest impact on community wellbeing. They should then concentrate their efforts on improving the performance of those attributes.

Case Studies 6.1 and 6.2 present two examples of level of service statements that describe those aspects of service that are most important to the communities that the organisations serve.

Case Study 6.1

Wellington Water Levels of Service

Wellington Water has developed the following Service Goals which are used to prioritise investment. Progress towards the achievement of these goals is regularly reported.



Case Study 6.2

Waimakariri District Council Levels of Service

The table below shows the levels of service that Waimakariri District Council use to monitor the performance of their wastewater network. The table highlights line of sight between the NZAMS service attributes, levels of service and community outcomes.

Community Outcomes	Level of Service	NZAMS Service Attribute
Core utility services are provided in a timely, sustainable and affordable manner	System Adequacy *The sewerage system is adequately sized and maintained.*	Provision Quantity
Harm to the environment from sewage and stormwater discharges is minimised.	Discharge Compliance *The treatment and disposal of sewage is managed in accordance with consent conditions.*	Environmental Impact
Sewerage schemes, community water supplies and storm water drainage provided are of a high standard.	Response to Sewerage System Faults *The sewerage system is actively maintained, and faults promptly attended to.*	Reliability
Harm to the environment from the spread of contaminants into ground and water is minimised.	Customer Satisfaction *The wastewater system is managed to an appropriate quality of service.*	

6.5 Performance measures

"What gets measured gets managed." William Thomson

The IIMM describes two categories of performance measures:

- **Customer performance measures**

  How the customer receives or experiences the service, e.g. the number of blockages reported at the same address in a given year.

- **Technical performance measures**

  What the organisation does to deliver service. These provide further context to customer performance measures and help predict how performance will change in the future. Average condition of network is an example of a technical performance measure.

Volume 2 of NZAMS defines a full set of attributes for describing how pipelines and the network are performing, both from a customer and technical perspective. Monitoring performance against these measures provides indications of potential problems which may require pipelines to be renewed.

The schema in Volume 2 are grouped into four cohorts as shown below and in Figure 6-1.

- **Network** Includes Condition, and Repairs, Maintenance and Operations schema
- **Capacity** Includes Utilisation and Demand schema
- **Sensitivity** Includes Criticality, Vulnerability, Risk and Resilience schema
- **Performance** Includes Design Performance, Financial Performance and Service Performance schema

Table 6-2 maps the customer and technical performance measures in the NZAMS to the service attributes. To identify which performance measures to monitor, asset managers should firstly identify the service attributes that have the greatest impact on their communities. Then identify the performance measures relevant to those service attributes. They should then assign initial targets. Monitoring of the performance measures and refinement of target are discussed in subsequent sections.

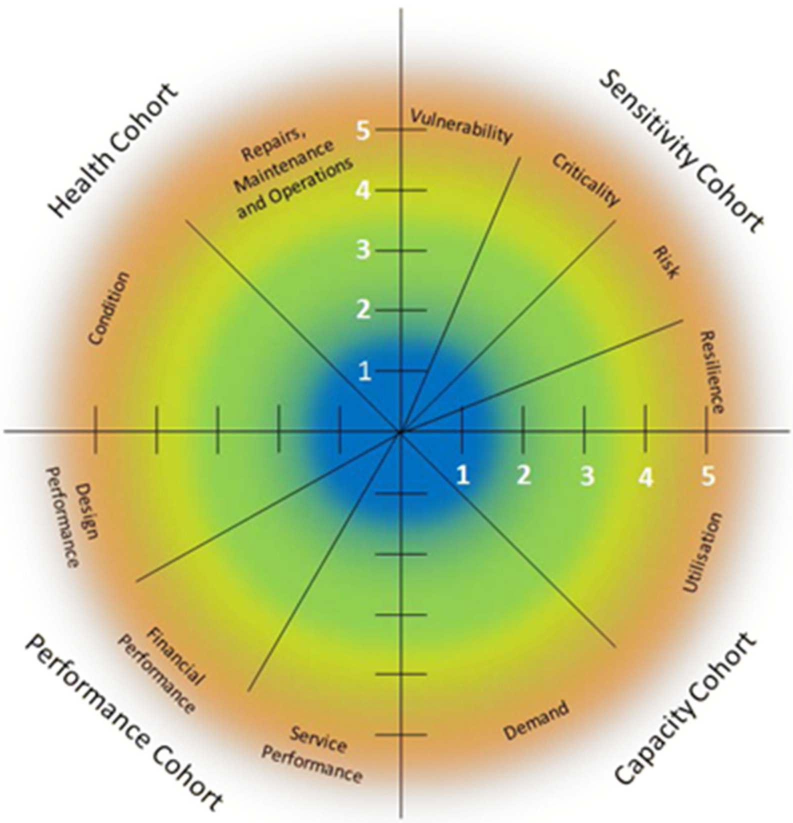


Figure 6-1 Decision-making Cohorts (New Zealand Treasury – National Infrastructure Unit, 2017)

Research Opportunity 6.1	**Measuring resilience** Processes for measuring and reporting the resilience of pipe networks are not well defined. The Pipe Renewals Resilience Project, commissioned by the UC Quake Centre, will develop a framework for developing and reporting on resilience for a variety of natural hazards.

Research Opportunity 6.2	**Testing of resilience measurement processes** Industry group to assess applicability/usefulness and gaps of process developed from Research Opportunity 6.1

Table 6-2 NZAMS Volume 2 schema relevance to service attributes

Customer Measure	Technical Measure	Provision	Quantity	Reliability	Public Health	Safety	Heritage	Culture	Resilience	Financial	Financial Impact	Environmental	Reputation	Compliance
Condition														
	Condition rating (1-5)			✓										
Repairs, maintenance and Operations														
Outage Duration				✓									✓	
Outage Number (number of people affected)				✓									✓	
Uncontrolled wet weather overflows (number of occurrences)					✓							✓	✓	
Controlled Wet Weather Overflows (number)					✓							✓	✓	
Overflow volume					✓									
Predicted overflows (number of occurrences)												✓	✓	
	Consent Compliance													✓

Customer Measure	Technical Measure	Provision	Quantity	Reliability	Public Health	Safety	Heritage	Culture	Resilience	Financial	Financial Impact	Environmental	Reputation	Compliance
Dry weather overflow (number of occurrences)			✓									✓	✓	
Repeat Dry Weather overflow (number)					✓							✓	✓	
Complaint Type (number)													✓	
Utilisation														
	Utilisation Average Day		✓											
	Utilisation Peak Hour		✓											
Demand														
	Total Connections (no of connections to asset)	✓												
	Average Hourly Demand	✓												
	Average Daily Demand	✓												
	Peak Hourly Demand	✓												
	Peak Daily Demand	✓												

Customer Measure	Technical Measure	Provision	Quantity	Reliability	Public Health	Safety	Heritage	Culture	Resilience	Financial	Financial Impact	Environmental	Reputation	Compliance
Vulnerability														
	Vulnerability Rating			✓					✓					
Criticality														
	Criticality rating			✓										
Risk														
	Risk Rating Overall			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Overall Likelihood Rating			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Consequence Rating Overall			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Resilience														
	Resilience Rating								✓		✓		✓	
Design Performance														

Customer Measure	Technical Measure	Provision	Quantity	Reliability	Public Health	Safety	Heritage	Culture	Resilience	Financial	Financial Impact	Environmental	Reputation	Compliance
	Actual Performance Primary Measurement (flowrate m^3/s)		✓											
Financial Performance														
	Revenue Amount The amount of annual revenue (excl. GST) that can be derived from utilisation of the asset (Connection Point / Zone)										✓			
	Tax Depreciation Rate										✓			
	Valuation Amount										✓			
Service Performance														
Cultural significance rating								✓					✓	
Number of repeat blockages reported at the same address (defined as 2 or more blockages) in a given year				✓										

Customer Measure	**Technical Measure**	**Provision**	**Quantity**	**Reliability**	**Public Health**	**Safety**	**Heritage**	**Culture**	**Resilience**	**Financial**	**Financial Impact**	**Environmental**	**Reputation**	**Compliance**
Residential Charges											✓			
The current recreational risk rating from the LAWA (Land Air Water Aotearoa) framework for beach water quality												✓	✓	
The current recreational risk rating (as a 1 to 4 rating) from the LAWA (Land Air Water Aotearoa) framework for river water quality												✓	✓	
Percentage of urban population connected to system		✓												
Are there cultural considerations in this network / zone?								✓					✓	
The number of complaints received per 1,000 connections by the local authority about sewage odour													✓	✓

Customer Measure	Technical Measure	Provision	Quantity	Reliability	Public Health	Safety	Heritage	Culture	Resilience	Financial	Financial Impact	Environmental	Reputation	Compliance
Are there cultural considerations for the iwi relating to Life Force								✓					✓	
Are there cultural considerations for the iwi relating to Spiritual								✓					✓	
Are there cultural considerations for the iwi relating to Sustenance								✓					✓	

7 Understand the Assets and How They Are Performing

7.1 Introduction

Having established the levels of service the wastewater system is required to deliver; the next step is to understand what assets the organisation owns and establish how the network and the assets within it are performing.

This enables asset managers to:

- Identify pipelines that require attention in the short term
- Predict how the network will degrade over time
- Estimate the amount of work that may be required in the future and to develop intervention and renewal strategies to ensure that the network continues to deliver acceptable levels of service.

Ongoing monitoring enables asset managers to check that intervention strategies are having the desired effect and provides early warning of departures from assumed behaviour.

Asset knowledge and performance monitoring is also required to:

- Satisfy legislative requirements, e.g. asset accounting, mandatory reporting to Department of Internal Affairs
- Benchmark against other organisations
- Report to regulators, e.g. for consent conditions

This module provides guidance for determining the type and amount of data that should be collected to understand the assets and how they are performing.

7.2 Key issues in data collection

Whilst there is a need to gather data on assets and their performance to improve decision-making, the cost of capturing and managing data should be balanced against the expected benefits. Data collection is a resource intensive process and careful consideration of data requirements is needed. (IPWEA, 2015). This is particularly the case with wastewater pipelines as they are buried and cannot be easily inspected.

It is not necessary to collect data on all assets, rather asset managers should concentrate on collecting the data that has greatest benefit for decision-making. To this end, data collection is often focused on:

- Significant assets or asset classes, i.e. the asset classes that make up most of the network or those assets that will cost significant amounts to replace
- High consequence assets, i.e. those assets where failure would have significant consequence
- Assets that could be in poor condition, i.e. those that are most likely to fail

Data collected on these assets can then be used to infer information on other assets that have not been inspected.

Case Study 7.1 is an example of how data on only a portion of the network was used to provide valuable insights.

Case Study 7.1	**Data Collection – Learnings from Pavement Management** Giving purpose to data is a key learning from the introduction of pavement management software in New Zealand. This is also applicable to wastewater systems. When renewals planning software was introduced into New Zealand, local authorities fell into two camps. Some tried to develop complete data sets before they undertook deterioration modelling and renewals planning. Others used the data they had available to start using the software even through the data was incomplete and, in some cases, inaccurate. The latter group had far more successful and sustainable programmes. By using the limited data, they had available, they were able to quickly identify the data that had the greatest impact on decision making and concentrate on improving that data (Henning, IDS).

7.3 Understanding what assets the organisation owns

7.3.1 Collection of data on new assets

Volume 1 of the NZAMS describes data which can be collected/generated when an asset is constructed.

The data is used for understanding the amount and type of assets that an organisation manages and for forecasting how networks may perform in the future.

Basic as-constructed data, such as pipe material and age, forms the basis of the most commonly used deterioration prediction tools and valuations.

Other as-constructed data such as construction techniques, constructor and installation conditions can be used to form an understanding of characteristics unique to the assets under the organisation's management. This may include portions of the network which are susceptible to certain forms of deterioration due to environmental conditions or construction defects caused by a specific contractor.

As-constructed data has the benefit of being easy to collect at the time of construction provided that appropriate processes and instructions are provided. Part of the value of as-constructed data is its wide availability. These data sets can be used for further statistical analysis.

The data identified in Volume 1 is summarised in Table 7-1. The data is classified as follows:

- Identification attributes – identifies the asset and its status, its location and provides information on the data that was used to populate attribute fields
- Physical attributes – describes the asset, e.g. material or diameter
- Environmental attributes – describes the environment around the asset, e.g. soil type or the material that flows through the pipeline
- Installation attributes – describes how the asset was constructed, e.g. date of construction or builder

Table 7-1 : NZAMS As-Constructed Data

Identification Attributes	Physical Attributes	Environmental Attributes	Installation Attributes
Unique ID	Pipe Type	Ground Water	Construction Date
Owner	Pipe Shape	Ground Type	Cost
Status	Length	Bedding Type	Installation Method
Operational Management Area	Nominal Diameter	Haunching	Manufacturer
From Node	Material	Backfill Material	Renewal Method
From Node Invert Level	Load Class	Protection Material	Manufacturer Warranty
To Node	Stiffness Class		
To Node Invert Level	Joint Method		

Identification Attributes	Physical Attributes	Environmental Attributes	Installation Attributes
Data Source	Design Life		
Horizontal Precision	Renewal Material		
Vertical Precision			

The data attributes specified in NZAMS Vol 1 are extensive, on the basis that it is cheap and easy to collect data during design and construction. The majority of the data would be included on a typical construction drawing. Even so, it is recommended that consideration be given to also capture a few additional attributes. See Research Opportunity 7.1.

Research Opportunity 7.1

Additional environmental attributes in New Zealand Metadata Standards

It is recommended that consideration be given to including the additional attributes shown in Table 7-2 in the next edition of NZAMS to enhance the identification of deterioration trends.

Table 7-2 : Additional Data Attributes Recommended to be included in NZAMS Vol 1.

Attribute Name	Assumed Effect on Deterioration Failure	Impact on Deterioration
Environmental Factors		
Exposure to Seawater	Pipelines closer to the coast may be more susceptible to deterioration	Medium
Contaminated Soils	Industrial wastes can increase the rate of deterioration of some pipeline materials. This is particularly relevant for PVC & PE pipelines	High

	Traffic loading	Literature has contradictory findings. Shallow pipelines under roads may be more susceptible to traffic loadings. However, some authors have noted that pipelines under main roads are constructed to higher standards than pipelines under lightly trafficked areas	Uncertain
	Other services	Pipelines may be damaged when other services are installed close by.	Medium
	Pipeline Slope (Derived from Node Invert Levels & Length)	Steep wastewater pipelines are more susceptible to erosion. Flat pipelines are more susceptible to blockage.	Medium

7.3.2 Collection of data on existing assets

Volume 1 of the NZAMS does not comment on what data should be collected on existing assets. Clearly it is not cost effective, or in some cases even possible to collect the same level of data on existing pipelines as it is on new assets.

Appendix 2 lists possible methods for determining the data attributes for existing assets and comments on the ease of data collection and usefulness of the data. It is recommended from this analysis that the data listed in Table 7-3 be collected on existing assets as a minimum, concentrating on the significant assets, critical assets and those that could be in poor condition.

Table 7-3 : Recommended Data to be Collected on Existing Assets

Attribute	Assumed Effect on Deterioration & Service Failure
Physical Attributes	
Pipe Type	Service pipes are likely to deteriorate quicker than main pipes as they tend to be smaller, shallower and possibly installed to lesser standards.
Length	Longer pipelines are more likely to have defects due to the number of joints and pipeline barrels.

Attribute	Assumed Effect on Deterioration & Service Failure
	Some literature sources state that longer wastewater pipelines are more susceptible to differential settlement that can cause blockage and sediment deposition, which in turn can facilitate pipeline deterioration.
Nominal Diameter	Smaller diameter pipelines are generally more susceptible to damage and deterioration than larger pipelines, as larger diameter pipelines have thicker walls and are stronger than smaller pipelines.
Material	The various pipeline materials behave differently. Some can be more susceptible to deterioration than others
Renewal Material	The various rehabilitation materials behave differently. Some might be more susceptible to deterioration than others.
Installation Attributes	
Construction Date	The older the pipeline the more susceptible it is to deterioration failure. The influence of age may, however, be overridden by other factors
Renewal Method	Rehabilitation material is likely to have more influence on deterioration than the method of rehabilitation

7.4 Understanding how assets are performing

Case Studies 7.2-7.4 discuss the performance measures that can be monitored and highlights that monitoring resources should be focused on those measures that relate to the service attributes that have the greatest impact on community wellbeing.

Often organisations focus on understanding the condition of their wastewater networks. Case Study 7.2 discusses the role of CCTV in understanding how assets are performing highlighting the usefulness and limitations of CCTV inspection. Case Study 7.3 discusses the shortcomings with condition gradings derived from the 3^{rd} Edition of the New Zealand Pipe Inspection Manual.

Case Study 7.4 gives examples of how organisations are monitoring performance, highlighting that undertaking extensive CCTV inspections is only one of many parameters that should be considered when assessing the performance of wastewater systems.

Case Study 7.2	The role of CCTV inspection in understanding how assets are performing

What can be determined from a CCTV Inspection (New Zealand Water and Wastes Association Inc , 2006)

CCTV inspection provides information for asset management, maintenance and rehabilitation purposes. CCTV inspections view the condition of assets and provide information on attributes. Condition data can be used to:

- Determine the structural condition of pipes to enable rehabilitation works to be prioritised
- Maintain a check on the structural condition and rate of deterioration of pipes to enable forward budgeting for maintenance and rehabilitation
- Provide an overall inventory of the asset and a global picture of system problems
- Check service conditions to enable regular maintenance planning
- Provide miscellaneous information for additional uses, such as locating unused lateral connections for new housing developments
- Provide a status of sewer and stormwater systems for industry benchmarking.

CCTV inspections also provide valuable information on the position and type/size of the pipes being inspected, such as:

- Connectivity, i.e. which manholes are connected by the pipe
- The location of pipes and manholes can be determined by the length of the pipe surveyed and the position of the manholes noted when the CCTV camera was put into or retrieved from the pipe
- The diameter of the pipe being inspected
- The material of the pipe being inspected

What cannot be determined from a CCTV Inspection

CCTV inspections cannot:

- Provide information beyond the inside surface of the pipe being inspected. CCTV inspections on their own cannot provide information on the condition or thickness of the pipe wall material, nor can they determine whether there are cavities behind the pipe wall.

	▪ Confirm that a pipe is not leaking. CCTV inspections may show that water is leaking into a pipe, if the inspections were undertaken during wet conditions. They may also show that material is leaking out of a pipe, e.g. through pipe breaks. However, CCTV inspections carried out in the dry cannot confirm that water is not leaking out of joints. The joints may look to be in good condition but may still be leaking. Even if the CCTV inspection is carried out during wet conditions there is no guarantee that the water table might not be below the pipe when the survey is carried out but raise up above the pipe later, causing water to leak into the pipe.

Case Study 7.3	**Shortcomings with Condition Grades Derived from 3rd Edition of New Zealand Pipe Inspection Manual** Condition Grades produced from the 3rd Edition of the New Zealand Pipe Inspection Manual do not necessarily align with the condition expected of pipes of that Grade. This results in most networks having a significant proportion of pipelines with a Condition Grade of 5, indicating that pipes have failed, despite the pipes functioning adequately. This will be rectified in the next edition which is currently being drafted. Under the current grading system, a pipeline is assigned a Grade 5 (fail) if the peak score exceeds 50 or the mean score exceeds 3. The peak score aligns reasonably well with what would be expected of a pipe at the end of its life. However, the gradings that arise from the mean score do not align. Pipelines with a mean score greater than 3 are assigned Grade 5 (fail). Table 4-1 shows the frequency of defects required to exceed this limit. These frequencies are too conservative, particularly regarding joint faults and surface damage, which are common in stormwater pipes.

Table 7-4 Frequency of Defects Resulting in Fail Grading

Defect	Defect Code	Severity	Condition Rating Score	Average Distance Between Faults for Fail Grading
Crack circumferential	CC	L	30	10
Crack longitudinal	CL	L	30	10
Crack multiple	CM	L	40	13
Joint faulty	JF	L	25	8
Pipe holed	PH	M	25	8
Surface damage	SD	S	3	1

Case Study 7.4

How Organisations are Monitoring Performance

Numerous organisations have moved away from undertaking routine CCTV inspection programmes and are instead undertaking CCTV inspection on an as-needed basis. Notable examples of this shift are discussed below:

Hauraki District Council

The council is more concerned about inflow and infiltration leaking into the wastewater system than pipe collapses. To measure flows, the council purchased a number of flow gauges. When they identify leak prone areas, they undertake CCTV together with other methods such as smoke testing and visual inspection to identify sources of water entering the system.

Watercare

Watercare monitors blockages and breaks in their local reticulated wastewater network. When areas of higher than normal blockages and/or breaks are identified, CCTV inspections are undertaken to identify potential issues in the area and to enable them to plan and scope proactive interventions.

Auckland Council Healthy Waters

Auckland Council have assigned a consequence-of-failure rating to each pipeline in the stormwater network. Regular CCTV inspections are undertaken on the pipelines that have a high consequence of failure to identify proactive interventions. Information derived from the CCTV inspections undertaken on the high consequence pipelines is used to estimate repair and renewals budgets for the remaining parts of the network that are not inspected.

Asbestos Cement Manual

Asbestos cement pipelines degrade through a gradual loss of wall thickness. The rate of degradation cannot be determined from CCTV inspections. The asbestos cement manual defines test methods for determining the extent of degradation and for estimating the remaining life of water mains. The test methods can also be used on wastewater pipes.

Research Opportunity 7.2

Remaining life of asbestos cement gravity wastewater pipelines

Develop methods to predict the remaining life of asbestos cement gravity wastewater pipelines similar to what has been done for pressure pipelines.

8 Forecast Changes in the Performance of Network

8.1 Introduction

Having determined how the network is currently performing, the next stage is to forecast how network performance might change in the future. Some aspects of performance will change as pipes age or as circumstances change while others will remain largely unchanged through the life of pipelines.

Failure to deliver the required level of service will occur from time to time. Service failure does not necessarily necessitate renewal as wastewater pipelines are repairable. However, renewal may be required when the rate of failure or risk of failure reaches unacceptable levels and renewal is the most appropriate option for addressing the issue.

Service failures occur for the following generic reasons:

- **Operational** The inability of the pipeline to convey the quantity of flow that it was designed to convey.
- **Strength** The inability of the pipeline to withstand the forces applied to it either during normal operation or shock events such as earthquakes.
- **Containment** The inability of the pipeline to stop water leaking in or wastewater leaking out.
- **Capacity** The inability of the pipeline to convey the required quantity of flow i.e. the required flow is greater than the design flow.

Whilst all pipes will eventually degrade to such an extent that they are not strong enough to support loads applied (strength failures), specific sections of the network will require attention well ahead of this time due to operational, containment or capacity issues. These issues do not change significantly into the future.

Predicting future performance of the network therefore involves two steps:

- Identify specific pipes that are not delivering the required level of service (operational, containment or capacity issues or strength failures during shock events). Consider whether performance is likely to change in the future, e.g. due to growth. This analysis is undertaken at a network, master planning level.
- Forecast the rate of deterioration for all pipelines in the network. Predict the influence this has on the level of service, risk and cost. This is completed in two sub-steps:
    - Forecast deterioration of the pipe wall degradation. This form of deterioration particularly affects AC pipes.

    - Predict rate of breaks likely to occur due to small discrete faults getting worse over time. This form of deterioration particularly affects earthenware pipes.
- There can be significant variance in deterioration rates for individual pipes. So, the focus is on forecasting the likelihood of failure rather that predicting when failures will occur on particular pipelines.

8.2 Which performance measures change over time

Table 8-1 indicates whether the performance measures for the various metadata schema will change over time.

All pipes will degrade and deteriorate to some extent as they age:

- The condition of the network will worsen
- Pipelines will be more vulnerable to collapse under normal conditions
- The likelihood of collapse will increase, which increases risk
- The frequency of repairs and maintenance issues will increase
- The cost of maintaining service will therefore increase.

The question that needs to be addressed however is; to what extent will these changes occur and whether they make a material difference. In the following sections it is argued that these changes are less of an issue because they occur over such a long time.

In most wastewater networks, it is likely that there will be pre-existing issues which need to be addressed. Network repairs or maintenance may be required in parts of the network due to operational failures, or, overflows may be occurring due to demand/capacity issues caused by containment failures or growth in upstream areas. Overflows may increase if growth occurs, but this will only impact a few pipelines in the network. Otherwise these issues will not change significantly change overtime.

Typically, criticality, consequence of failure and resilience will not change over the life of pipelines.

Table 8-1 Performance measures which change over time

NZAMS Schema	Performance change over time	Comments
Condition	Yes	Likely to deteriorate as pipes age
Repairs, maintenance and operations	Yes	There is typically a base number of repairs and maintenance required on all pipes, but as pipes age, the amount is unlikely to increase
Utilisation	For some pipelines	Utilisation is increased by increased flow in upstream areas which is a factor of amount of inflow and infiltration entering into the system and growth. However, this is not an issue for most of the pipes in the network which do not service significant upstream areas.
Demand	For some pipelines	As per Utilisation
Vulnerability	Yes	As pipelines age, they are likely to be more vulnerable to strength or containment failures under normal circumstances. However, their vulnerability to shock events will largely stay the same, being more a function of the location of the pipeline causing it to be vulnerable to shock events rather than condition.
Criticality	No	The significance of removal of a section of the network is unlikely to change over time unless the network is reconfigured, there is significant growth or change in the type of users connected to the system.

NZAMS Schema	Performance change over time	Comments
Risk	Yes	Likelihood of failure is likely to increase as pipelines age, refer vulnerability. However, the consequence of failure is likely to remain unchanged.
Resilience	No	Mostly a function of the location of the pipeline.
Design performance	Potentially	May be affected as consequence of changes in other performance measures.
Financial performance	Potentially	May be affected as consequence of changes in other performance measures.
Service performance	Potentially	May be affected as consequence of changes in other performance measures

8.3 Service failures

8.3.1 What are services failures

Service failure occur when the wastewater system is not able to provide the intended service.

Service failure does not necessarily imply the need to renew a wastewater pipeline as wastewater pipelines are “repairable systems”. In many cases, failures can be tolerated, and the system repaired. When repairs are undertaken, the condition is returned to as bad-as-old state, i.e. the likelihood of failure after repair is the same as just before the repair was undertaken.

This contrasts with say light bulbs that are not repairable. When lightbulbs fail, they need to be replaced and condition is returned as good-as-new.

Renewal may be required when the rate of failure or risk of failure reaches unacceptable levels and renewal is the most appropriate option for addressing the issue.

8.3.2 Modes of service failure

Wastewater pipelines fail to provide service for four reasons (modes of failure), being:

Operational

The pipeline is not able to convey the quantity of flow that it was designed to convey.

- **Silt, fat and roots build up** can affect the ability of the pipelines to convey wastewater. Pipes that contain dips or have shallow grades are prone to silting. Earthenware and older cast in situ concrete pipes may be prone to root blockage. However, roots entering through laterals can cause blockages in all pipe materials. The prevalence of blockages due to fat depends on the material discharged into the wastewater system. Fat blockages can occur in all pipe materials but may be more prevalent in pipes that contain roots or dips. Blockages can be avoided through proactive jetting, root cutting and monitoring of grease traps. Renewal is not normally warranted.

Strength

The pipeline is not able to withstand the forces applied to it either during normal operation or during shock events.

- **Degradation of short sections of pipelines**. Typically, there is a baseline rate of failure which is not age related and is due instead to events such as third-party damage. However, degradation tends to increase with age with small defects becoming worse over time, eventually causing sections of pipeline to collapse. Earthenware pipes are prone to this type of failure. Such failures can often be repaired without the need to renew the entire pipeline. However, renewal may be warranted when extensive sections of pipeline have degraded in this way.
- **Deterioration of the pipe wall** to the point that the wall can no longer withstand the loads applied. Renewal is required when a pipeline reaches this stage. If repairs are made, then other sections of pipeline are likely to collapse soon after. Asbestos cement, brick and Armco pipelines are susceptible to this type of deterioration. Concrete pipes that are subjected to hydrogen sulphide attack are also susceptible.
- **Shock events** such as earthquakes, landslides etc can result in significant forces being applied to pipes causing pipes to be broken and damaged. The likelihood of damage occurring is related to the:
    - Location of pipes which influences how likely it is that pipes will be subjected to a shock event and the magnitude of forces applied
    - Ability of the pipe to withstand the forces applied which is related to pipe size and material.

- Deterioration does not significantly impact the ability of a pipeline to withstand a shock event. Although older pipe materials are more vulnerable to failure, this is function of the characteristics of the pipe material. If a shock event occurred early in the life of the pipeline it is likely that they would still fail.

Containment

The pipeline is unable to stop water leaking in or wastewater leaking out.

- **Joints leakage.** The more joints in a pipeline, the more likely it is that a pipeline will leak. Pipes with older jointing systems are more likely to leak than those with newer jointing systems. Therefore, earthenware and older cast in situ concrete pipes (CCTV code CP) are prone to this type of failure. Newer spun concrete pipes (CCTV code CS), PVC and PE pipes are less prone to this type of failure.
- **Leakage through cracked and damaged pipes.** Rigid pipes such as earthenware, older cast in situ concrete pipes and asbestos cement pipes are more prone to damage
- **Groundwater leaking into pipes** (infiltration) can cause capacity failures resulting in wastewater overflows. Water leaking out of pipes (exfiltration) can contaminate watercourses and ground water supplies.

  However, water can also enter wastewater networks through manholes and though private drainage. This water is often more significant than the water infiltrating in the public network (Water New Zealand, 2015).

Capacity

The pipeline is not able to convey the required quantity of flow i.e. the required flow is greater than the design flow. Capacity failures relate to changes in demand rather than age or degradation.

- Wet weather flow – due to inflow and infiltration in upstream areas can increase flows above the design capacity resulting in wet weather overflows from manholes and pumps stations. Climate change is likely to influence the frequency and intensity of wet weather events.
- Growth in upstream areas can also increase flows however, wet weather flows are typically of greater concern.

Table 8-2 shows how which performance schema are influenced by the various failure type, in order to provide line of sight between the failures, performance measure and ultimately service attributes.

Table 8-2 Effect of failure types on performance schema

	Condition	Repairs and Maintenance	Utilisation	Demand	Criticality	Risk	Resilience	Vulnerability	Design Performance	Financial Performance	Service Performance
Operational		✓								✓	✓
Strength	✓	✓				✓	✓	✓		✓	✓
Containment	✓					✓			✓		✓
Capacity			✓	✓		✓			✓		✓

Table 8-3 summarises likely changes in service failure over time. Table 8-4 to Table 8-7 indicates which types of pipes are vulnerable to the various types of failure, shows the indicators of failure and potential interventions to avoid failures. This information can be used to develop infrastructure planning studies to improve operational, containment or capacity issues or strength failures during shock events. In this way, identifying pipelines require intervention and the timing of the intervention. These studies may include:

- Integrated Catchment Modelling
- Infiltration & Inflow investigation
- Resilience assessment

Case Study 8.1 discusses the process for assessing seismic resilience of pipelines. Significant improvements in resilience can be achieved by realigning pipelines to avoid areas prone to faults, landslides or lateral spread and renewing pipelines in areas subject to liquefaction with pipelines constructed from modern materials.

Table 8-3 Change in service failure over time

Failure Mode	Failure Subcategory	Extent of Network	Increases with time
Operational	Silt, fat and roots build up	Particular pipelines	Slight
Strength	Deterioration of short sections of pipelines	All	Yes, slowly
	Deterioration of the pipe wall	All	Yes, for vulnerable pipe materials (refer Table 8-5)
	Natural Disasters	Particular pipelines	No
Containment	Infiltration	Particular pipelines	Slight
	Exfiltration	Particular pipelines	Slight
Capacity	Wet weather	Particular pipelines	Slight
	Growth	Particular pipelines	Slight

Table 8-4 Operational failure

Operational	The pipeline is not able to convey the quantity of flow that it was designed to convey		
	Silt	**Fat**	**Roots build up**
Vulnerable Pipes	Pipes with dips or shallow grades	Occurs in all pipes materials but more common in pipes with root blockage and dips	Earthenware and cast in situ concrete pipes Roots can enter through lateral connections on any pipe material
Indicators	Dry weather overflows	Dry weather overflows	Dry weather overflows
Potential Interventions	Proactive jetting Replacement	Proactive jetting Monitoring of grease traps	Root cutting

Table 8-5 Strength failure

Strength	**The pipeline is not able to withstand the forces applied to it either during normal operation or during shock events.**		
	Degradation of short sections of pipelines	**Deterioration of the pipe wall**	**Shock events**
Vulnerable Pipes	Earthenware	Asbestos cement Brick Armco Concrete subject to hydrogen sulphide	Pipes located in areas subject to landslides, earthquake faults, lateral spread or liquefaction. Older pipe materials such as earthenware, cast in situ concrete or asbestos cement pipes are more vulnerable than newer pipe materials to damage and blockage in areas of liquefaction.
Indicators	Age, CCTV inspection	Age, CCTV, for asbestos cement pipes physical testing	Ground performance
Potential Interventions	Spot repairs, renewal if degradation is extensive	Renewal	Realignment of pipelines or in areas prone to liquefaction, renewal

Table 8-6 Containment failure

Containment	The pipeline is unable to stop water leaking in or wastewater leaking out
	Leakage through joints or cracks
Vulnerable Pipes	Earthenware Older cast in situ concrete
Indicators	Wet weather overflow, flow gauging
Potential Interventions	Pipeline rehabilitation or renewal (undertaken in conjunction with renewal/rehabilitation of private laterals and manhole)[3]

Table 8-7 Capacity failure

Capacity	The pipeline is not able to convey the required quantity of flow i.e. the required flow is greater than the design flow	
	Wet weather flows	**Catchment development**
Vulnerable Pipes	Earthenware Older cast in situ concrete	Pipelines downstream of where growth is occurring
Indicators	Overflows at manholes and pump stations	Overflows at manholes and pump stations
Potential Interventions	Renewal/rehabilitation of upstream catchments Upsizing of pipelines Installation of tanks to store peak flows	Upstream drainage improvements Renewal

[3] Significant amounts of water can leak into wastewater networks through private property laterals or manholes (inflow & infiltration) as well as through public mainlines and laterals.

Table 8-8 shows how which performance schema the various failure types influence.

Table 8-8 Effect of failure types on performance schema

Failure Type	Condition	Repairs and	Utilisation	Demand	Criticality	Risk	Resilience	Vulnerability	Design Performance	Financial Performance	Service Performance
Operational		✓								✓	✓
Strength	✓	✓				✓	✓	✓		✓	✓
Containment	✓					✓			✓		✓
Capacity			✓	✓		✓			✓		✓

Case Study 8.1

Assessing Seismic Resilience to Prioritise Renewals – Underground Utilities – Seismic Assessment and Design Guidelines

The *Underground Utilities – Seismic Assessment and Design Guidelines* (2017) provides a methodology for assessing the vulnerability of underground utility systems to earthquake ground motions.

The process allows the estimation of post-event levels of service. The process considers a number of factors in estimating the levels of service.

The estimated post-event levels of service can be used to prioritise renewals. Highest renewal priority is given to those pipelines which demonstrate the largest estimated shortfalls in post-event levels of service.

Improvements would typically involve realigning pipelines to avoid areas prone to faults, landslides or lateral spread and renewing pipelines in areas subject to liquefaction with pipelines constructed from modern materials.

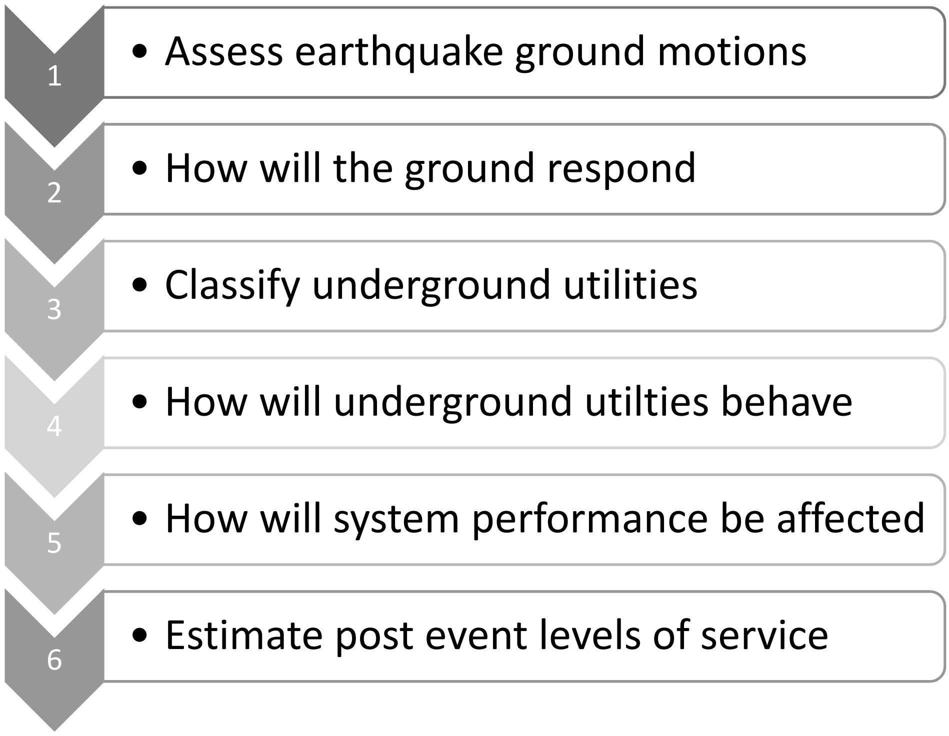


Figure 8-1 : Process for assessing system vulnerability

Case Study 8.2 shows the findings of a study to understand the main causes of overflows in wastewater network

Case Study 8.2

Main Causes of Dry Weather Overflows

Figure 8-2 highlights that most failures in Watercare's wastewater network under dry weather conditions are operational failures which can typically be addressed through proactive or reactive maintenance. Changing maintenance practices and customer behaviours will have more impact on reducing failure rates than increasing pipe renewals.

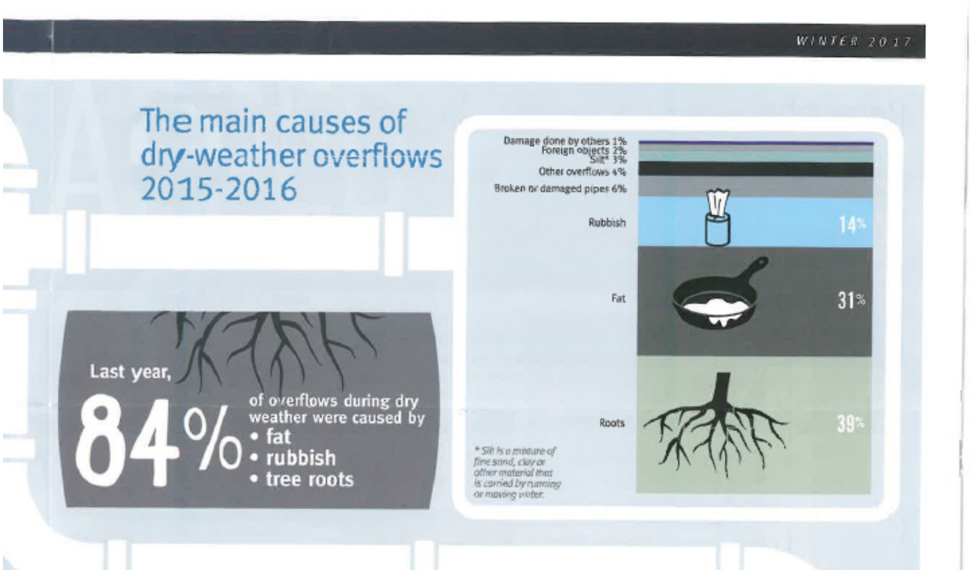


Figure 8-2 : Main causes of dry weather overflows in Watercare's wastewater network

Case Study 8.3 highlights that there are multiple reasons for renewal of a pipeline. With degradation related failure being far lesser of a concern than other types of failures.

Case Study 8.3

Watercare Abandoned Wastewater Pipelines

Analysis of the number of pipelines replaced in Watercare's local wastewater network highlights that a portion of the network is replaced each year irrespective of age and the amount does not significantly vary between older and newer pipe materials. This indicates that replacement due to pipe degradation is less of a driver than non-degradation issues such as replacement because of interfaces with other activities or capacity.

Watercare typically abandons and replace about 0.3%/yr. of the pipeline in the local wastewater network, as shown in Figure 8-3. At this rate, the entire network will be replaced over the next 333 years with an average replacement time of 167 years.

The reasons for abandonment and replacement are numerous and they have not been recorded in a manner that can be easily analysed. However, it can be seen from Figure 8-3 that there is not significant variance between the replacement rate for newer pipe materials (e.g. PE 0.2% year) and older materials (e.g. earthenware 0.4%/yr.).

It is likely that the portion of asbestos cement pipelines requiring replacement will increase in the future when wall deterioration reaches a stage that pipe collapse will occur.

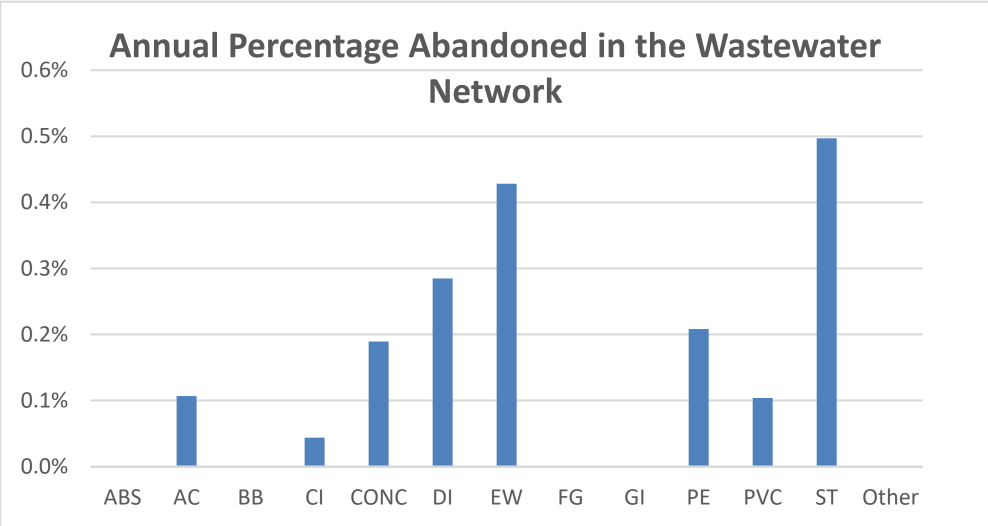


Figure 8-3 : Annual Abandoned and Removed Sewer Pipes (150-225dia)

8.4 Historical pipe performance analysis

Statistical analysis of the historical performance of pipelines is a useful first step for developing an understanding of the performance of the network. Relatively simple statistical tools such as 'box and whisker plots' and bar graphs can be used to display large quantities of data and show long term trends. The identification of long-term trends is in itself a powerful tool which can show future problems without the need for forecasting performance changes. More advanced statistical methods such as correlation tables can be used to show the strength of the relationship between various parameters on a particular aspect of performance. This type of analysis can be used to identify the causes behind certain changes in performance thus providing the basis for intervention selection.

Case Study 8.4 is an example of how statistical analysis was used to understand an apparent increase in break rates in a pipe network. Note that this example is from a pressure network, however, the principle is equally applicable to a gravity network.

Case Study 8.4

Watercare Services Limited North Shore Breakages

In 2013, a report was commissioned to investigate an apparent increase in watermain breaks, specific to the North Shore area. Watermains in the area were continually installed with the earliest being up to 113 years ago.

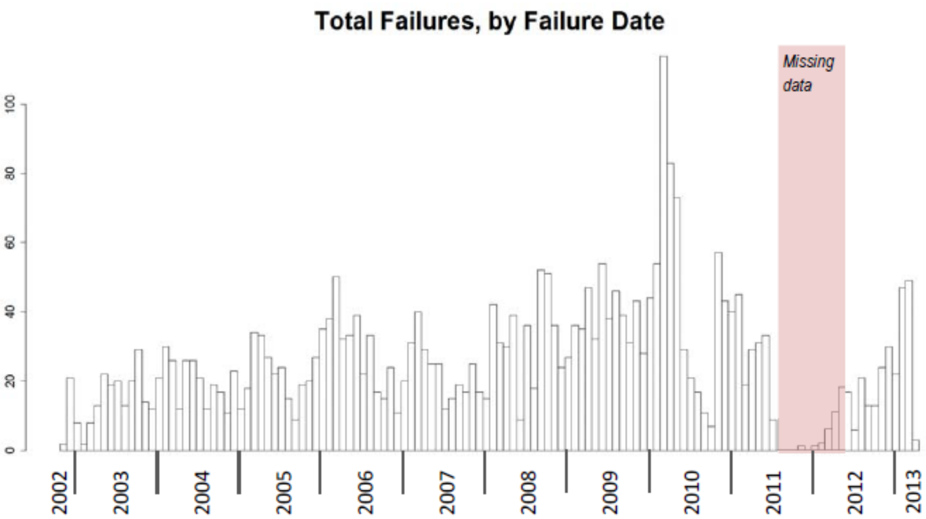


Figure 8-4 Total failures, by Failure Date

Analysis of overall total failures confirmed that the frequency *of* breaks *was* indeed increasing*. This increase was most likely attributed to the aging network.*

Key:

Significant correlation

Very significant correlation

					Pipe type						Failure mode					Pipe Diameter (mm)					
			Soil Moisture Deficit	Total Fails	AC	ALK	CI	GI	PE	PVC	LEACRK	LEAGEN	LEAHOL	LEAJNT	LEASPL	X25	X32	X50	X100	X150	X200
	3235	Total Fails	0.70																		
Pipe type	1655	AC	0.77	0.95																	
	79	ALK	0.26	0.31	0.23																
	126	CI	0.60	0.78	0.82	-0.10															
	180	GI	0.18	0.46	0.43	0.43	0.29														
	248	PE	0.57	0.88	0.85	0.29	0.57	0.16													
	588	PVC	0.58	0.97	0.88	0.46	0.71	0.50	0.87												
Failure mode	717	LEACRK	0.61	0.95	0.88	0.33	0.63	0.46	0.87	0.90											
	1276	LEAGEN	0.41	0.84	0.74	0.11	0.72	0.09	0.86	0.87	0.75										
	191	LEAHOL	-0.04	0.25	0.07	0.30	-0.17	0.29	0.14	0.31	0.25	0.22									
	345	LEAJNT	0.67	0.65	0.67	0.54	0.32	0.41	0.62	0.58	0.77	0.28	-0.09								
	231	LEASPL	0.26	-0.18	0.00	0.04	0.07	0.39	-0.43	-0.27	-0.22	-0.59	-0.38	0.17							
Pipe Diameter (mm)	355	X25	0.38	0.84	0.74	0.40	0.42	0.31	0.89	0.85	0.92	0.77	0.39	0.64	-0.47						
	354	X32	0.37	0.25	0.19	0.90	-0.03	0.42	0.12	0.33	0.30	-0.04	0.08	0.65	0.27	0.24					
	1692	X50	0.63	0.94	0.90	0.51	0.59	0.62	0.85	0.94	0.93	0.70	0.32	0.74	-0.12	0.86	0.40				
	1389	X100	0.71	0.91	0.96	0.08	0.93	0.33	0.81	0.85	0.79	0.81	-0.03	0.50	-0.04	0.64	0.05	0.79			
	520	X150	0.70	0.85	0.88	0.15	0.72	0.04	0.90	0.77	0.82	0.78	-0.04	0.62	-0.21	0.78	0.10	0.74	0.86		
	345	X200	0.55	0.87	0.78	0.39	0.70	0.27	0.76	0.89	0.80	0.84	0.32	0.44	-0.27	0.80	0.27	0.77	0.78	0.82	

Figure 8-5 : Failure Correlation Table (extract)

A correlation analysis was undertaken to understand what factors most heavily correlate with each other. Correlation does not generally show causation however a correlation analysis is a useful starting point to identify trends.

The analysis indicates that total failures were closely related to the following factors

- Pipe type
- Asbestos cement
- Polyvinyl chloride
- Failure modeLeak - crack
- Pipe diameter
- 50mm
- 100mm

8.5 Predicting the impact of pipe deterioration

There are two general approaches to deterioration modelling, i.e. deterministic modelling and probabilistic modelling.

Deterministic models are more commonly used. These assume that deterioration follows a predetermined pattern, i.e. similar pipelines in similar environments will deteriorate at similar rates. Deterministic models predict average condition. They are useful for determining what factors, other than time, may affect asset performance. However, average behaviour is less helpful for predicting when specific pipelines will require intervention as there can be significant variation in behaviour between the best and worst performing pipelines in a network, refer Case Study 8.5.

Predicting the behaviour of the worst performing pipelines is more important for renewal planning. Probabilistic models are required for this type of prediction. Probabilistic models predict the likelihood that a pipeline will deteriorate to a specific condition.

Case Study 8.5	**Variation in Deterioration Rates – Asbestos Cement Water Mains** Not all pipelines behave the same. Within a cohort of similar pipelines there can be a large variation between the best and worst performing pipelines. The variation in behaviour starts at the time of installation due to differences in manufacturing tolerances and installation practices. Variation in behaviour increases throughout the life of the pipe as some pipelines are subjected to worse conditions than others. Figure 8-6 which is an extract from the New Zealand Asbestos Cement Pipe Manual shows the expected life of a 100mm diameter water main pipe. This graph has been prepared by analysing the condition of several hundred pipe samples. The mean life expectation of a pipe operating at 80m pressure is 48 years. However, 85% of pipes will be expected to reach the end of their lives between 27 years and 89 years.

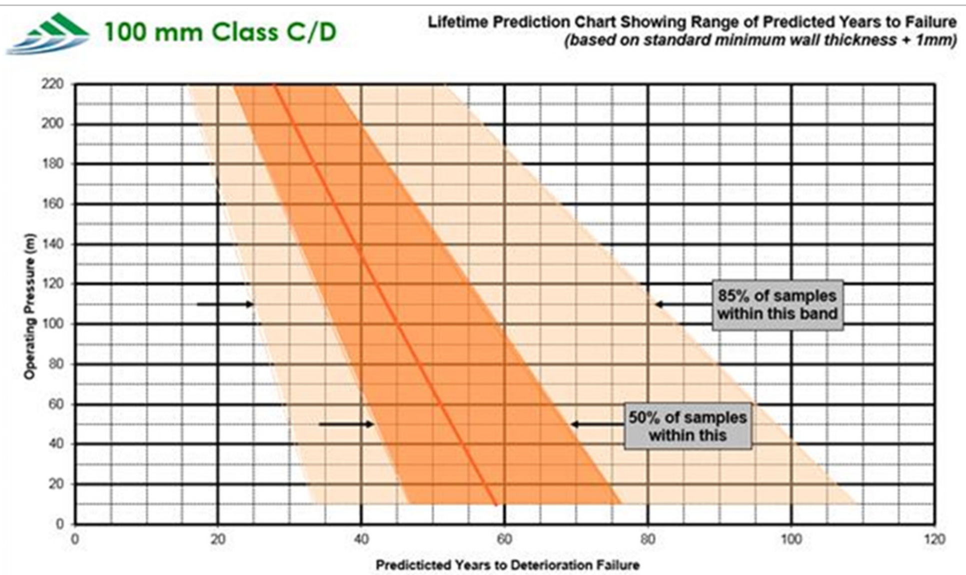


Figure 8-6 : Predicted Life of 100mm Diameter AC Pipes

Figure 8-7 displays the above information from in a different format, showing the cumulative probability of failure (POF). About 1.5-2% of the network will fail annually after about 30 years.

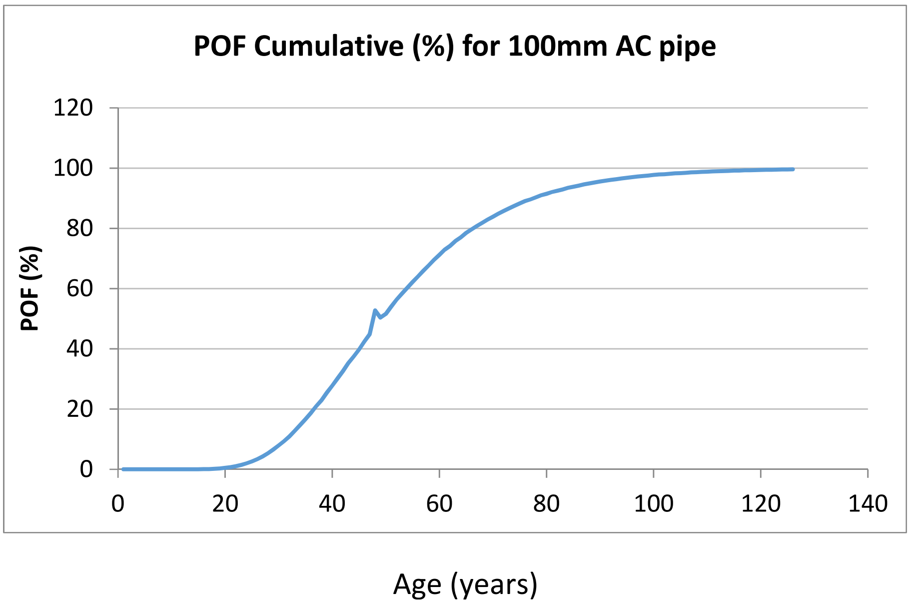


Figure 8-7 : Cumulative Probability of Failure (POF) of 100mm Diameter AC Pipes

8.5.1 What factors affect the rate of failure?

The rate of deterioration of wastewater pipelines can be influenced by several physical, environmental and construction factors. The key factors are outlined in Table 8-9.

Table 8-9 Key factors affecting pipeline degradation

	Degradation of short sections of pipelines	Deterioration of the pipe wall	Joints deteriorate and leak	Silt, fat and roots build up
Asbestos Cement		Susceptible		
Armco		Susceptible		
Cast in-situ concrete			Susceptible especially with age and number of joints	Susceptible to root blockage if older
Concrete		Susceptible due to hydrogen sulphide attack		
Earthenware	Susceptible especially with age		Susceptible especially with age and number of joints	Susceptible to root blockage
Dipped/ shallow grade pipe				Susceptible to silt

Research Opportunity 8.1	**National pipe data portal** Design and implementation of a data framework for aggregating pipe data for New Zealand pipes. This will be both testing and implementing a state-of-the–art data federation technology. The creation of larger data sets which can be accessed by organisations which would otherwise have only small data sets will contribute to the identification of factors affecting the vulnerability of pipelines and the development of deterioration profiles.

8.6 Deterministic modelling

8.6.1 Age-based

Age-based renewal planning is the most commonly used approach. Age-based renewals planning is undertaken on the basis a pipeline is renewed when it reaches a predefined estimated useful life. It is straightforward to apply, does not require specialist software or modelling resources and has limited data requirements.

The useful life is the average expected life. There can, however, be significant variance in behaviour of individual pipelines and individual pipelines may require replacement many years before or after the estimated useful life.

Whilst age may be appropriate for identifying candidates for further investigation, it is not suitable for determining specific pipelines requiring renewal. Also, the technique does not predict the quantity of breaks and blockages likely to occur.

The expected lives used in New Zealand appear to be overly conservative. Refer Case Study 8.6.

Case Study 8.6

Comparison of useful lives

Table 8-10 compares the useful lives proposed from the literature research with those from the New Zealand Asset Management Manual. The difference in the two indicates that the lives recommended in the New Zealand Asset Management Manual are overly conservative resulting in the application of depreciation rates which are higher than necessary.

Table 8-10 : Comparison of useful lives

Material/Material Code	New Zealand Asset Management Manual	Useful Life Proposed following literature Research	
Asbestos Cement (AC)	60 years	150DN	81 years
		200-250DN	90 years
		300-375DN	100 years
Polyvinyl Chloride (PVC)	80 years	Pre-1996	75 years
		Post 1996	100 years
Earthenware (EW)	80 years		167 years
Concrete (CONC)	60 years		114 years

The impact of revised useful lives becomes more evident over an extended period as the difference in accumulated renewals becomes larger.

Figure 8-8 shows the accumulated renewals quantity (in meters) for a typical network comprising AC, PVC and EW pipes. Accumulated renewal quantity is shown based on the useful lives recommend in the New Zealand Asset Management Manual and the revised useful lives from the Literature Research. There is a large difference in the first 25 years of forecasting due to data being available only to the year 1900. After the first 25 year, the gap decreases for a period then starts to increase again. Long term, the difference in renewal quantities from the two useful lives increases.

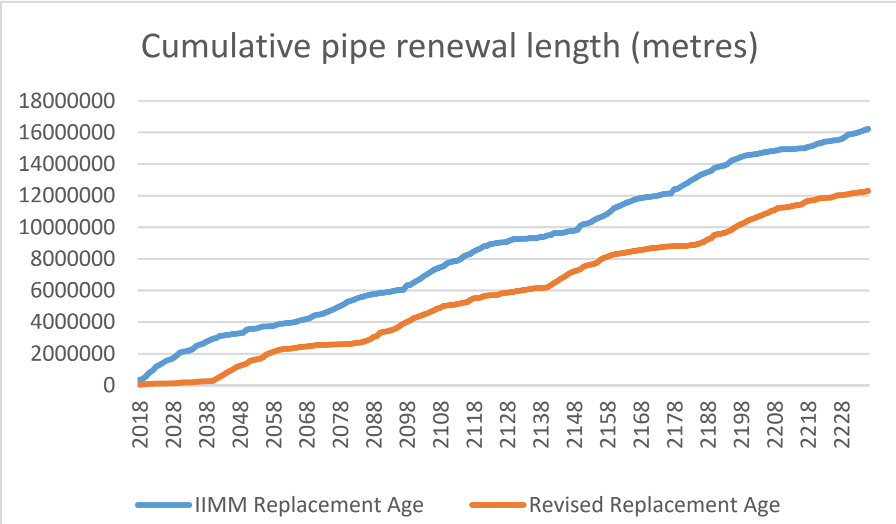


Figure 8-8 Accumulated renewal spend comparison

Research Opportunity 8.2

Useful Life of Wastewater Pipelines

Reassess the useful life of wastewater pipelines and determine New Zealand standard lives.

8.6.2 Condition based renewal planning

Condition based renewal planning is undertaken on the basis a pipeline is renewed when it reaches a predefined condition.

Planning for this renewal approach requires understanding of how the condition of a pipeline changes over time.

Figure 8-9 shows four curves from literature showing how the average condition of a network may change over time. The worst-case prediction indicates that the average time to reach failure, i.e. Grade 5, is more than 100 years.

However, as the curves are predicting the average condition of the network, some pipelines will reach failure before the predicted time and some later. Therefore, the curves cannot be used to predict the condition of individual pipelines, nor can they be used to predict the number of pipelines requiring renewal.

This technique does not predict the quantity of breaks and blockages likely to occur.

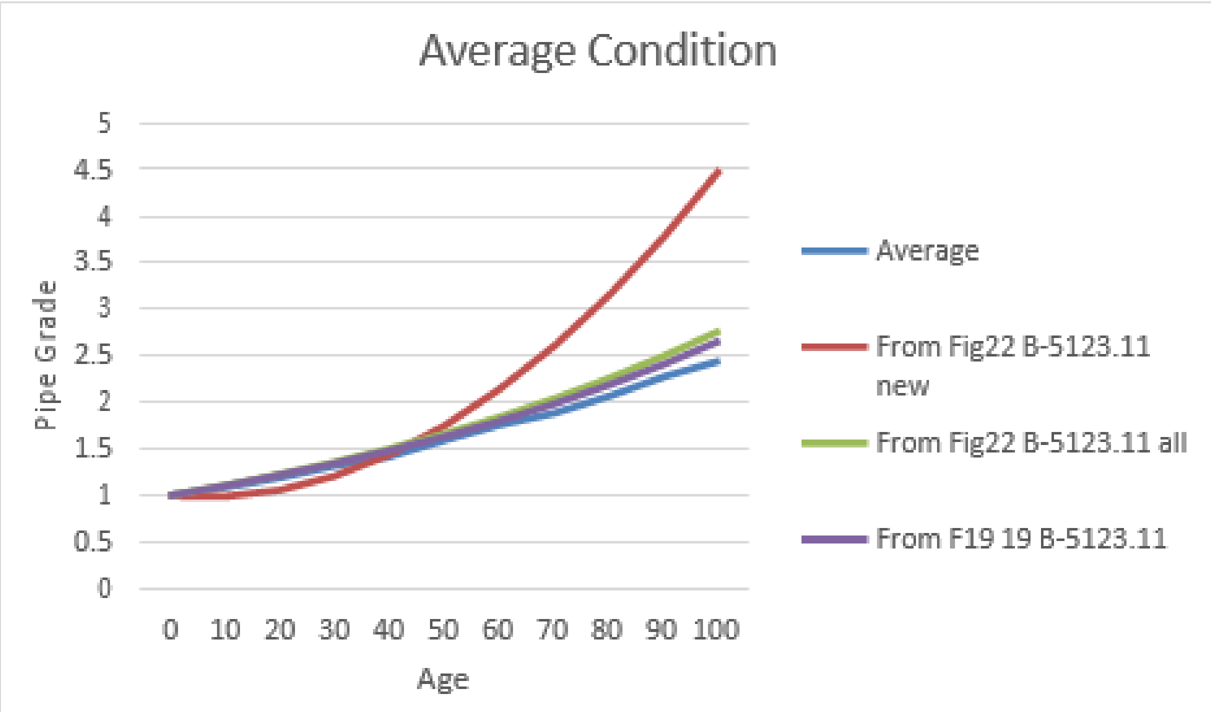


Figure 8-9 Average condition curves

8.6.3 Expected number of failures per year

Another approach is to predict the expected number of failures. This approach enables future break rates to be predicted which feeds into forecasting of maintenance budgets. The approach predicts average failure rates. Individual pipeline failure rates may be better or worse than what the curves suggest. The approach does not predict the condition of individual pipelines.

Case Study 8.7 is an example of a break rate study in an older network.

Case Study 8.7

Seattle Public Utilities

Seattle Public Utilities analysed historic repair data to develop failure curves for predicting expected break rates.

15 years of point repair data for vitrified clay (earthenware) and concrete pipe were analysed, and failure prediction curves produced based on normalized Weibull-based distributions. This study indicated that for both pipe materials, failures were occurring at much lower rates than previously predicted, refer Figure 8-10 . The failure rate is linear and shows no sign of exponential increase.

Even for 200-year-old earthenware pipes, the break rate is predicted to be only 7 breaks/yr./100km. The analysis identified that that earthenware pipes on steep slopes, clay soils and fill failed more often than pipes in other areas. Modification factors of between 1.6 to 1.75 are applied to the standard curves for pipes in these areas.

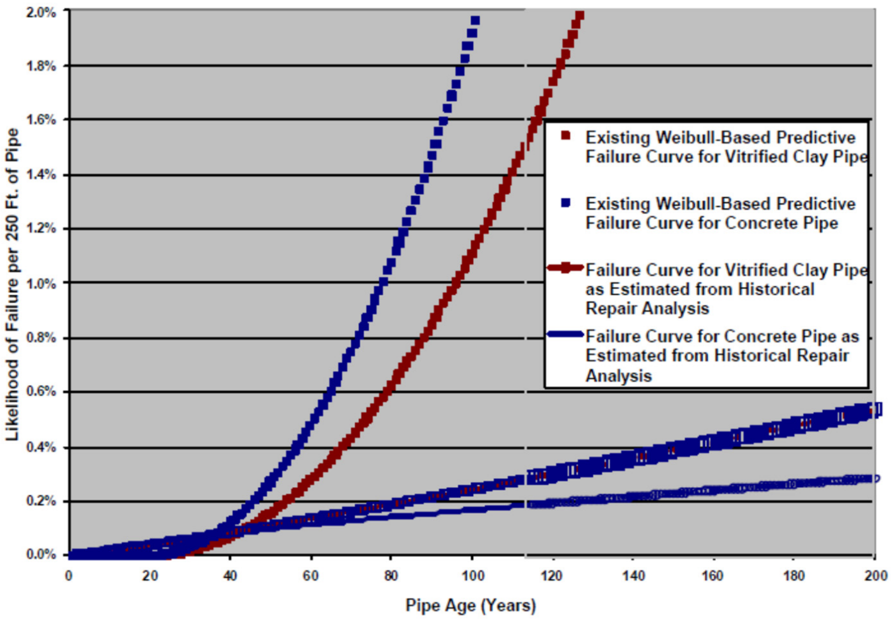


Figure 8-10 Seattle Public Utilities Comparing Pre- and Post- Study Failure Curves (T. Martin, D. Johnson & S. Anschell)

Research Opportunity 8.3	**Develop Failure curves for Predicting Expected Break rates** Analyse break rates to develop failure curves for predicting expected break rates for wastewater pipelines in New Zealand

Research Opportunity 8.4	**Develop deterioration curves for pipe materials and sizes** Analyse condition grades to develop deterioration curves for predicting expected condition of wastewater pipelines in New Zealand.

8.7 Probabilistic modelling

Probabilistic modelling predicts the likelihood that a pipeline will deteriorate to a particular condition. Figure 8-11 provides an example of a Markov probabilistic analysis undertaken by the NRC Institute for Research in Construction (NRC-IRC), based on sewer asset data obtained from eleven municipalities in Canada. Figure 8-11 shows the proportion of the network that could be expected to be in each condition grade as pipelines age. Table 8-11 shows the information in tabular form.

This data can then in turn be used to predict the likelihood of an individual pipeline deteriorating from one condition grade to the next within a given period. For example, at 10 years 9% of the pipelines are at grade 2 and none are in grade 3. Whereas at 20 years 2% of the pipelines are at grade 3. If it is assumed that all of the grade 3 pipelines were previously in grade 2, the likelihood of a 10-year-old pipeline that was in grade 2 moving to grade 3 is 22%, i.e. 2%/9%.

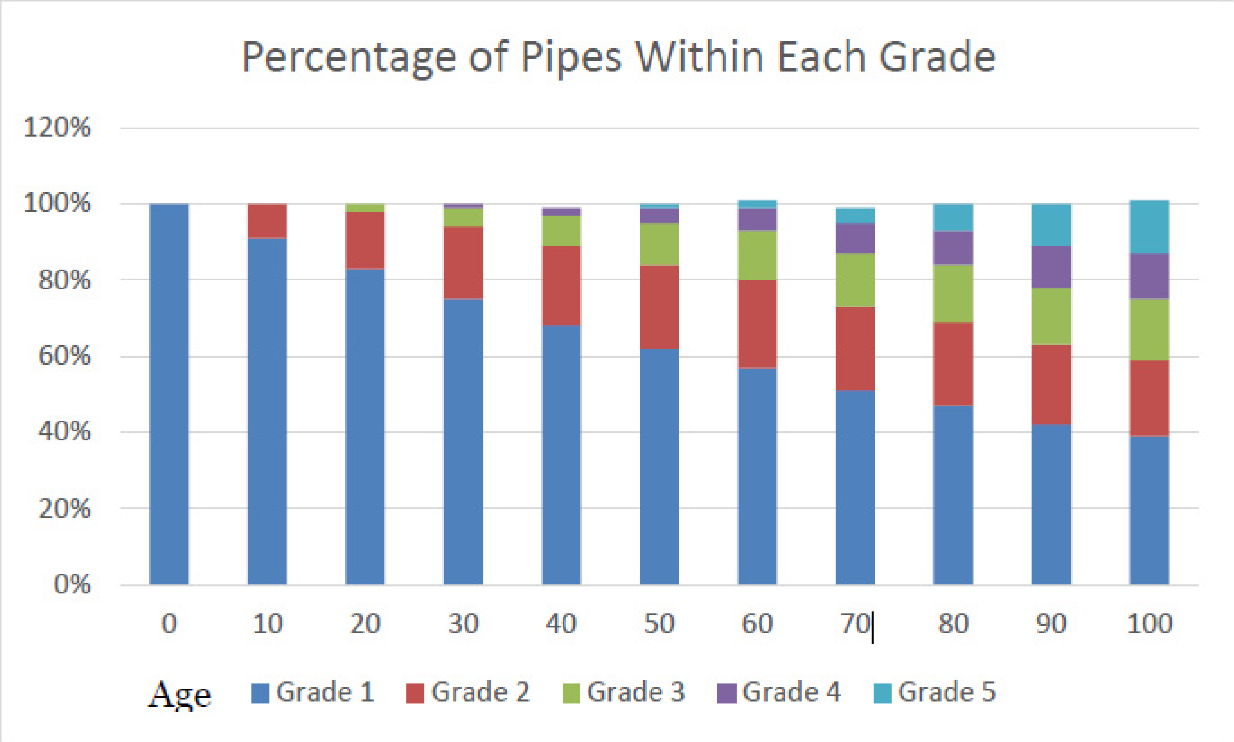


Figure 8-11 : Pipes falling within each grade

Table 8-11 Percent of pipes falling into each grade, by age

Age	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
0	100%	0%	0%	0%	0%
10	91%	9%	0%	0%	0%
20	83%	15%	2%	0%	0%
30	75%	19%	5%	1%	0%
40	68%	21%	8%	2%	0%
50	62%	22%	11%	4%	1%
60	57%	23%	13%	6%	2%
70	51%	22%	14%	8%	4%
80	47%	22%	15%	9%	7%
90	42%	21%	15%	11%	11%
100	39%	20%	16%	12%	14%

Case Study 9.8 shows how Auckland Council applied a similar approach to develop a pipe deterioration model for the pipelines in their network. Case studies 10.1 & 10.2 discuss how this deterioration model is then used to determine the timing of the first inspection and subsequent inspections.

Case Study 9.8	**Auckland Council** A pipe deterioration model for Auckland Council Stormwater was developed by first comparing the NRC-IRC model against condition information derived from a sample of 72km of CCTV inspections completed on the Auckland Council network in 2013/14. The model from NRC-IRC was then adjusted to better reflect the observed condition. For this exercise, a likelihood of failure score (LOF) was assigned based on the peak defects observed from the CCTV inspection rather than the condition grade derived from the New Zealand Pipe Inspection Manual.

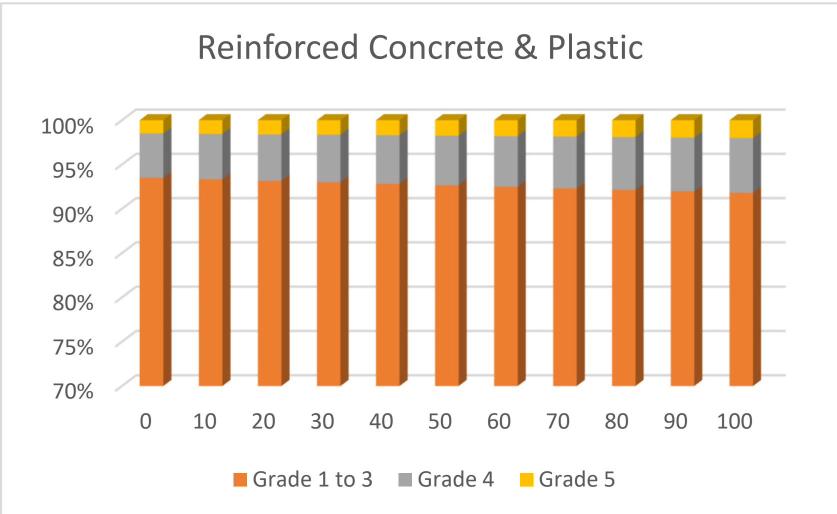


Figure 8-12 : Calibrated Deterioration Model – Reinforced Concrete & Plastic

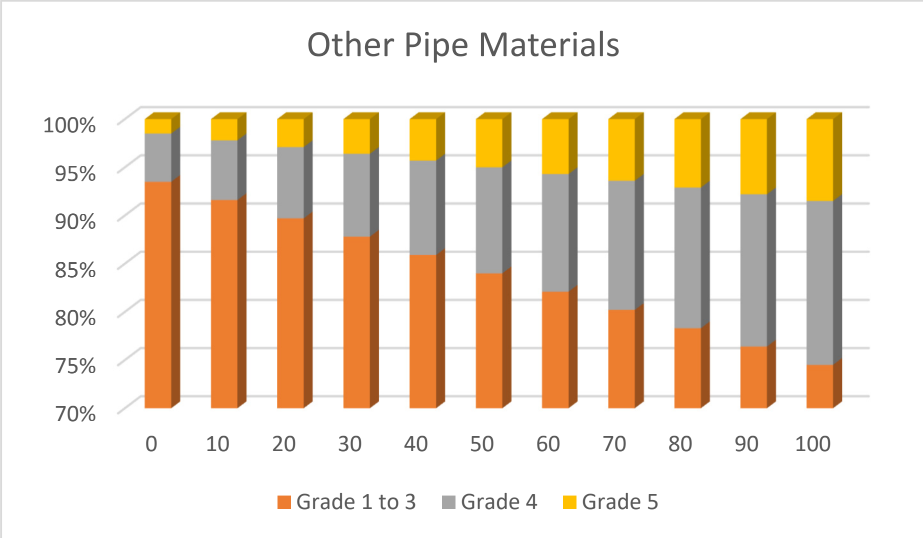


Figure 8-13 : Calibrated Deterioration Model – Other Materials

Research Opportunity 8.5	**Probability to failure models for asset groups not managed through whole-of-life performance methods** Creating probability to failure models for asset groups not managed through whole-of-life performance methods. These models are often used for potable pipes where condition monitoring is a challenge and failure probability is a more appropriate model.

9 Develop Intervention Strategies

9.1 Introduction

Having assessed the current performance of the wastewater network and how performance may change in the future, the next step is to determine the interventions that could be undertaken to maintain or improve levels of service.

This module describes the generic intervention strategies that are available and identifies their impact on performance measures which are developed at an asset group/class level.

The impact of interventions is considered from two perspectives; firstly, interventions to address specific issues not related to degradation and then issues to address pipeline degradation. The latter will eventually affect all pipelines in the network, whilst the former only affects some of the network.

The appropriate intervention strategy is selected through evaluation of whole of life costs and benefits from both degradation and non-degradation perspectives.

A risk-based approach is recommended for the management of degradation failures, as degradation rates for individual pipes cannot be predicted. In this way condition assessment is concentrated on those pipelines with the greatest consequence and/or likelihood of failure.

All renewals decisions involve an element of intuitive decision-making to address the many factors that need to be considered in reaching a decision to renew a pipeline. However, the quality of renewals decision making can be improved by documenting these intuitive judgements.

9.2 Available interventions

There are various interventions that can be undertaken including:

- Repair - replacing short sections of pipeline either reactively when pipelines fail or proactively repairing e.g. replacing faulty sections identified from CCTV inspections. The condition of the pipeline over the short section of pipeline replaced is improved but the condition of the remainder of the pipeline is unchanged. The capacity of the pipeline and all other performance attributes remain unchanged.
- Rehabilitation - a liner is installed within the pipelines to improve the condition, strength and water tightness of the pipelines. The capacity of the pipeline may be slightly reduced. Other parameters such as vulnerability are improved but the pipeline is exposed to the same hazards as the pipeline remains in the same position.

- Online renewal - the pipeline is replaced in its existing position. The size of the pipeline may be increased to improve capacity. Dips may be removed. However, the pipeline is still exposed to the same hazards.
- Offline renewal - the pipeline is replaced on a different alignment to the existing pipeline, offering the ability to increase capacity and reduce exposure to hazards. Criticality may be improved if multiple pipelines are installed.
- Storage - storage tanks are installed to reduce the size and frequency of wastewater overflow. Existing pipelines are unchanged.
- Maintenance - debris, roots and fats are removed from pipelines reducing the likelihood of operational failures such as dry weather overflows occurring. Other performance parameters are unchanged.
- Inspection: the condition of the pipeline is inspected e.g. CCTV inspection from which the likelihood of operational and strength related failures can be determined. Proactive interventions can then be undertaken if required.

The various interventions impact upon the performance measures in different ways as shown in Table 9-1. The challenge for the asset manager is to select the appropriate interventions and timing of the interventions, given the cost of the intervention and its impact on performance measure.

Table 9-1 Impact of interventions on performance measures

Metadata Cohort	Schema/ Decision Element	Repair	Rehabilitation	Online – Renewal	Offline – Renewal	Inspection	Maintenance	Storage
Health	Condition	BAO	New	New	New	NC	NC	NC
	Repairs, Maintenance & Operations	BAO	New	New	New	NC	Improve	NC
Capacity	Utilisation	NC	NC	Improve	Improve	NC	NC	Improve
	Demand	NC	NC	Improve	Improve	NC	NC	Improve
Sensitivity to surroundings	Vulnerability	BAO	New	New	Improve	NC	NC	NC
	Criticality	NC	NC	NC	Improve	NC	NC	NC
	Risk	BAO	New	New	New	Improve	NC	NC
	Resilience	NC	New	New	Improve	NC	NC	NC
Performance	Design Performance	NC	New	Improve	Improve	NC	NC	NC
	Financial Performance	NC	New	New	New	NC	NC	NC
	Service Performance	NC	New	New	New	NC	NC	NC

Key:

NC	No Change in performance measures
BAO	Performance measure returned to pre-fault level i.e. Bad as Old level
Improved	The performance measure is improved
New	The intervention returns the performance measure to “As new” level i.e. the performance measure is that of a new asset

9.3 Selection of interventions

As pipes age and deteriorate, the rate of collapse related repairs will increase thereby increasing cost, risk, service outages and disruption to the community. Eventually these issues will exceed tolerable levels and renewal will be required. This is the latest time for renewals intervention.

However, a lot of the network will likely require intervention before this time to address non-degradation issues such as operational, containment or capacity failures.

The impact of interventions is considered from two perspectives; firstly, interventions to address specific issues not related to degradation and then issues to address pipeline degradation. The latter will eventually affect all pipelines in the network, whilst the former only affects some of the network.

The appropriate intervention strategy is selected through evaluation of whole of life costs and benefits from both degradation and non-degradation perspectives.

9.4 Condition assessment - the role of risk in condition assessment and renewals planning

Condition assessment is a key part of the interventions strategy. Condition assessment is undertaken to estimate the risk of failure and to enable proactive interventions to be undertaken to keep the risk of failure below tolerable levels.

The risk approach acknowledges that it is neither practicable nor cost ineffective to collect all condition data on all assets. Condition assessment efforts are therefore prioritised so that higher-risk assets are inspected more frequently and at a more granular level.

Condition assessment may be targeted where performance monitoring indicates potential issues, i.e. higher than typical blockage rates, or where there is a high consequence of failure.

The NZAMS define consequence grades for wastewater pipelines. Assets with a high risk of failure are managed proactively to limit the frequency of failures whereas a run to failure approach is adopted for assets with a low consequence of failure.

Figure 9-1 shows the relationship between risk and the timing of interventions. Conceptually, interventions to reduce the likelihood of failure should be undertaken before the risk of failure exceeds the maximum level of risk that can be tolerated. Risk being the product of consequence of failure and likelihood of failure. The consequence of failure will remain largely constant throughout the life of a pipeline, but the likelihood of failure will typically increase as pipelines age. Therefore, the higher the consequence of failure, the earlier that the risk threshold will be reached, and intervention will be required.

Available interventions range from undertaking proactive repairs to avoid failure through to complete renewal of the pipeline. Generally, the greater the consequence of failure, the earlier the pipeline is renewed and the more often that condition is assessed.

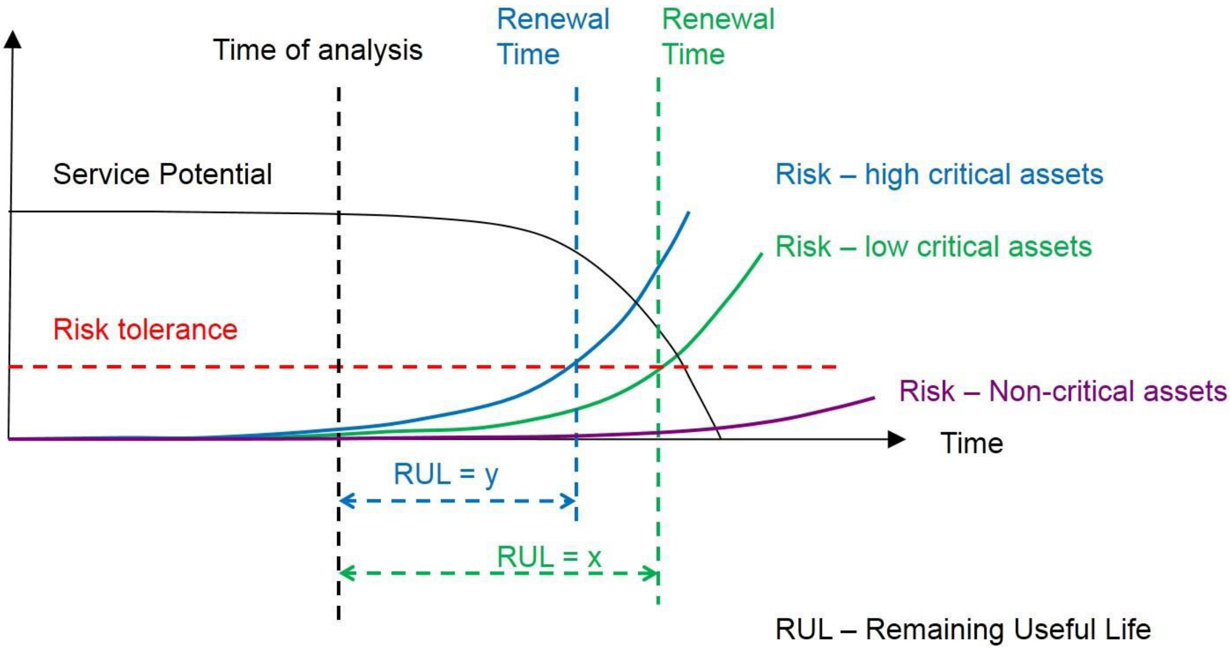


Figure 9-1 : Risk and Remaining Useful Life

Case study 9.1 provides an example of how risk management concepts are applied in practice to manage wastewater systems.

Case Study 9.1	**Auckland Council Risk Approach** Auckland Council adopt a risk management approach to manage pipelines in their stormwater network. The conceptual approach is shown in Figure 9-2. The approaches adopted in the various zones shown in the figure are as follows:

Run to failure	Assets with a low consequence of failure are permitted to fail and are repaired/renewed upon failure as this is generally the most cost-effective approach.
Predict	In this zone the focus is on predicting the likely condition of assets to determine when to intervene to keep the likelihood of failure below the threshold level. It is acknowledged that there can be a significant variance in the condition of assets and some assets may fail whilst in this zone, but the rate of such failures should be below the threshold level.
Proactive intervention	In this zone the condition of individual assets is assessed, and proactive works undertaken to ensure that the likelihood of failure threshold is not exceeded.
Avoid	The target is to avoid assets deteriorating to a state that the likelihood of failure exceeds the thresholds set. The higher the consequence of failure, the lesser the likelihood of failure that can be tolerated.

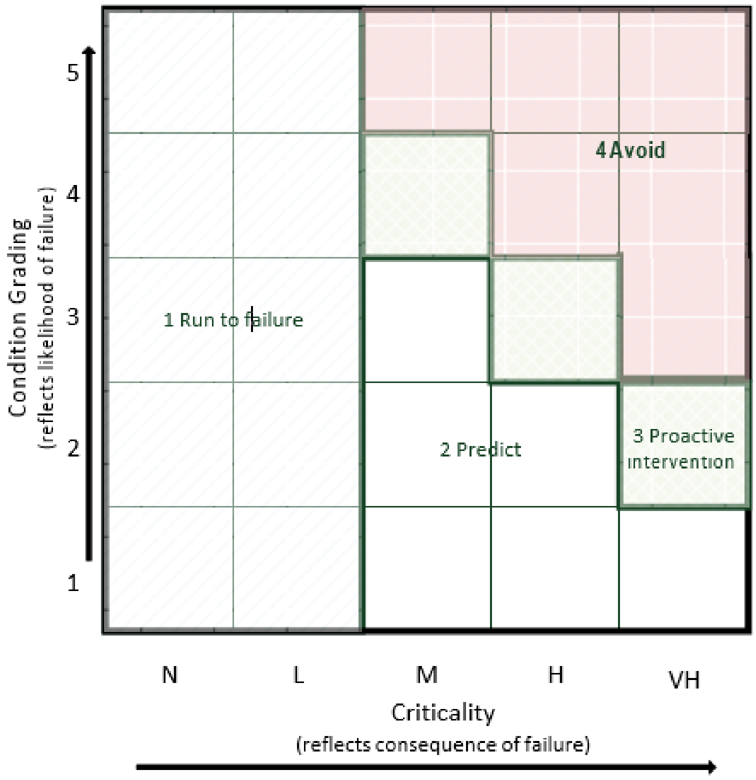


Figure 9-2 : Auckland Council Renewals Strategy Framework

This approach results in a mix of proactive and reactive works being undertaken as shown in Figure 9-3.

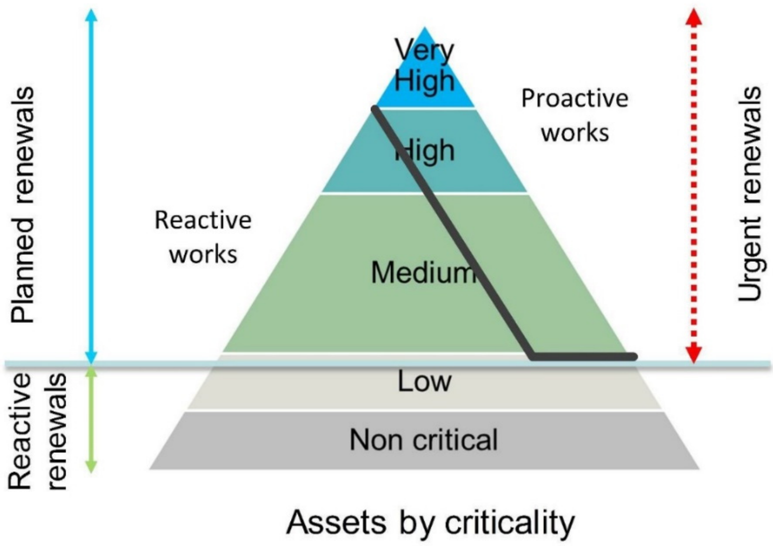


Figure 9-3 : Mix of reactive and proactive works

Determining the timing of the first inspection and subsequent inspections is discussed in Case Study 9.2.

Case Study 9.2 describes how the risk management approach can be applied to develop a condition assessment programme, defining the timing of the first inspection and then subsequent inspections.

Case Study 9.2

Auckland Council Inspection Schedule

The age at which a pipe should be inspected for the first time was calculated from the following formula:

$$Age\ 1st\ Inspection = Maxi\ Tolerable\ Likelihood\ of\ failure / Likelihood\ \ of\ Grade\ 5$$

Calculated dates for the first inspection are given in Table 9-2.

Table 9-2 Date of first inspection

Age	Age 1st Inspection (yrs.)		
Criticality	VH	H	M
Concrete & Plastic	15	20	30
Others	10	15	20

Subsequent Inspections for Repairs

If a pipe is known to be in a particular condition, it raises two questions:

- When should it be inspected again?
- Should it be repaired or replaced?

It was identified that a significant proportion of pipes that are Grade 4 will deteriorate to Grade 5. These pipes should be repaired as soon as practical.

For pipes in Grade 1 – 3 condition then the period to the next inspection was calculated using the formula:

$$Period\ of\ next\ inspection\ = \frac{maximum\ tolerable\ liklihood\ level}{likelihood\ of\ deteriorating\ to\ Grade\ 5}$$

Proposed Condition Assessment Programme

The condition assessment programme that has been developed from the above analysis is shown below.

Concrete, PVC & PE Pipes			
	Period to Inspection		
Criticality	VH	H	M
Age at 1st Inspection (yrs.)			
	15	20	30
Subsequent Actions if pipe found to be:			
Condition Grade 5	Repair/replace	Repair/replace	Repair/replace
Condition Grade 4	Repair/replace	Repair/replace	Repair/replace
Condition Grade 3	Re-inspect in 5 years	Re-inspect in 10 years	Re-inspect in 15 years
Condition Grade 1 & 2	Re-inspect in 10 years	Re-inspect in 15 years	Re-inspect in 20 years

Other Pipe Materials			
	Period to Inspection		
Criticality	VH	H	M
Age at 1st Inspection (yrs.)			
	10	15	20
Subsequent Actions if pipe found to be:			
Condition Grade 5	Repair/replace	Repair/replace	Repair/replace
Condition Grade 4	Repair/replace	Repair/replace	Repair/replace
Condition Grade 3	Re-inspect in 2 years	Re-inspect in 4 years	Re-inspect in 6 years
Condition Grade 1 & 2	Re-inspect in 10 years	Re-inspect in 15 years	Re-inspect in 20 years

9.4.1 Economic considerations

From a purely economic perspective the most appropriate time to renew a pipeline is when the cost of retaining the pipeline in service is no longer cheaper than replacing the pipeline with a new one. This is the point when the lifecycle cost is minimised.

This concept is shown in Figure 9-4. The lifecycle cost consists of two components:

- Cost of installation/renewal – the longer the pipeline remains in service the cheaper the annualised cost of installation/renewal
- Operations and maintenance costs – these are likely to increase the longer the pipeline remains in service, i.e. as the pipeline ages the frequency of repairs will most likely increase.

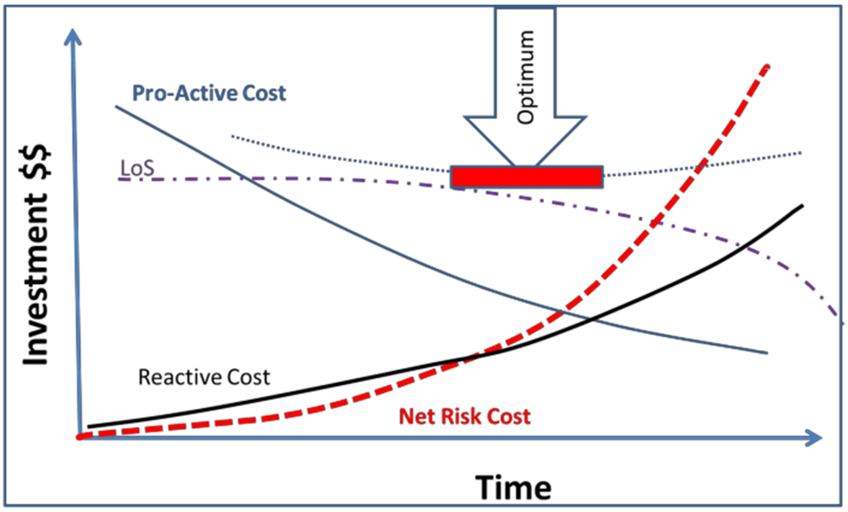


Figure 9-4 : Finding the Optimum Replacement Timing (Henning)

However economic considerations are not normally the primary driver for pipeline renewal. The example calculation in Case Study 9.3 demonstrates that at the optimum time for replacement from a purely economic perspective the failure rate is very high. In most cases pipelines are repaired well before this time due to level of service or risk considerations.

Case Study 9.3	**Optimum time for replacement**
	The optimum time to replace a pipeline from a purely economic perspective depends on the cost of undertaking repairs, renewal costs, financing costs and operating costs as shown in the following example. The following is an indicative assessment of the optimum time to replace a sample wastewater pipe. Consider 150mm diameter water main Cost of replacing 1km = $400/m x 1,000m = $400,000 Financing cost of delaying replacement by 1 year = 5% x $400,000 = $20,000 Cost of making a repair = $2000 Then optimum economic time to renew a pipeline is when the cost of repair of failure equals the cost of deferring replacement. = $20,000/$2000 = 10 failures/km/year = 1000 failures/100km/year

9.5 Operationalisation of renewals practices

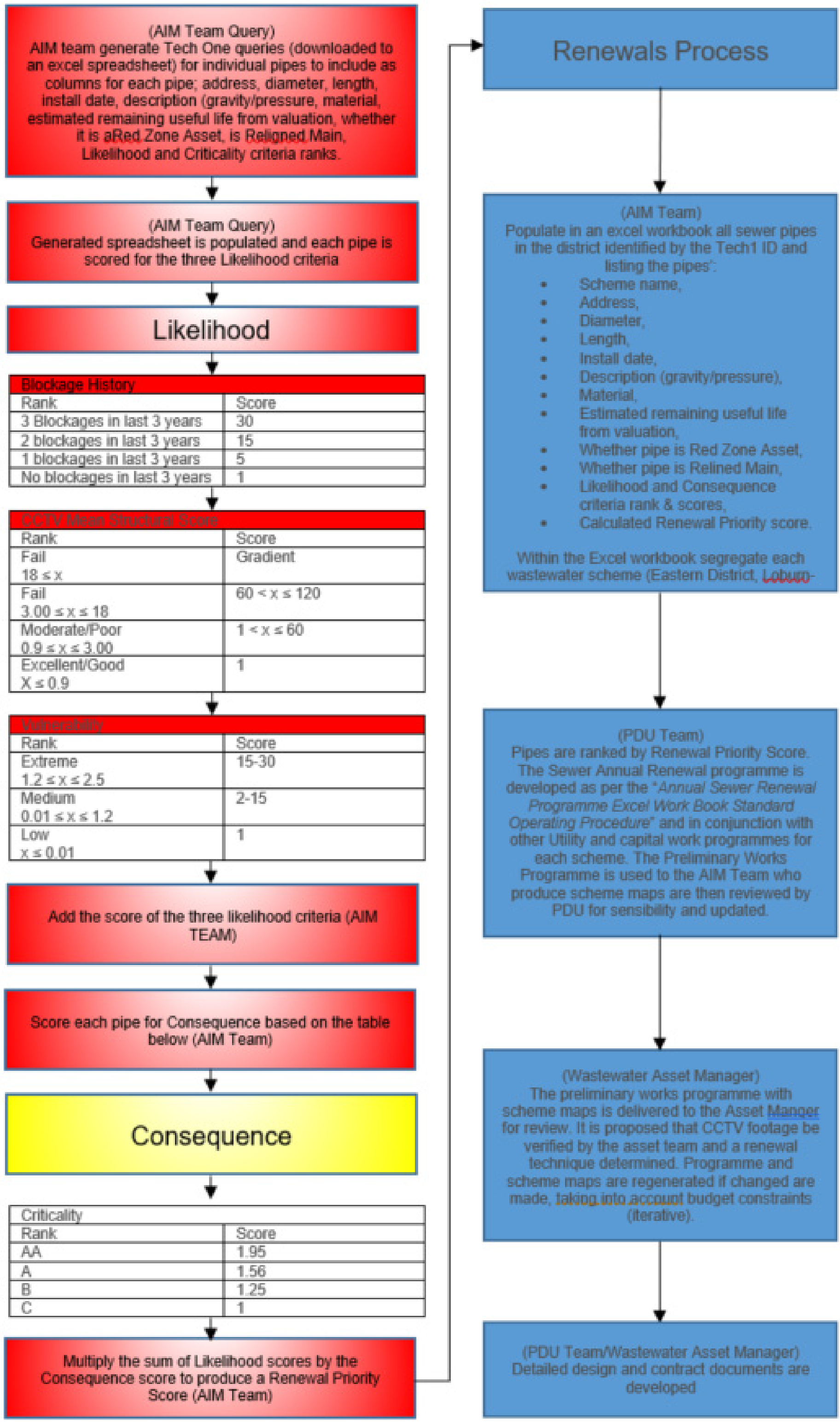
Whilst the principles of integrated asset management and renewals planning are generally well understood, there is significant room for improvement in the practical application of these principles at an operational level and in the standardisation of tools and approaches. There are many factors that need to be considered in reaching the decision to renew a pipeline. All renewals decisions involve an element of intuitive decision-making. However, the quality of renewals decision making can be improved by documenting these intuitive judgements. Case Study 9.4 discusses this in more detail. Case Study 9.5 provides an example the documentation developed by one organisation.

Case Study 9.4	**Masters Research Project** James Thorne, a master's thesis student at the University of Canterbury, has been investigating "Intuitive Decision Making for Wastewater Network Asset Management". His research has concluded that while the principles of integrated asset management are generally well understood, there is significant room for improvement in the practical application of these principles at an operational level and in the standardisation of tools and approaches. There are many factors which currently limit deterministic approaches to wastewater network asset management prioritisation including: ▪ Network complexity ▪ Socio-technical factors that are difficult to quantify ▪ Unknown causality and failure relationships ▪ Incomplete or low confidence data Given the barriers bulleted above, decisions often rely on expert judgement inputs. There is merit in this intuitive approach provided that an appropriate quality assurance process is applied. James identified documentation of intuitive judgements as one such way to improve the quality of wastewater network asset management decision-making. He developed and pilot tested a survey where decision makers can rank and record the significance of several factors that are taken into account when determining priority for investigation and renewal of pipes. The recorded significance scores could be used to benchmark future decisions, to pass on or transfer decision knowledge, to demonstrate processes applied for audit purposes or to be challenged and refined over time.

Case Study 9.5

Waimakariri District Data Renewals Planning Process

The process below has been developed by Waimakariri District Council to document their renewals planning process.



Research Opportunity 9.1	**Useful life, risk/criticality and whole-of-life costs of different pipe classes** Development of improved models for risk, useful life and whole-of-life models by material type, size, use, age, ground condition, hazard exposure.

Research Opportunity 9.2	**Optimised renewal investment** Defining the data requirements that lead to optimised renewal investment decisions. Testing the sensitivity to data availability and quality. Experiment with different analytical approaches to pipe renewals. These approaches include: ▪ Development of a decision logic algorithm that identifies the appropriate intervention criteria for deficient age, conditions and/or failure risk of pipes. ▪ Quantifying the impact of different treatment strategies with respect to return on investment.

10 Works Programme Development

10.1 Introduction

The final step is to draw together the previous modules to develop a works programme that documents future:

- Budgets
- Level of service predictions
- Risk & resilience profiles
- Monitoring and Condition Assessment programmes

The works programme feeds into the 30 Year Infrastructure Strategy, establishment of depreciation rates and funding plans and provides overall context for determining works to be undertaken on individual pipelines.

However, there are multiple different works programmes that an organisation may adopt. Selection of the works programme depends on financial constraints, level of service improvements and the level of risk that the organisation is willing to accept. Key decision makers and stakeholders must therefore be consulted in the works programme selection.

Establishing a works programme involves:

- Estimating the least cost budget by determining requirements for degradation related renewals, forecasting likely performance parameters and determining expected budgets.
- Identifying invention strategies to address non-degradation related issues e.g. growth, resilience and estimating costs and benefits of undertaking these interventions before degradation related renewals is needed.
- Presentation of the preferred intervention strategy, assumptions and uncertainty to decision makers stakeholders to agree an intervention strategy

10.2 Works programme development

The process of developing a works programme involves:

- Estimating the least cost budget, made up of:
  - Baseload of renewals required for general containment, capacity and blockages and due to interfaces with other works such as road renewals. Indications from the Watercare Wastewater network are that between 0.2% to 0.4% of the network is renewed annually for these reasons and this is largely unrelated to the age of the network (Case Study 8.3).
  - Replacement of pipelines that are vulnerable to degradation of the pipeline wall, e.g. asbestos cement pipelines. Case Study 8.5 indicates that once asbestos cement pipelines reach 30 years old about 1.5-2% of these pipelines will fail annually and require renewal.
- Estimate the expected rate of reactive repairs required for the least cost budget. Case Study 8.7 provides an example of how this can be done.
- Develop a risk-based condition assessment programme for the least cost budget option, refer Case Studies 9.1 & 9.2.
- Undertake network level master planning to identify specific pipes that are not delivering the required level of service, e.g. growth issues, wet weather overflows or resilience concerns. Determine appropriate intervention strategies for these pipes. Identify the cost of completing these renewals earlier than is required in the least cost budget. (refer Section 9).
- Present works program options to decision-makers and stakeholders together with assumptions and uncertainty. Enter into discussions to decide upon the preferred works programme given cost constraints and level of service and risk priorities, as discussed in this section.
- Document the process to operationalise renewals decisions, refer Case Study 9.4 for example.

It is often beneficial to complete the first step, estimate the least cost works programme, at the beginning of the renewals planning process, to give an indication of the scale of potential issues and enable the subsequent steps in the renewals planning process to be targeted where they may have the greatest impact.

Case Study 10.1 provides an example of a decision support tool that enables asset managers to consider various input scenarios and analytical methods, identifying uncertainties and the impact that these may have on renewal requirements.

Case Study 10.1

Renewals Planning Dashboard

The decision support dashboard developed for Hastings District Council's water supply pipework enables asset managers to develop robust renewals forecasts, that consider various input scenarios and analytical methods, identifying uncertainties and the impact that these may have on renewal requirements.

The dashboard was developed by Harmonic, in conjunction with IDS and Opus.

Renewal requirements are forecast using three different analytical methods, i.e. age driven, statistical based and the dTIMS optimised forecast. Through comparison of the forecasts, asset managers can gain an understanding of the uncertainties in the forecasts and the factors that influence these uncertainties.

The dashboard forecasts renewal quantities, costs and break rates. Information is shown graphically and spatially.

The impact that different levels of expenditure have on break rates can be compared using the dTIMS analysis. The sensitivity of predictions is reported.

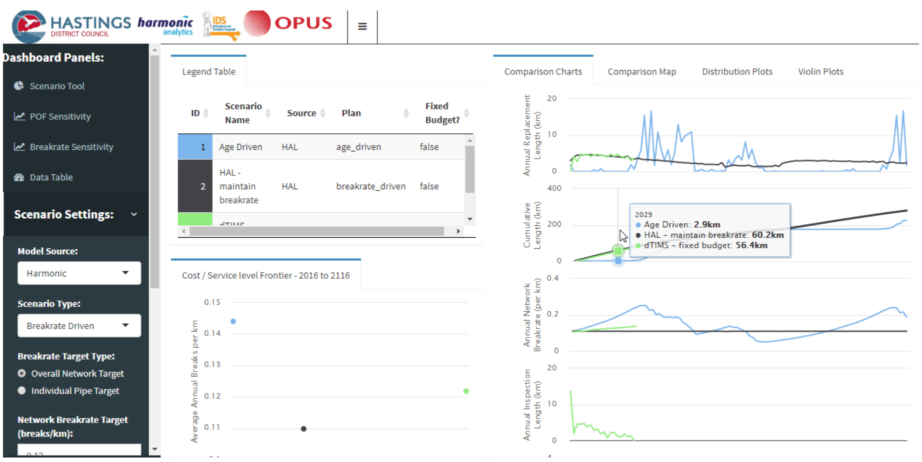


Figure 10-1 : dTIMS dashboard screenshot

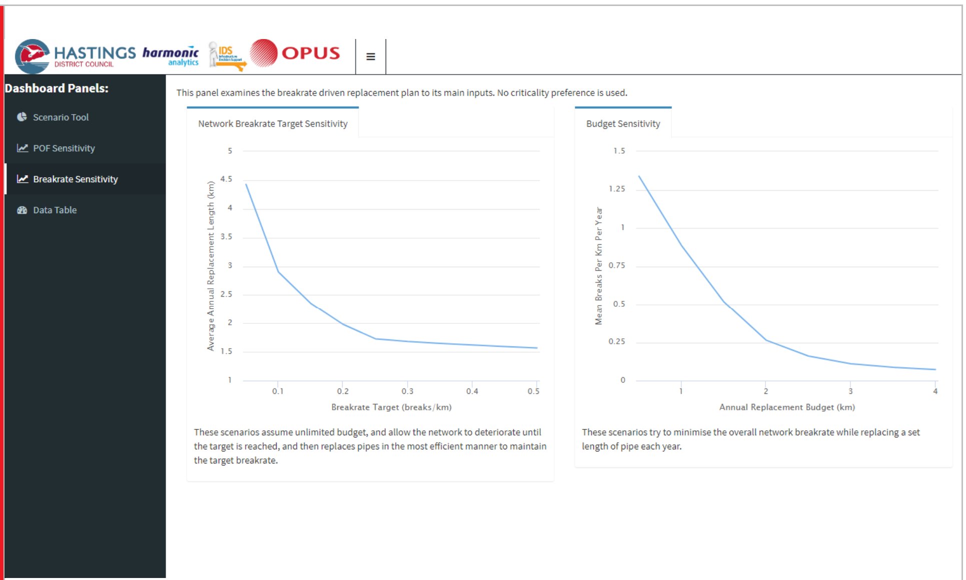


Figure 10-2 : dTIMS dashboard screenshot

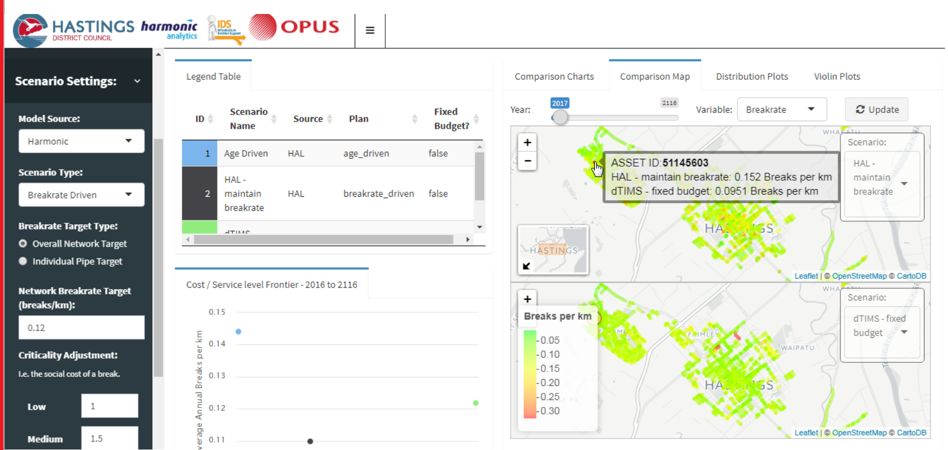


Figure 10-3 : dTIMS dashboard screenshot

10.3 Consulting with Stakeholders

It is essential that key decision makers and stakeholders be consulted in the selection of the works programme selection. As noted earlier, there are multiple different works programmes that an organisation may adopt. Selection of the works programme depends on financial constraints, level of service improvements and the level of risk that the organisation is willing to accept.

Case Study 10.2 outlines the "Smart Investment" approach adopted by Wellington Water in which they:

- Develop budgets for implementation of different strategies using available data on assets and network.
- Then compare impacts of different intervention strategies to objectively select appropriate strategy.

The key success factors of this approach are:

- Having a clear narrative for key decision makers
- Focussing on the service and customer outcomes
- Sharing the brutal facts on service performance
- Recognising that it's a journey, improvements may take several decades to implement.

Case Study 10.2	**Wellington Water Case Study** The Wellington region is facing significant challenges in delivering its three water services: ▪ Maintaining service after a seismic event ▪ Impacts from flooding ▪ Wastewater overflows to the environment ▪ Infrastructure required to enable growth ▪ Renewing aging infrastructure Councils that Wellington Water serve have significant areas of service performance requiring improvement. Improving service performance is a long-term objective that extends beyond the next 20 years. With the pace of performance improvement governed by the funding. To select a works programme, Wellington Water first develop a minimum cost works programme. They then assess the costs of bringing forward service improvements. The additional costs of service improvements are shown graphically, refer Figure 10-4. The full portfolio of improvements and the portion spent on each strategic improvement area is shown in Figure 10-5.

Figure 10-6 reinforces to key decision makers that steady progress is being made towards improving service, but it may take several decades. The figure also demonstrates that prioritising particular service improvements can have secondary benefits and result in improvements in other service areas.

These three figures succinctly present work programme options in a way that promotes discussion on priorities and trade-offs. Providing decision makers with the key information on cost and service improvement that is needed to collaboratively select a works programme.

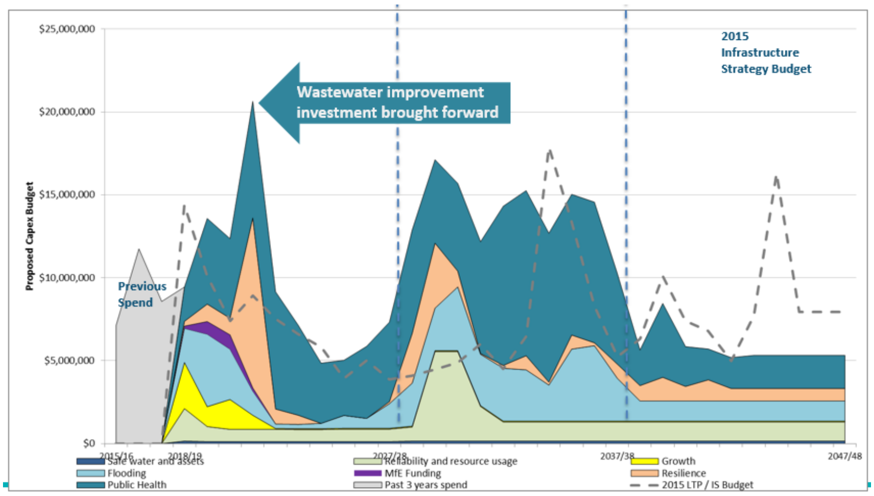


Figure 10-4: Impact of bringing forward investments

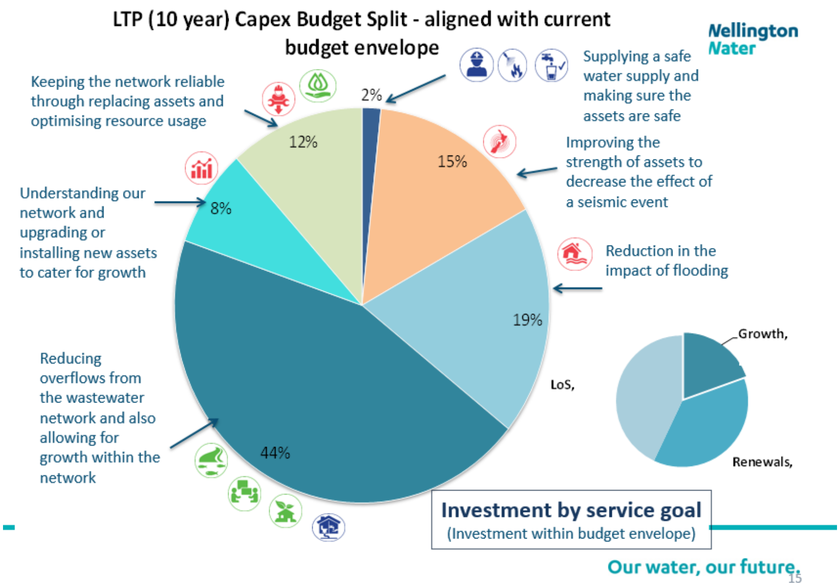


Figure 10-5 : Capex budget split

Three Water Outcomes	Service Performance Improvement (years)						Key Outcomes Achieved
	5	10	15	20	25	30	
Safe and healthy water	amber	amber	amber	amber	amber	green	• WW network improvement plan will lead to a significant reduction in waste water overflows, i.e. from one CBD location this will reduce from 12 to 2 overflows per year
Respectful of our environment	amber	amber	amber	amber	amber	green	• Upgrades to WWTP will significantly reduce the number of bypass discharges. Improved sludge mgmt. (dryer) will lead to reduction of disposal to landfill.
Resilient networks supporting the economy	red	red	red	red	amber	amber	• Hydraulic modelling across the 3Waters will allow understanding of network capacity issues (and agile planning for growth) • Stormwater upgrades will reduce the impacts of flooding in CBD and local areas and improve stormwater discharge quality • Increase water supply storage in low level zone for improving resilience levels of service and additional reservoir for growth • Upgrades of key reservoirs (from class D) and WW pump stations will also improve seismic resilience

Figure 10-6 : Progress tracking

11 Conclusions

The Pipeline Renewal Framework presented in this document provides a structured process to assist users obtain the desired level of service from their pipeline networks through renewals planning. Users can follow the entire Framework to guide them through the full journey of renewals or, select certain modules for adoption into their own renewals planning processes. In doing so, the pipeline renewal planning throughout New Zealand can be improved to achieve better outcomes, more efficiently.

Appendix 1 – Research Opportunities

Research Opportunity 2.1

Metadata standards development and application

It is proposed that industry/academic workshops be undertaken to define the pathways for implementing the NZAMS. This includes the process for developing the yet-to-be written volumes 3 and 4 of the Metadata Standards on Intervention Strategies and Analytics. It also includes re-working Volume 2 into a workable and pragmatic document based on Industry feedback.

Research Opportunity 6.1

Measuring resilience

Processes for measuring and reporting the resilience of pipe networks are not well defined. The Pipe Renewals Resilience Project, commissioned by the UC Quake Centre, will develop a framework for developing and reporting on resilience for a variety of natural hazards.

Research Opportunity 6.2

Testing of resilience measurement processes

Industry group to assess applicability/usefulness and gaps of process developed from Research Opportunity 6.1

Research Opportunity 7.1

Additional environmental attributes in New Zealand Metadata Standards

It is recommended that consideration be given to including the additional attributes shown in Table 7-2 in the next edition of NZAMS to enhance the identification of deterioration trends.

Table 7-2: Additional Data Attributes Recommended to be included in NZAMS Vol1.

Attribute Name	Assumed Effect on Deterioration Failure	Impact on Deterioration
Environmental Factors		
Exposure to Seawater	Pipelines closer to the coast may be more susceptible to deterioration	Medium
Contaminated Soils	Industrial wastes can increase the rate of deterioration of some pipeline materials. This is particularly relevant for PVC & PE pipelines	High
Traffic loading	Literature has contradictory findings. Shallow pipelines under roads may be more susceptible to traffic loadings. However, some authors have noted that pipelines under main roads are constructed to higher standards than pipelines under lightly trafficked areas	Uncertain
Other services	Pipelines may be damaged when other services are installed close by.	Medium
Pipeline Slope (Derived from Node Invert Levels & Length)	Steep wastewater pipelines are more susceptible to erosion. Flat pipelines are more susceptible to blockage.	Medium

Research Opportunity 7.2

Remaining life of asbestos cement gravity wastewater pipelines

Develop methods to predict the remaining life of asbestos cement gravity wastewater pipelines like what has been done for pressure pipelines.

Research Opportunity 8.1

National pipe data portal

Design and implementation of a data framework for aggregating pipe data for New Zealand pipes. This will be both testing and implementing a state-of-the–art data federation technology.

The creation of larger data sets which can be accessed by organisations which would otherwise have only small data sets will contribute to the identification of factors affecting the vulnerability of pipelines and the development of deterioration profiles.

Research Opportunity 8.2

Useful Life of Wastewater Pipelines

Reassess the useful life of wastewater pipelines and determine New Zealand standard lives.

Research Opportunity 8.3

Develop Failure curves for Predicting Expected Break rates

Analyse break rates to develop failure curves for predicting expected break rates for wastewater pipelines in New Zealand

Research Opportunity 8.4	**Develop deterioration curves for pipe materials and sizes** Analyse condition grades to develop deterioration curves for predicting expected condition of wastewater pipelines in New Zealand.

Research Opportunity 8.5	**Probability to failure models for asset groups not managed through whole-of-life performance methods** Creating probability to failure models for asset groups not managed through whole-of-life performance methods. These models are often used for potable pipes where condition monitoring is a challenge and failure probability is a more appropriate model.

Research Opportunity 9.1	**Useful life, risk/criticality and whole-of-life costs of different pipe classes** Development of improved models for risk, useful life and whole-of-life models by material type, size, use, age, ground condition, hazard exposure.

Research Opportunity 9.2	**Optimised renewal investment** Defining the data requirements that lead to optimised renewal investment decisions. Testing the sensitivity to data availability and quality. Experiment with different analytical approaches to pipe renewals. These approaches include: ▪ Development of a decision logic algorithm that identifies the appropriate intervention criteria for deficient age, conditions and/or failure risk of pipes. ▪ Quantifying the impact of different treatment strategies with respect to return on investment.

Appendix 2 Collection of Data on Existing Assets

Attribute Name	Contents	Data Source if Not Recorded During Construction	Assumed Effect on Deterioration Failure	Availability of data	Impact on Deterioration	Impact on Renewal Cost
Physical Attribute						
Pipe Type	Type of asset, e.g. Pipe, service main	Reviewing network arrangement	Service pipes are likely to deteriorate quicker than main pipes as they tend to be smaller, shallower and possibly installed to lesser standards.	High	High	Low
Pipe Shape	Shape of the pipe.	Visual inspection, CCTV	Literature is split on whether circular or egg-shaped pipelines deteriorate quicker	Medium	Uncertain	Nil
Length	Asset length in metres, e.g. 100.55	Manhole spacing's, CCTV	Longer pipelines are more likely to have defects due to the number of joints and pipeline barrels. Some literature sources state that longer wastewater pipelines are more susceptible to differential settlement that can cause blockage and sediment deposition, which in turn can facilitate pipeline deterioration.	High	Medium	High

Attribute Name	Contents	Data Source if Not Recorded During Construction	Assumed Effect on Deterioration Failure	Availability of data	Impact on Deterioration	Impact on Renewal Cost
Nominal Diameter	Nominal Diameter of the asset in millimetres, e.g. 450	Visual inspection, CCTV	Smaller diameter pipelines are generally more susceptible to damage and deterioration than larger pipelines. As larger diameter pipelines have thicker walls and are stronger than smaller pipelines.	Medium	High	High
Material	Material of the asset	CCTV	The various pipeline materials behave differently. Some can be more susceptible to deterioration than others.	Medium	High	Nil
Load Class	Pipe load class as specified by the manufacturer, e.g. Class 4	Excavated sample	The better the pipeline class the less susceptible to damage and deterioration	Low	Medium	Nil
Stiffness Class	Pipe nominal stiffness class as specified by the manufacturer, e.g. SN 4	Excavated sample	The greater the pipe stiffness the less susceptible to damage and deterioration	Low	Medium	Nil
Joint Method	Pipe to pipe joint method, e.g. RRJ	Excavated sample	Different types of joints behave and deteriorate differently. Joint type will generally be dictated by pipeline material but not always	Low	Medium	Nil

Attribute Name	Contents	Data Source if Not Recorded During Construction	Assumed Effect on Deterioration Failure	Availability of data	Impact on Deterioration	Impact on Renewal Cost
Design Life	Indicates the Manufactured Life / expected life on use. Design Life length in years	Inferred from pipe material	Design life does not directly correlate to the rate of deterioration.	Low	Low	Nil
Renewal Material	Relined or renewed material, e.g. Fibreglass	CCTV	The various rehabilitation materials behave differently. Some might be more susceptible to deterioration than others.	Medium	High	Nil
Environmental Attributes						
Ground Water	If there's ground water in the location.	Inferred from boreholes or excavations in vicinity	Fluctuations in groundwater can result in differential settlement. Wastewater pipelines below the water table may be more susceptible to infiltration which can cause loss of supporting soil. Acidic groundwater in peat soils may accelerated deterioration of the pipeline wall in concrete and asbestos cement pipelines.	Medium	Medium	Nil

Attribute Name	Contents	Data Source if Not Recorded During Construction	Assumed Effect on Deterioration Failure	Availability of data	Impact on Deterioration	Impact on Renewal Cost
Ground Type	Ground type on the site, e.g. BSLT	Geological maps	Pipelines in sand may be more susceptible to loss of ground support. Pipelines in clay may be more susceptible to ground movements	Medium	Medium	Mediu m
Bedding Type	Bedding Type	Excavated sample	Influence on deterioration rates is uncertain	Low	Uncertain	Nil
Haunching	Indicates whether haunching was required when laying the pipe.	Excavated sample	Influence on deterioration rates is uncertain	Low	Uncertain	Nil
Installation Attributes						
Construction Date	Date the asset was constructed/built/ installed EG: 12/03/2000	Inferred from other construction dates of other installations in the vicinity	The older the pipeline the more susceptible to deterioration failure. The influence of age may be overridden by other factors.	High	High	Nil
Cost	Cost of the asset determined at time of construction in dollars, e.g. 130.25	Inferred from similar installations in the vicinity	Not applicable	Low	Nil	Nil

Attribute Name	Contents	Data Source if Not Recorded During Construction	Assumed Effect on Deterioration Failure	Availability of data	Impact on Deterioration	Impact on Renewal Cost
Installation Method	Pipe installation method. EG: TR	Possibly able to be inferred from location/depth/material type	Effect is uncertain. Pipelines installed by open trenching may deteriorate differently to pipelines installed by drilling and other trenchless methods. However, there is little international research into the effect on installation method on pipeline performance.	Low	Uncertain	Nil
Manufacturer	Manufacturer of the asset	Nil	In some cases, manufacturing techniques or QA may influence deterioration rates but impact is uncertain	Low	Medium	Nil
Renewal Method	Relining or renewal method, e.g. cured in place, pipe burst, slip-lined	Possibly inferred from CCTV	Rehabilitation material is likely to have more influence on deterioration than the method of rehabilitation	Medium	Low	Nil

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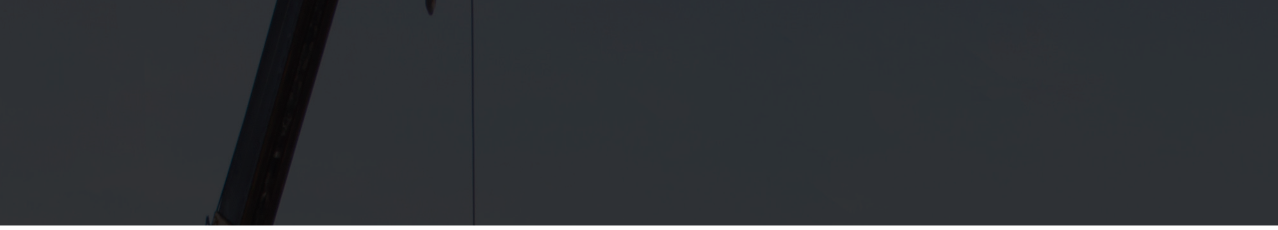

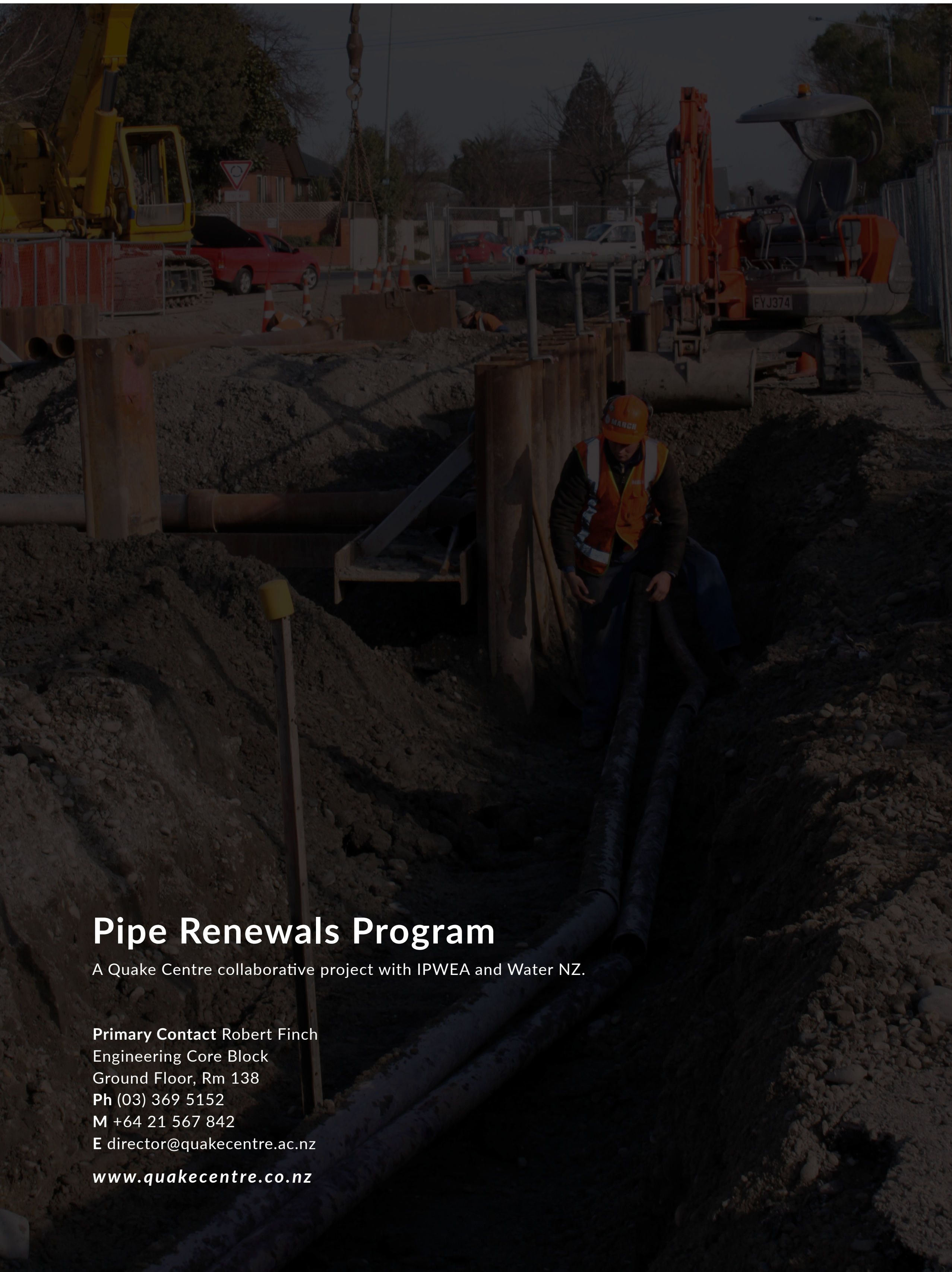

Pipe Renewals Program

A Quake Centre collaborative project with IPWEA and Water NZ.

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