ASSESSING WELLINGTON WATER'S PIPE CONDITION DATA CAPTURE

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A report developed for the Building Innovation Partnership at the University of Canterbury and Wellington Water by Cedric Papion, Stantec.

Reviewed by Dr Theuns Henning, Building Innovation Partnership and the University of Auckland

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Prepared by: ______________________
Signature

Cedric Papion
Printed Name

Reviewed by: ______________________
Signature

Ben Davies, Theuns Henning (Building Innovation Partnership)
Printed Name

Approved by: ______________________
Signature

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Printed Name

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Executive Summary

Data pertaining to pipe condition factors, defects and failures is collected, managed and used by different parts of Wellington Water's organisation. Over time, this had led to data sets that are hard to track, join and interpret as a whole.

Wellington Water has commissioned both the Building Infrastructure Partnership (BIP) and Stantec, via the University of Canterbury, to assess how pipe condition data is currently captured and how this may be improved, with a potential alignment with the future national water pipe failure database.

The Wellington Water pipe condition data is fragmented across several systems. Of these, the condition web map, currently in test phase, appears to be the most promising for the purpose of analysis failures and their causes, in conjunction with the Maximo work orders records.

This report presents the findings from Stantec's investigation, prepared for University of Canterbury.

Figure 0-1 summarises the issues identified. Table 0-1 captures the same information in a table format, along with options for consideration.

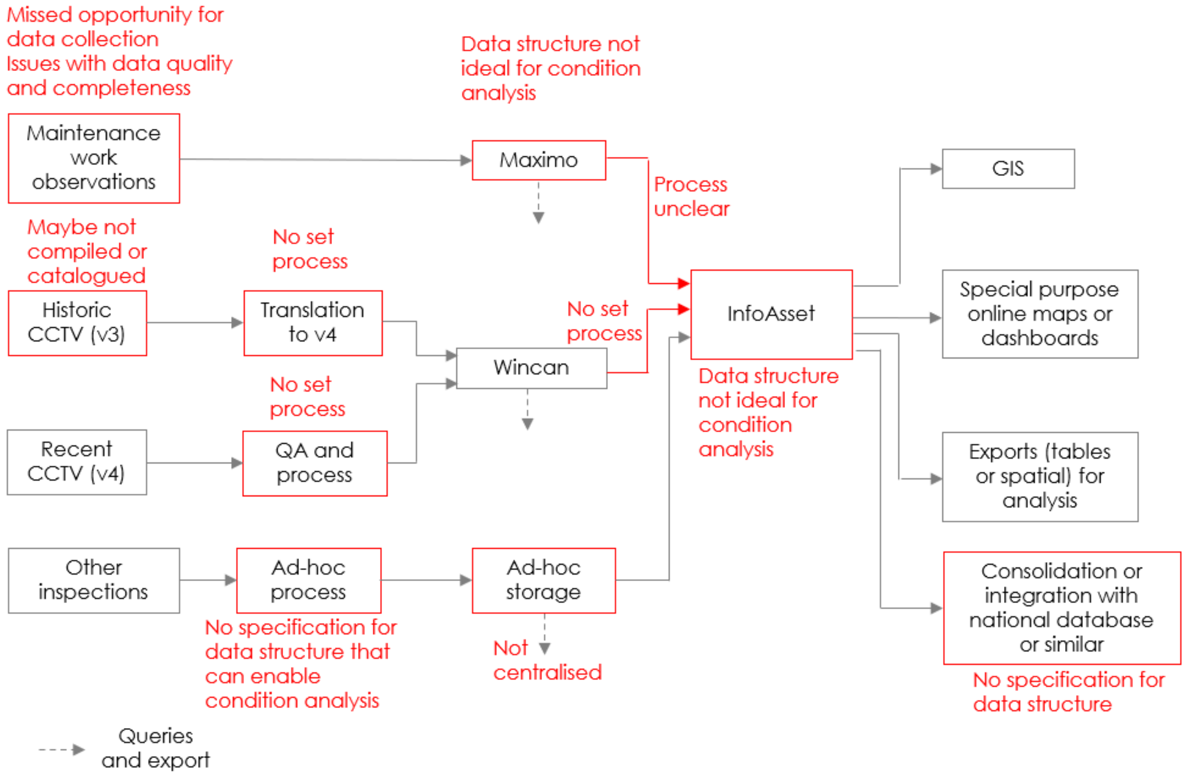

Figure 0-1: Pipe condition data map and summary of issues

Table 0-1: Summary of options

Issue	Option for consideration	Comment
The condition data collected during maintenance work is incomplete and unreliable.	Better understand current barriers to quality data capture – shadow maintenance crews, list issues, record opportunities.	
	Outline a role for dedicated data collection, working alongside maintenance crews when asset is accessible.	
	Improve interface, improve mandatory task system to support quality data capture.	
	Raise awareness of maintenance crews on purpose of data capture and, if required, educate on how to capture it.	
	Improve incentives, priorities or contract terms promoting quality data capture by field crews.	
	Increase the consistency of data capture across maintenance teams and depots.	
	Monitor technology developments in the field of computer vision to automatically detect and recognise features of the asset and its condition	For example, a manhole may be surveyed using a tablet with its key features recognised, measured and recorded (e.g. dimensions, inlet/outlet, wall condition), or defects may be automatically identified from a maintenance CCTV video.
The structure of the condition data collected during maintenance work is not ideal for condition analysis.	Modify the observation codes in Maximo so they align with the overall system (see Appendix B for a starting point).	This requires a common language for factors, defects and failures between Maximo and InfoAsset.
	Specify opportunistic data observations to capture (any defect/failure plus selected factors)	See Table 4-5 as a starting point
Historic CCTV may not be compiled or catalogued	Confirm if this is the case. If required, develop strategy for cataloguing and compiling into Wincan.	
Historic CCTV (v3) is not in the same format as recent CCTV (v4)	Investigate if a process already exists for using GPIM v3 data in a v4 environment. If not, develop one.	This should be considered at national level.

Issue	Option for consideration	Comment
There is no set process for loading recent CCTV (v4) into Wincan	Develop a set process, including QA in batches and consolidation at project completion.	We understand ProjectMax are working on this.
There may be no set process for exporting from Wincan into InfoAsset.	Investigate if a process already exists. If not, develop one.	This requires a common language for factors, defects and failures between Wincan and InfoAsset.
There is no standard structure for non-CCTV inspection data that can enable condition analysis	Expand the intervention guides to specify what condition factors, defects and failures should be recorded, when and how.	This requires a common language for factors, defects and failures. Water NZ are working on a pipe inspection manual for pressure pipes.
Non-CCTV inspection data is not centralised	Develop a set process to transfer non-CCTV data to InfoAsset.	
There may be no set process for exporting from Maximo into InfoAsset.	Investigate if a process already exists. If not, develop one.	This requires a common language for factors, defects and failures between Maximo and InfoAsset.
The structure of the data in InfoAsset may not be ideal for condition analysis and criticality score records	Confirm if this is the case. Confirm whether the data structure in InfoAsset can be altered. If appropriate, develop a data structure compatible with the other systems in use, including external ones such as other utilities or a national database of pipe failure (see Appendix A for a starting point).	This requires a common language for factors, defects and failures between water utilities.
The overall data flow path may not be ideal	Confirm if the current combination of data storage systems (Wincan, Maximo, InfoAsset) are the best option and whether direct data connections can and should be in place.	For example, field crew observations could be fed directly to InfoAsset (or equivalent) as well as Maximo.

Two work streams stand out as both challenging and providing a significant benefit.

The first one consists in standardising what data is recorded for condition factors, defects and failures. Ideally there would be a national standard for this but unfortunately it is not finalised at this stage. Unless more clarity is provided in the short term by the National Transition Unit (NTU) we suggest that a combination of the Pipe Inspection Manual and the BIP terminology provides a practical starting point, along with suggested improvements in Appendix A and B. This common language should be used across all systems (e.g. Wincan, Maximo, InfoAsset) if possible, and clear translation processes should be in place otherwise.

The second work stream consists in improving the condition data capture when the assets are accessible during maintenance work. This would likely require an improvement to the field device software as well as dedicated resources to undertake the data capture in conjunction with maintenance staff. It was initially intended to shadow maintenance crews to record barriers to data capture and list opportunities for improvement, but this could not be achieved due to operations staff workloads and availability.

Failures and defects are, in theory, already captured through the existing systems but additional condition factors could be collected opportunistically during maintenance. Table 0-2 lists key factors that could be recorded during maintenance work based on whether:

- They are not commonly and reliably recorded through other sources.
- They can easily be recorded during maintenance work.
- They add value for asset condition modelling.

Table 0-2: Key factors that could be recorded during maintenance work

Factor	Captured in GIS inventory (current or possible)	Captured during CCTV	Importance of capturing during maintenance (including reported / detected)
Diameter	Yes	No	High, easy, high value
Material	Yes	Yes	High, easy, high value
Lining	Not always	Rarely	High, only source
Coating	Rarely	Rarely	High, only source
Joint type	Rarely	No	High, only source
Slope	Yes	No	High value, may not be practical
Cover depth	No	No	High, only source
Trees near system	Rarely	No	High, only source
Groundwater level	Rarely	No	High, only source
Trench backfill	No	No	Medium, only source, value uncertain
Moisture content	Rarely	No	Medium, only source, value uncertain, may not be practical
Tidal influence	Rarely	No	Medium, only source, value uncertain, may not be practical
Pipe bedding	No	No	To be investigated
Corrosive impurities	No	No	To be investigated (duplicate?)
Corrosivity	No	No	To be investigated (duplicate?)
Sulfides	No	No	To be investigated (duplicate?)

We recommend that the next phase of the work confirms the need for addressing the issues identified and assesses the feasibility of the options proposed.

1 Introduction

1.1 Background

Information pertaining to pipe condition, defects and failures is used to support asset management decisions. This information is collected by different providers, through different projects and for different groups within Wellington Water. The data quality and structure vary and the overall data set is not easy to interpret and analyse. This situation is not unique to Wellington Water and most utilities face similar issues to different degrees.

Maintenance work requires field staff to access the asset and this is seen as a missed opportunity to capture asset data, beyond the requirement of the maintenance activity.

While data collected across the local networks is the most pertinent, it can be augmented by data collected across the country. This can support inferences and predictions of asset condition but requires some consistency in data collection methods and the definition of the terms used. The Building Innovation Partnership (BIP), based at the University of Canterbury, is working toward a national water pipe failure database to assist with the sharing of this information.

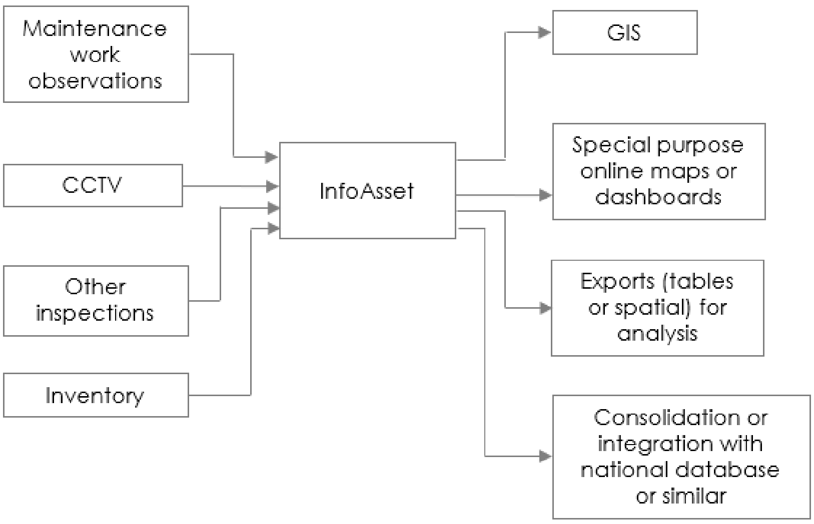

Figure 1-1: Simplified schematic of pipe condition data sources and uses

Wellington Water has commissioned both the Building Infrastructure Partnership (BIP) and Stantec to assess how pipe condition data is currently captured and how this may be improved, with a potential alignment with the future national water pipe failure database. This project is driven by BIP with input from the University of Canterbury, steering from University of Auckland and a contribution from Stantec to access the information and provide commentary (this report).

BIP is based in the Department of Civil and Natural Resources at the University of Canterbury. It works closely with the Department of Civil and Environmental Engineering at the university of Auckland as well as consultancies and contractors across NZ and overseas.

1.2 Objectives

The overall objective of the activity is to improve Wellington Water's ability to evaluate the condition of its asset, enable the prediction of asset condition and help plan interventions by linking causes to failures.

The specific objectives are to:

- Assess the current pipe condition data capture / record practices in the field.
- Identify possible issues and outline options for data capture improvements.

1.3 Scope

This work is not a comprehensive process mapping of data capture, management and use.

The scope of work is as follows:

- Undertake a cursory assessment of Maximo and CCTV records in terms of code frequency, completeness and alignment with BIP's typology.
- Discuss with Wellington Water's Digital Products and Services (DPS) team to outline the current field data capture system and understand the main barriers to better data capture.
- Propose improvements to the data capture systems.

The scope is limited to pipe assets, with a focus on gravity sewer pipes as a starting point.

More specifically, the primary focus is on maintenance data. It is however important to understand where this data goes, what it is used for and what other data it is used with – as such, this report also provides an overview of other data sources and how they overlap with maintenance data.

2 Condition data capture guidance

2.1 Introduction

Several documents propose frameworks to capture and record information pertaining to water pipe condition. These may be focused on factors contributing to failure (e.g. pressure rating or soil type), condition (e.g. location of a root intrusion or overall condition score) or failure (e.g. a sewer overflow).

This section summarises sources which are particularly relevant in the New Zealand context.

2.2 Water Services Reform Asset Data Standard

The Department of Internal Affairs (DIA), via the National Transition Unit (NTU), is in the process of developing a Water Services Reform Asset Data Standard. The version dated April 2023[1] includes a recommended water pipe data structure.

It includes proposed field names and values for aspects relevant to pipe condition:

- Some can be sometimes determined visually:
    - Bedding type
    - External coating
    - Jointing method
    - Material
    - Relining material
    - Depth
    - Diameter (external)
    - Diameter (internal)
    - Internal lining
- Some require as-builts or other desktop-type information:
    - Criticality rating
    - Data quality
    - Design resilience rating
    - Earthquake resilience design level
    - Relining date
    - Pressure rating

It does not contain any guidance on localised defects, condition, performance or failure history.

At the time of writing, we understand the Standard has not been formally adopted by Wellington Water.

[1] https://uploads-ssl.webflow.com/633baff82399315469c9838d/646aa32ac22c46352a6f3056_WSR%20Asset%20Data%20Standard_v3.4.docx

2.3 Gravity Pipe Inspection Manual

The NZ Gravity Pipe Inspection Manual (GPIM) was developed by Water New Zealand. Its latest edition, version 4, provides a detailed methodology for undertaking CCTV inspection, a list of codes for defect observations (Appendix A) and a method for calculating condition scores.

2.4 Wellington Water Intervention Guides

Wellington Water has developed a series of documents guiding internal processes for pipe condition assessments:

- Drinking water pipe asset intervention guide (2022)
- Stormwater water pipe asset intervention guide (2022)
- Wastewater water pipe asset intervention guide (2022)
- Condition assessment techniques for pipes – an intervention guide (2022)

These guides outline what to inspect, when, why and how. They have a strong focus on the link between causes and failure modes.

The guides provide a list of asset data required for planning and scoping interventions. Some of this data may in theory be collected opportunistically during asset inspection or maintenance. Some have a direct link with asset condition while other relates to the general asset configuration. In particular, the guides indicate that photographs should be taken, illustrating the following:

- Direct link with asset condition:
    - Type of ground conditions and bedding material.
    - Ground water level, if present.
    - Types of joints.
    - Corrosion protection system (if applicable).
    - Manufacturer's marking (on the pipes) with stamped pipe specification on pipe barrel.
- Asset configuration
    - For water valves: valve type and configuration.
    - For wastewater rising mains: upstream and downstream connections to pump stations, isolating valves or other pipework.
    - For wastewater gravity pipes: manhole configuration.
    - For stormwater pipes:
        - inlet structure type and associated protective works (e.g. debris screen)

- outlet / discharge structure type
- flow control structures for gravity systems
- other components such as fish passages and associated works.

The documents contain specific guidance on how to record failure modes. This is captured in Appendix 2 of the Drinking Water guide and Appendix 3 of the Wastewater and Stormwater guides. We note that the proposed failure modes for drinking water and stormwater are extremely detailed, while the list for wastewater is higher-level and probably more useful from the perspective of field data collection (Table 2-1).

Table 2-1: Failure modes (adapted from Appendix 3 of Wastewater intervention guide)

Failure mode category	Failure mode	Primary potential causes
Pipe, physical	Burst, blowout, split	Construction issues, corrosion, erosion, ground movement, impact, fatigue, pressure
Pipe, physical	Break, fracture	Excessive loading, construction issues, poor/loss of bedding support, bending, impact
Pipe, physical	Longitudinal splitting	Leaching, corrosion, erosion, ground movement
Pipe, physical	Circumferential failure	Construction defect, ground movement
Pipe, physical	Collapse	Leaching, corrosion, erosion, ground movement
Pipe, physical	Pitting	Iron/steel corrosion
Pipe, physical	Corrosion	H2S attack, iron corrosion
Pipe, hydraulic	Blockage	Root intrusion, eroded deposits, fat, sag or dips, collapse
Joint, physical	Joint failure	Acid attack, ground movement, construction issues, weld seam failure

3 BIP Typology (failure categorisation)

Many other systems have been proposed for capturing pipe asset data and condition data. University of Auckland (Tizmaghz et al, 2022) has reviewed these and proposed a system for classifying information pertaining to pipe deterioration. While the paper focuses on sewer pipes, the system can easily be adapted to other water pipe types. This system has been documented in a literature review (BIP, 2023) and adopted by the project team (April 2023) and is referred to in this document as "the BIP typology".

However, it is important to note that Wellington Water has not adopted this system. Alternative systems may be proposed at a later date, for example a direct copy of Watercare's system. The BIP typology is therefore a convenient reference for benchmarking, but is not a final standard to work to.

The BIP typology distinguishes three top-level categories: factors, defects and failures. As with any system there is room for interpretation and grey areas but overall it is relatively simple.

A "factor" may be the design pressure or the local ground conditions for example.

A "defect" may be a crack or a root intrusion.

A "failure" may be a sewer overflow or another "problem that requires immediate action". This makes failures easy to identify as they appear on a work register.

Factors contributing to the development of defects which in turn become failures. The term "factor" refers to the BIP typology in this report unless otherwise indicated.

We have slightly adapted the typology from the original paper to take into account key guidance document from Section 2, provide more clarity where needed and include water distribution pipes. Table 3-1,

Table 3-2 and Table 3-3 list the subcategories for failures, defects and factors.

Table 3-1: Failure classification (adapted from Tizmaghz et al)

Term	Class	Category
Pipe Collapse	Failure	Physical
Pipe Break	Failure	Physical
Major leak (distribution)	Failure	Physical
Overflow (drainage)	Failure	Hydraulic
Odour	Failure	Quality
Groundwater Contamination	Failure	Quality
Land Contamination	Failure	Quality
Surface Water Contamination	Failure	Quality
Coastal Contamination	Failure	Quality

Table 3-2: Defect classification (adapted from Tizmaghz et al)

Term	Class	Category	Group
Pipe Cracks - circumferential	Defect	Physical	Pipe
Pipe Cracks - longitudinal	Defect	Physical	Pipe
Pipe Cracks - multiple	Defect	Physical	Pipe
Pipe Holes	Defect	Physical	Pipe
Pipe Fractures	Defect	Physical	Pipe
Pipe Internal Corrosion	Defect	Physical	Pipe
Pipe External Corrosion	Defect	Physical	Pipe
Scouring	Defect	Physical	Pipe
Undetected Construction Damage	Defect	Physical	Pipe
Third-Party Damage	Defect	Physical	Pipe
Joints Cracks/Holes/Fractures	Defect	Physical	Joint
Joints Damaged Seal	Defect	Physical	Joint
Joints Pulled Out	Defect	Physical	Joint
Joints Extruding Seal	Defect	Physical	Joint
Joint Misalignments	Defect	Physical	Joint
Lining Tears/Breaks	Defect	Physical	Lining
Lining Scouring	Defect	Physical	Lining
Lining Corrosion	Defect	Physical	Lining
Lining Delamination	Defect	Physical	Lining
Lining Bulging	Defect	Physical	Lining
Deformed pipe	Defect	Physical	Lining
Voids	Defect	Hydraulic	Bedding
Sediments	Defect	Hydraulic	Deposits
Fog	Defect	Hydraulic	Deposits
Debris	Defect	Hydraulic	Obstructions
Roots	Defect	Hydraulic	Obstructions
Encrustation	Defect	Hydraulic	Obstructions
Permanent obstruction	Defect	Hydraulic	Obstructions
Groundwater Infiltration	Defect	Hydraulic	Undesirable inflow
Stormwater cross-connections	Defect	Hydraulic	Undesirable inflow
Oil	Defect	Quality	Release of undesirable substance
Fat	Defect	Quality	Release of undesirable substance
Grease	Defect	Quality	Release of undesirable substance
Wipes	Defect	Quality	Release of undesirable substance
Paper	Defect	Quality	Release of undesirable substance
Rubbish	Defect	Quality	Release of undesirable substance
Sanitary Products	Defect	Quality	Release of undesirable substance

Term	Class	Category	Group
Exfiltration	Defect	Quality	H2S production and release
Dissolved Sulphide	Defect	Quality	H2S production and release
Turbulence	Defect	Quality	H2S production and release
Splashing	Defect	Quality	H2S production and release

Table 3-3: Factor classification (adapted from Tizmaghz et al)

Term	Class	Category	Group
Land use	Factor	Design and construction	Planning and design
User connection density	Factor	Design and construction	Planning and design
Approach (combined/separate)	Factor	Design and construction	Planning and design
Pipe layout	Factor	Design and construction	Planning and design
Traffic load	Factor	Design and construction	Planning and design
Construction load	Factor	Design and construction	Planning and design
Interaction with other services	Factor	Design and construction	Planning and design
Shape	Factor	Design and construction	Pipe characteristics
Diameter	Factor	Design and construction	Pipe characteristics
Section length	Factor	Design and construction	Pipe characteristics
Material	Factor	Design and construction	Pipe characteristics
Lining	Factor	Design and construction	Pipe characteristics
Coating	Factor	Design and construction	Pipe characteristics
Joint type	Factor	Design and construction	Pipe characteristics
Design life	Factor	Design and construction	Pipe characteristics
Installation date (or age)	Factor	Design and construction	Installation properties
Installation method	Factor	Design and construction	Installation properties
Installation quality	Factor	Design and construction	Installation properties
Trench width	Factor	Design and construction	Installation properties
Slope	Factor	Design and construction	Installation properties
Cover depth	Factor	Design and construction	Installation properties
Pipe bedding	Factor	Design and construction	Installation properties
Trench backfill	Factor	Design and construction	Installation properties
Restraints	Factor	Design and construction	Installation properties
Maximum flow rate	Factor	Operational	Hydraulic operation
Maximum pressure	Factor	Operational	Hydraulic operation
Pressure range	Factor	Operational	Hydraulic operation
Corrosive impurities	Factor	Operational	Sewage composition
Sediments	Factor	Operational	Sewage composition
Acceptable FOG load	Factor	Operational	Sewage composition
Inspection regime	Factor	Operational	Maintenance strategies
Frequency of sewer cleaning	Factor	Operational	Maintenance strategies

Term	Class	Category	Group
Sewer cleaning method	Factor	Operational	Maintenance strategies
Quality of repairs	Factor	Operational	Maintenance strategies
Temporary loading	Factor	Operational	Temporary loading
Trees near system	Factor	Operational	Trees near system
Expansive properties	Factor	Environmental	Soil
Moisture deficit index	Factor	Environmental	Soil
Corrosivity	Factor	Environmental	Soil
Sulfides	Factor	Environmental	Soil
pH	Factor	Environmental	Soil
Redox potential	Factor	Environmental	Soil
Moisture content	Factor	Environmental	Soil
Groundwater level	Factor	Environmental	Soil
Wet/dry cycles	Factor	Environmental	Soil
Tidal influence	Factor	Environmental	Soil
Movement	Factor	Environmental	Soil
Frost penetration	Factor	Environmental	Soil
Sinkholes	Factor	Environmental	Soil
Rainfall	Factor	Environmental	Climate
Temperature	Factor	Environmental	Climate
Earthquakes	Factor	Environmental	Catastrophic events
Wildfires	Factor	Environmental	Catastrophic events

The typology does not inherently tie certain defects to certain failures: there can be multiple interactions between factors, defects and failures. Instead, it is meant to be the basis for a standard language to use for pipe data.

This study, therefore, assessed the pipe data through this lens:

- Can the existing data be mapped to the BIP typology?
- Are there critical BIP categories not informed by the current data?

4 Pipe data sources and commentary

4.1 Introduction

The primary focus of this study is the Maximo maintenance work orders' data. To assess what gaps this may have that cannot currently be filled with existing information, it is important to understand what this data is used with, where it goes and what it is used for.

The data sources considered for this work are:

- Maintenance work orders (Maximo).
- Standard inspection reports, through CCTV.
- Non-standard inspection reports, for example for pressure pipes.
- Asset information not related to defects and failures, such as GIS and InfoAsset.

For each data source, we provided a brief overview of the following:

- Output structure, completeness and reliability.
- Alignment with the BIP terminology.
- Opportunities for improvement, including opportunistic data capture.

4.2 Maintenance crew records / work orders

4.2.1 OVERVIEW

Fulton Hogan and Wellington Water use Maximo as a platform to record work orders for maintenance crews. These are effectively failures from the BIP definition. No data was available for failures outside the Maximo register, which include the problems that have been addressed through capital expenditure project, as opposed to operational activities recorded in Maximo.

The Maximo data covers the period from June 2020 and includes over 60,000 completed work orders across three water assets as of June 2023.

Field staff use mobile devices to record their activities and observations as the job progresses from an initial site walk-over through to investigation, completion and close-out. Certain data capture tasks are mandatory, other are optional.

4.2.2 STRUCTURE AND COMPLETENESS

The key aspects of the Maximo data that can assist with subsequent condition evaluation are:

- The date of the job.
- The "asset_id" associated with the job.
- The "cause_description" field (e.g. 'tree roots').
- The "problem_description" field (e.g. 'blockage').
- Any photos taken and attached to the job.

Also relevant is the "remedy_description" field, which describes the maintenance action taken. While it does not directly informs about the condition of the asset, it can help validate the remaining data fields.

Approximately half of the work orders have "asset_id", "cause_description" and "problem_description" fields populated.

Table 4-1: Maximo completeness

Category	Count	% with asset_id	% with asset_id, cause and problem
WS	43,381	56	52
WW	11,962	65	62
SW	8,025	48	44
Overall	63,368	57	53

The most common codes are presented in Table 4-2 to Table 4-4.

Table 4-2: Most common combinations - wastewater

problem_description	cause_description	Count
Blockage	Rags-Wipes - fabrics (clothes-underwear etc) - baby wipes	2122
Blockage	Tree Roots	1539
Blockage	Accumulation of Fat Residues - Fat bergs	298
Blockage	Accumulation of Residues	235
Blockage	No Issue Identified	214
Breakage	Cracked or Split	206
Breakage	Structural Collapse	174
Overflow (WET)	Overload - Beyond Capacity	167
Leak	Leak Confirmed - Unable to locate	142
Breakage	3rd Party Damage	117

Top categories only. June 2020 to May 2023

Table 4-3: Most common combinations - stormwater

problem_description	cause_description	Count
Blockage	Silt-Sediment	379
Blockage	Tree Roots	276
Blockage	Accumulation of Residues	267
Blockage	Rags-Wipes - fabrics (clothes-underwear etc) - baby wipes	258
Flooding	Extreme Weather Conditions	173
Leak	Leak Confirmed - Unable to locate	125
Breakage	Cracked or Split	106
Breakage	Structural Collapse	103
Service Cover Issue	Required Refitting	86
Dirty - Not clean	Lack of Maintenance	73

Top categories only. June 2020 to May 2023

Table 4-4: Most common combinations - potable water

problem_description	cause_description	Count
Leak	Joint Failure	7963
Leak	Seal - Gland Failure	4564
Breakage	Cracked or Split	2016
Operational Failure	Failure to close	1748
Breakage	Material Degraded	797
Leak	Faulty Installation	741
Breakage	Hole in Pipe	643
Operational Failure	Seized	525
Breakage	3rd Party Damage	431
Operational Failure	Faulty Installation	352

Top categories only. June 2020 to May 2023

Anecdotal feedback from DPS suggests that the field crews do not consistently populate the correct “cause_description”, “problem_description” and “remedy_description” fields. This varies between depots. At a high level it appears to be a combination of:

- Limited resource / time constraints.
- Data capture is a low priority compared to maintenance work (this itself may be driven by contract conditions, incentives and education on how the data gets used later on).
- Poor design of the data capture interface.
- Poor structure of the data system: the user has to select each of cause / problem / remedy in sequence, each choice restricts the subsequent options. This can be seen as a tree workflow in principle. However, there are multiple pathways possible to a similar remedy. The structure has not struck the right balance and is both restrictive and confusing.

It was initially intended to shadow maintenance crews to record barriers to data capture and list opportunities for improvement, but this could not be achieved due to operations staff workloads and availability.

The Maximo system is intended to record maintenance activities as part of the maintenance contract. The records therefore almost always relate to a failure, which required an action. There is currently no reason to capture defects (not requiring immediate action) or factors on their own within Maximo.

Maximo work orders can contain attachments. These are generally photographs taken by field crew. From a cursory review of randomly selected work orders, these appear to be generally pre-work site overviews, to be used for reinstatement purposes. They rarely provide any meaningful information about the asset condition. Notably, the photographs do not contain any of the information suggested by key guidance documents listed in Section 2.

The Maximo "cause_description" choices (Table 4-2 to Table 4-4) loosely align with the failure modes listed in Wellington Water's intervention guides appendices (Table 2-1). There is an opportunity for standardisation.

4.2.3 MAPPING WITH BIP TERMINOLOGY

All the failure terms from the BIP terminology can be collected during maintenance work. In fact, the maintenance records are the only source of information for failures, using the definition of "problem requiring immediate action". The "problem_description" field from Maximo (Table 4-2 to Table 4-4) broadly aligns with the BIP failure definitions (Table 3-1). A field mapping is provided in Appendix B.

Most defect terms from the BIP terminology can conceivably be collected during maintenance work. These observations can be also obtained through CCTV inspections but the maintenance work provides an opportunity to collect recent information pertaining to a failure. The "cause_description" field from Maximo (Table 4-2 to Table 4-4) broadly aligns with the BIP defect definitions (

Table 3-2), and to a certain extent it can be mapped to the GPIM codes. A standardisation of the language would be beneficial.

Condition factors are currently not captured during maintenance work.

4.2.4 OPPORTUNITIES FOR IMPROVEMENT

The identified avenues for improvement on the Maximo system for the purpose of condition assessment can be grouped in two categories:

- Improve the data structure.
- Improve data capture.

Improve the data structure

A standardisation of the language across Wellington Water's asset management guidance documents, Maximo and InfoAsset (see Section 4.4 on data consolidation) would be beneficial.

The Maximo data structure currently only allows one type of defect to be recorded for a given work order ("cause_description"). However, the maintenance work is an opportunity to capture potentially multiple observations.

The actual location of the observation currently cannot be captured, only the pipe id (at best). This could be added as an option.

Table 4-5 lists key factors that could be recorded during maintenance work based on whether:

- They are not commonly and reliably recorded through other sources.
- They can easily be recorded during maintenance work.
- They add value for asset condition modelling, based on the wastewater renewals framework (Quake Centre) and the condition modelling work undertaken by BIP.

Appendix C provides a full list, including failures and defects.

Table 4-5: Key factors that could be recorded during maintenance work

Factor	Captured in GIS inventory (current or possible)	Captured during CCTV	Importance of capturing during maintenance (including reported / detected)
Diameter	Yes	No	High, easy, high value
Material	Yes	Yes	High, easy, high value
Lining	Not always	Rarely	High, only source
Coating	Rarely	Rarely	High, only source
Joint type	Rarely	No	High, only source
Slope	Yes	No	High value, may not be practical
Cover depth	No	No	High, only source
Trees near system	Rarely	No	High, only source
Groundwater level	Rarely	No	High, only source
Trench backfill	No	No	Medium, only source, value uncertain
Moisture content	Rarely	No	Medium, only source, value uncertain, may not be practical
Tidal influence	Rarely	No	Medium, only source, value uncertain, may not be practical
Pipe bedding	No	No	To be investigated
Corrosive impurities	No	No	To be investigated (duplicate?)
Corrosivity	No	No	To be investigated (duplicate?)
Sulfides	No	No	To be investigated (duplicate?)

Improve data capture

The data capture interface would need to be modified to reflect a standard language, to allow the capture of multiple defect observations and the capture of new condition factors.

Different strategies can be proposed to improve the data capture itself.

The first strategy consists in achieving a better data capture from the maintenance crews. This would require resourcing, educating, incentivising, supporting and monitoring maintenance crews. It may be integrated in the Maximo interface by extending the use of mandatory tasks. It is hard to imagine how this could be successfully implemented in the current context of high turnover and pressure over urgent maintenance.

The second strategy consists deploying dedicated data capture resources that would work alongside maintenance crews when the asset is accessible.

A combination of both may also be considered, with for example, some routine data captured by maintenance crews and special cases covered by dedicated resource.

We suggest the following avenues for consideration.

Table 4-6: Opportunities for improvement - Maximo

Issue	Option for consideration	Comment
The condition data collected during maintenance work is incomplete and unreliable.	Better understand current barriers to quality data capture – shadow maintenance crews, list issues, record opportunities.	
	Outline a dedicated data collection role working alongside maintenance crews when asset is accessible.	
	Improve interface, improve mandatory task system to support quality data capture.	
	Raise awareness of maintenance crews on purpose of data capture and, if required, educate on how to capture it.	
	Improve incentives, priorities or contract terms promoting quality data capture by field crews.	
	Increase the consistency of data capture across maintenance teams and depots.	
	Monitor technology developments in the field of computer vision to automatically detect and recognise features of the asset and its condition	For example, a manhole may be surveyed using a tablet with its key features recognised, measured and recorded (e.g. dimensions, inlet/outlet, wall condition), or defects may be automatically identified from a maintenance CCTV video.
The structure of the condition data collected during maintenance work is not ideal for condition analysis.	Modify the observation codes in Maximo so they align with the overall system (see Appendix B for a starting point).	This requires a common language for factors, defects and failures between Maximo and InfoAsset.
	Specify opportunistic data observations to capture (any defect/failure plus selected factors)	See Table 4-5 as a starting point

4.3 Condition assessments

4.3.1 CCTV

4.3.1.1 General

CCTV inspections form the bulk of the pipe condition assessments. They are almost exclusively undertaken for gravity sewer and stormwater pipes. The output of CCTV inspections includes a video footage, a report-format list and location of observations (log sheet) and two condition scores (operational and structural).

CCTV inspections identify defects, sometimes failures and more rarely factors. CCTV inspections are sometimes combined with laser / sonar which provide additional information on the shape and internal diameter of the pipe.

4.3.1.2 Historical inspections

Wellington Water regularly commissions contractors to undertake CCTV inspections. The bulk of the historical inspections has been carried out according to version 3 of the NZ Gravity Pipe Inspection Manual (GPIM).

Historically, these inspections have been requested by various groups within Wellington Water, without much coordination.

Wellington Water has developed a GIS map[2] indicating which pipes have been surveyed, the condition score for the pipes surveyed including the video footage, and the location and details of observations. This map is still in a test phase and it is not clear how much of the historical CCTV is currently, or will eventually be included.

[2] https://gis.wellingtonwater.co.nz/portal/apps/instant/media/index.html?appid=dd329529e04b447f9288170fa0c7a717#

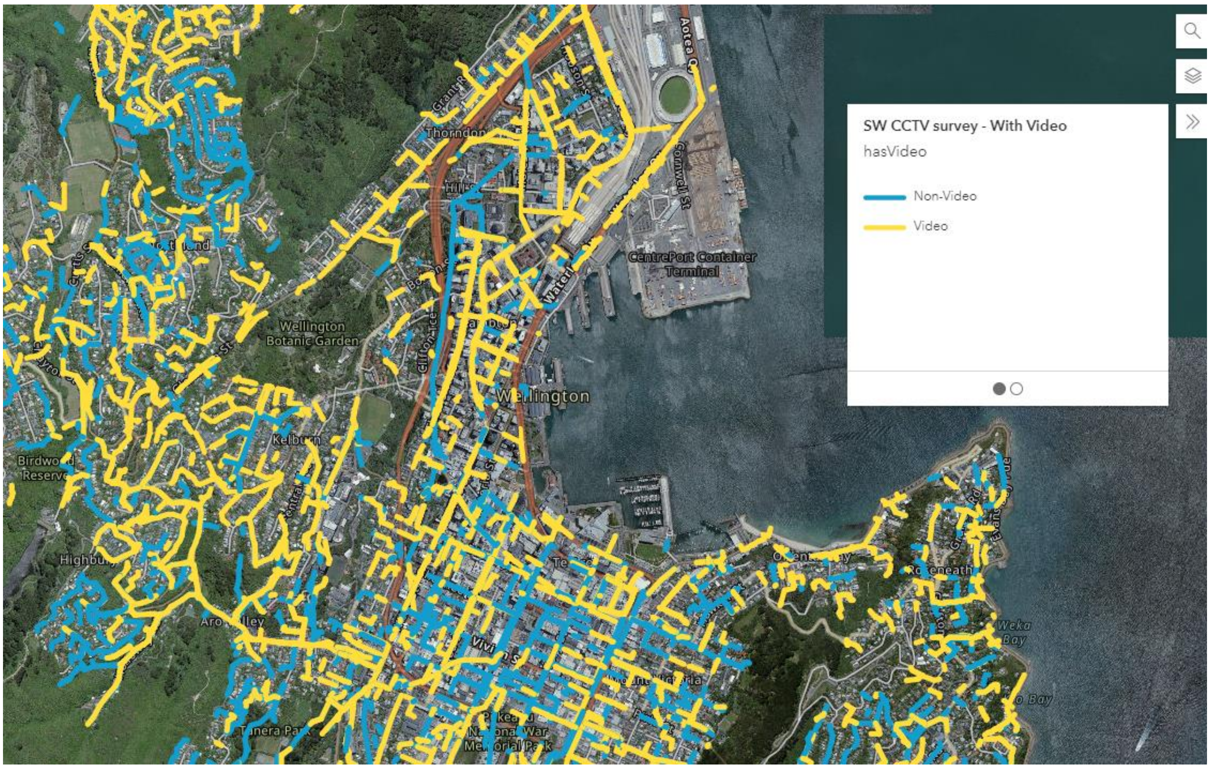

Figure 4-1: Map showing the extent of CCTV surveys

Wellington Water has a Wincan software license for managing and accessing CCTV data. We understand that this is currently being rolled out, with CCTV gradually pushed to Wincan.

At least in part, the observations and condition scores from the CCTV inspection are ported via the Wincan software to Wellington Water's InfoAsset system. At the time of writing, an extract of this data could not be provided so we cannot comment on it.

4.3.1.3 Recent inspections

Recent inspections were undertaken using version 4 of the manual, which was released in 2021. Version 4 includes more detail for certain observation codes, different code categories, more guidance for laser surveys and a different method for calculating operational and structural scores. Outputs and summaries from the two versions are therefore not directly comparable.

Of particular note are the inspections undertaken as part of the Very High Criticality Asset condition assessment (VHCA). Over 200km of pipe were inspected in 2020-21, mainly gravity sewers. This work was managed by ProjectMax, which quality-checked the output provided by inspection contractors, calculated condition scores and proposed an engineering assessment of major issues identified by the inspection. This is relevant for this study not only because the assets are, by definition, critical but also because this is one of the few extensive, quality-checked and consolidated inspection report datasets undertaken under version 4 of the GPIM. This is therefore the best example of what may be available from CCTV inspections from this point onward.

The inspection video files and log sheets are uploaded by the inspection contractor to the Wincan cloud platform in batches. From there, quality checks and corrections can be undertaken. All the batches of a given project are subsequently merged and ready for use. At that stage, the video files and log sheets can be downloaded via the online application and analysed or exported via a desktop Wincan application. Project Max are in the process of developing specifications for this workflow to make it easier to compile, manage and query.

Currently, only the VHCA inspections are stored in this platform. Only part of these inspections have been merged at project level and are ready to use at scale.

4.3.1.4 Structure and completeness

ProjectMax's review indicates that CCTV data collected prior to 2015 is generally of poor quality and not suitable for condition assessment. The 2015-2021 data is of average quality and does benefit from quality checks but can be used for condition assessment.

It is not clear to what extent the historical (2015-2021) CCTV inspection observation and scoring can and should be used. On one hand, the reliability is limited, the information is dated and the compatibility with recent standards is imperfect. On the other hand, the volume of data obtained through the historical CCTV inspections may justify accepting these limitations.

The recent CCTV inspection datasets developed under GPIM v4 can be considered as a good starting point overall for condition assessment.

4.3.1.5 Mapping with BIP terminology

The GPIM v4 is the industry standard for the coding of observations; the observation codes and scores from the reports undertaken under this version should therefore be retained without changes.

It may be useful to augment this information with the corresponding factors / defect / failure code in the BIP typology. This would facilitate subsequent analysis where CCTV observations are used in conjunction with other datasets.

A field mapping for GPIMv4 codes to the BIP typology is proposed in Appendix A.

4.3.1.6 Opportunities for improvement

We suggest the following avenues for consideration.

Table 4-7: Opportunities for improvement - CCTV

Issue	Option for consideration	Comment
Historic CCTV may not be compiled or catalogued	Confirm if this is the case. If required, develop strategy for cataloguing and compiling into Wincan.	
Historic CCTV (v3) is not in the same format as recent CCTV (v4)	Investigate if a process already exists for using GPIM v3 data in a v4 environment. If not, develop one.	This should be considered at national level.
There is no set process for loading recent CCTV (v4) into Wincan	Develop a set process, including QA in batches and consolidation at project completion.	We understand ProjectMax are working on this.

4.3.2 PRESSURE PIPES

4.3.2.1 General

CCTV inspection is not commonly used for pressure pipes. These tend to be smaller and therefore harder to fit in for a camera. Water supply pipes tend to be harder to bring offline and there are contamination concerns. Importantly, the failure mechanisms for pressure pipes differ from those of gravity pipes and a visual inspection will likely not reveal signs of weakness.

Other techniques are used to evaluate the condition and/or remaining life of pressure pipe asset (Pancholy et al, 2020, Wellington Water's intervention guide for condition assessment techniques, 2022). Leak detection techniques are commonplace but they only identify defects or failures once it is too late to prevent them. Following the BIP terminology principles, a water supply defect would be a leak small enough to be undetected, a water supply failure would be a leak large enough, visible enough or old enough to be detected and therefore warrant a work order.

Wellington Water regularly commissions contractors to undertake leak detection on the water supply network. Leaks identified are added to a register for open leaks, along with leaks visible from the street and reported by the public. Reported leaks constitute the vast majority of the recorded leaks.

A few commercially available techniques estimate the remaining wall thickness, which is a factor that can be used to identify a defect risk before it occurs. For ferrous and asbestos pipes, or those with cement lining, a gradual reduction in wall thickness is a common occurrence over time and this provides a good insight in the condition of the pipe. However, this does not detect instances of pitting, a joint about to fail or even a plastic pipe about to crack.

Consequently, inspections other than CCTV are more complex and provide less insight; they are therefore only used for asset perceived as critical and are relatively rare. No data pertaining to non-CCTV inspection was compiled or assessed as part of this study but we understand that data produced by these inspections varies significantly in its format, structure and content.

We also understand that Water New Zealand is currently working on an inspection manual for pressure pipes.

Once this is released, we recommend reviewing how Wellington Water pipe condition data is recorded and managed against this manual.

4.3.2.2 Structure and completeness

Leak reported by the public or detected by specialised teams are recorded by the Customer Hub in an Open Leak register and eventually in the Maximo system, which is described in the next section.

There is no standard structure for data generated through other, non-CCTV inspections for pressure pipes.

4.3.2.3 Mapping with BIP terminology

The BIP terminology does not include entries specific to pressure pipes. The obvious suggestions are:

- Minor leak (not warranting immediate action, defect)
- Major leak / burst (warranting immediate action, failure)

The distinction between the two should align with Wellington Water's prioritisation system, which includes leak flow, visibility and runtime.

We understand that the non-CCTV inspections of pressure pipes can inform the following BIP terminology items:

- Defects:
    - Pipe / deformation
    - Pipe / scouring
    - Lining / scouring
    - Lining / corrosion
    - Lining / bulging
- Factors
    - Pipe shape
    - Pipe diameter
    - Pipe length

4.3.2.4 Opportunities for improvement

We suggest the following avenues for consideration.

Table 4-8: Opportunities for improvement - pressure pipes

Issue	Option for consideration	Comment
There is no standard structure for non-CCTV inspection data that can enable condition analysis	Expand the intervention guides to specify what condition factors, defects and failures should be recorded, when and how.	This requires a common language for factors, defects and failures. Water NZ are working on a pipe inspection manual for pressure pipes.

4.4 Data consolidation

Vision

The current vision is that all condition data (factors, defects, failures) should be centralised in InfoAsset, possibly with links to attachments such as videos on Wincan or maintenance details in Maximo. From InfoAsset, the data should be passed to GIS, dedicated online maps, dashboards, one-off queries for condition studies and higher-level systems such as a national pipe failure database or similar.

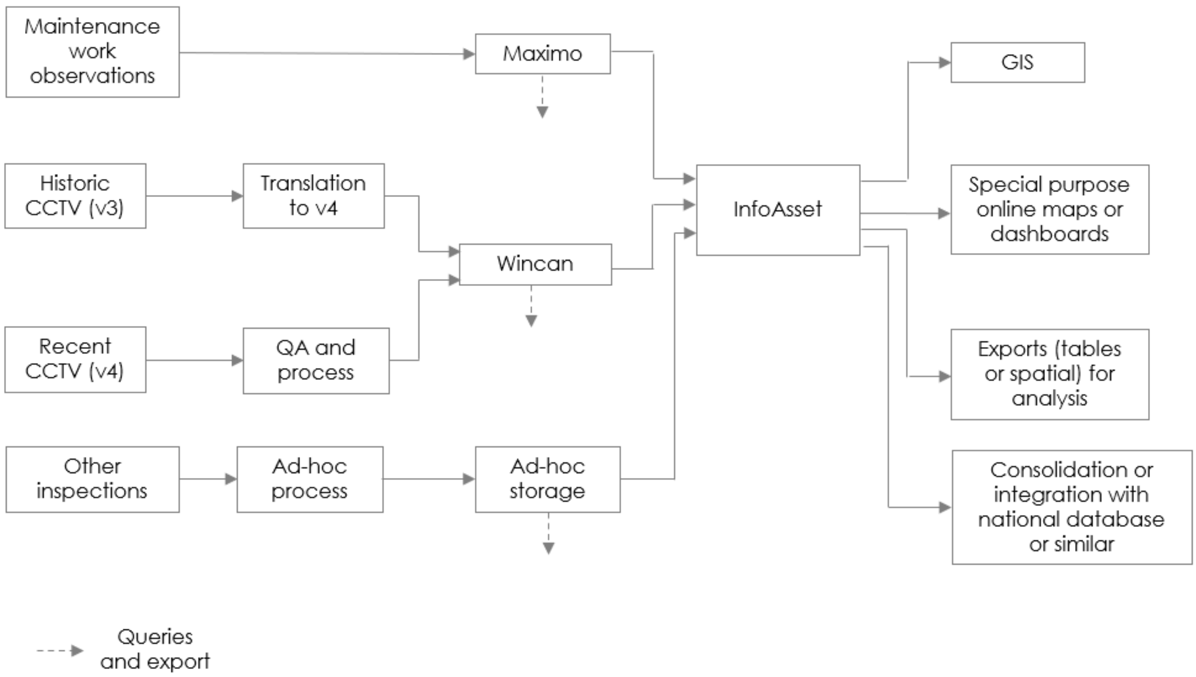

Figure 4-2: Current vision for data pertaining to pipe condition factors, defects and failure

InfoAsset as central repository

Wellington Water provided an InfoAsset extract for a high-level review.

The InfoAsset data structure is based on a series of joined tables, for example each row of the pipe table also includes data for the upstream downstream nodes such as elevation. Specifically for pipes, it contains over 80 default fields, some of which align well with inventory data (material, lining, diameter, depth…) but only touch on condition factors (ground water, date cleaned) and defects/failures (condition score, odour, nuisance). InfoAsset also contains 85 user-defined fields, although these appear to be largely unpopulated for the Wellington Water dataset.

From the InfoAsset extract provided, there are no obvious way to capture CCTV observations. This appears to be done using InfoAsset Manager[3], which is an extension of InfoAsset; it is not clear if Wellington Water has access to it or uses it.

It is also unclear how Maximo data is transferred to InfoAsset, and how a common language for defects and failure can be found between Wincan, Maximo and InfoAsset.

We understand that non-CCTV inspection data is currently not transferred into InfoAsset, and solutions need to be developed on a case-by-case basis because the format and content of the inspections differ greatly.

We understand that InfoAsset does not currently allow the storage of the various criticality scores developed by Wellington Water. This is anecdotal but it illustrates how the data structure in InfoAsset is likely to require improvements to enable queries for condition studies, asset management and integration with external systems.

Additionally, it is not clear how reliability / uncertainty is recorded in InfoAsset. This is an essential piece of information to consider alongside any score or metric. Condition, criticality and confidence could in theory be stored in InfoAsset, using user text and user number fields.

Finally, it may be worthwhile challenging the current data flow path as outlined in Figure 4-2. For example, it may be possible and beneficial to push data directly from field observations to InfoAsset (or similar), thus bypassing Maximo - Maximo would still remain as the COG maintenance activities system.

Other data sources

Several other sources of information can be used to estimate condition factors, or support asset condition analysis. These include:

- Hydraulic models (maximum pressure, pressure range, maximum velocity, leakage estimate for water supply, inflow and infiltration estimate for wastewater).
- Automated data creation to support leakage management activities (summary of connection count and pipe length, running minimum night flow estimates, records of active leakage detection and repair, loss estimate).

These data are better suited for compilation, joining and analysis outside of InfoAsset and have no overlap with data that could or should be collected during maintenance work.

[3] https://help2.innovyze.com/infoassetmanager/Content/HTML/IN/Using_CCTV_Survey_Data.htm

Standard language

Standardising the language for factors, defects and failures across Wellington Water's asset management documents, the maintenance records (Maximo), GIS and InfoAsset would be beneficial. Where changes are not possible (e.g. set fields in proprietary software), standard field mapping processes and tools should be in place.

5 Issues and Options

Figure 5-1 summarises the issues mentioned throughout the report. Table 5-1 captures the same information in a table format, along with options for consideration.

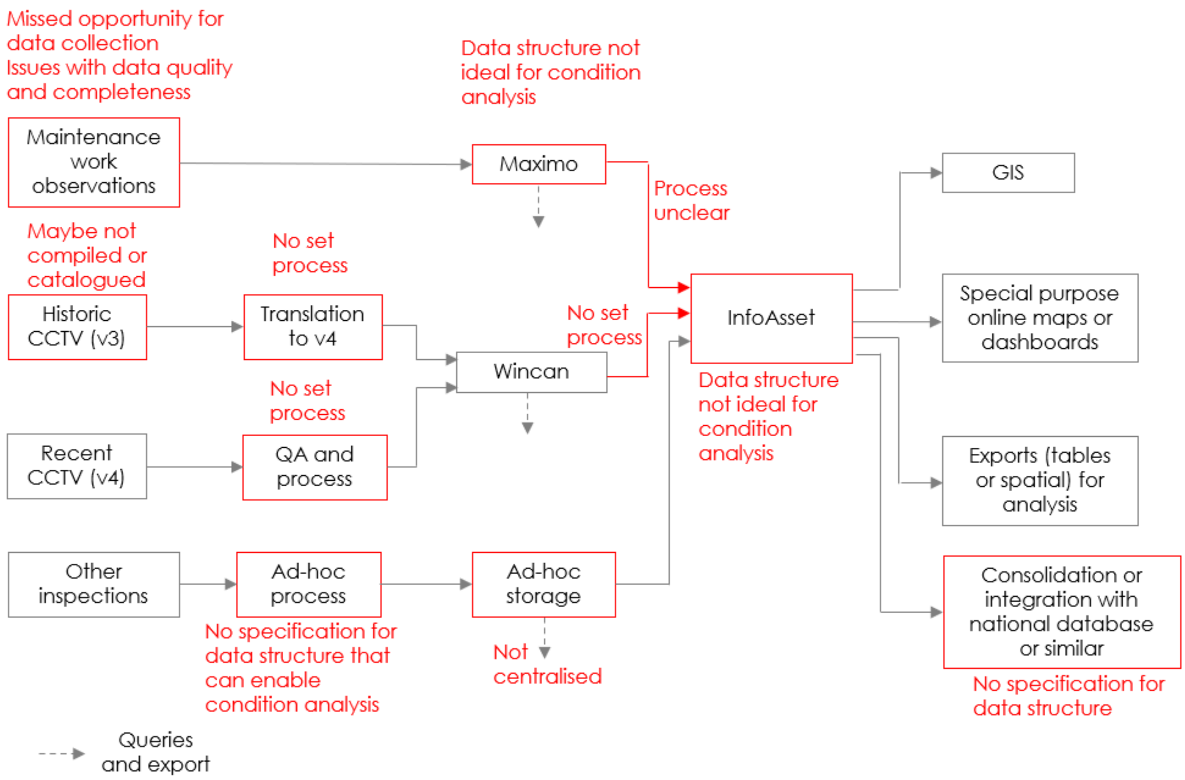

Figure 5-1: Summary of issues

Table 5-1: Summary of options

Issue	Option for consideration	Comment
The condition data collected during maintenance work is incomplete and unreliable.	Better understand current barriers to quality data capture – shadow maintenance crews, list issues, record opportunities.	
	Outline a role for dedicated data collection, working alongside maintenance crews when asset is accessible.	
	Improve interface, improve mandatory task system to support quality data capture.	
	Raise awareness of maintenance crews on purpose of data capture and, if required, educate on how to capture it.	
	Improve incentives, priorities or contract terms promoting quality data capture by field crews.	
	Increase the consistency of data capture across maintenance teams and depots.	
	Monitor technology developments in the field of computer vision to automatically detect and recognise features of the asset and its condition	For example, a manhole may be surveyed using a tablet with its key features recognised, measured and recorded (e.g. dimensions, inlet/outlet, wall condition), or defects may be automatically identified from a maintenance CCTV video.
The structure of the condition data collected during maintenance work is not ideal for condition analysis.	Modify the observation codes in Maximo so they align with the overall system (see Appendix B for a starting point).	This requires a common language for factors, defects and failures between Maximo and InfoAsset.
	Specify opportunistic data observations to capture (any defect/failure plus selected factors)	See Table 4-5 as a starting point
Historic CCTV may not be compiled or catalogued	Confirm if this is the case. If required, develop strategy for cataloguing and compiling into Wincan.	
Historic CCTV (v3) is not in the same format as recent CCTV (v4)	Investigate if a process already exists for using GPIM v3 data in a v4 environment. If not, develop one.	This should be considered at national level.

Issue	Option for consideration	Comment
There is no set process for loading recent CCTV (v4) into Wincan	Develop a set process, including QA in batches and consolidation at project completion.	We understand ProjectMax are working on this.
There may be no set process for exporting from Wincan into InfoAsset.	Investigate if a process already exists. If not, develop one.	This requires a common language for factors, defects and failures between Wincan and InfoAsset.
There is no standard structure for non-CCTV inspection data that can enable condition analysis	Expand the intervention guides to specify what condition factors, defects and failures should be recorded, when and how.	This requires a common language for factors, defects and failures. Water NZ are working on a pipe inspection manual for pressure pipes.
Non-CCTV inspection data is not centralised	Develop a set process to transfer non-CCTV data to InfoAsset.	
There may be no set process for exporting from Maximo into InfoAsset.	Investigate if a process already exists. If not, develop one.	This requires a common language for factors, defects and failures between Maximo and InfoAsset.
The structure of the data in InfoAsset may not be ideal for condition analysis and criticality score records	Confirm if this is the case. Confirm whether the data structure in InfoAsset can be altered. If appropriate, develop a data structure compatible with the other systems in use, including external ones such as other utilities or a national database of pipe failure (see Appendix A for a starting point).	This requires a common language for factors, defects and failures between water utilities.
The overall data flowpath may not be ideal	Confirm if the current combinaton of data storage systems (Wincan, Maximo, InfoAsset) are the best option and whether direct data connections can and should be in place.	For example, field crew observations could be fed directly to InfoAsset (or equivalent) as well as Maximo.

6 Conclusion

Data pertaining to pipe condition factors, defects and failures is collected, managed and used by different parts of Wellington Water's organisation. Over time, this had led to data sets that are hard to track, join and interpret as a whole. This report outlines a number of potential issues as well as remediation options (Table 5-1).

Two work streams stand out as both challenging and providing a significant benefit.

The first one consists in standardising what data is recorded for condition factors, defects and failures. Ideally there would be a national standard for this but unfortunately it is not finalised at this stage. Unless more clarity is provided in the short term by the NTU we suggest that a combination of the Pipe Inspection Manual and the BIP terminology provides a practical starting point, along with suggested improvements in Appendix A and B. This common language should be used across all systems (e.g. Wincan, Maximo, InfoAsset) if possible, and clear translation processes should be in place otherwise.

The second work stream consists in improving the condition data capture when the assets are accessible during maintenance work. This would likely require an improvement to the data structure in Maximo (or bypassing Maximo), an improvement to the field device software as well as dedicated resources to undertake the data capture in conjunction with maintenance staff. Failures and defects are, in theory, already captured through the existing systems but additional condition factors could be collected opportunistically during maintenance. Table 4-5 provides a list of condition factors that could potentially be recorded during maintenance. It was initially intended to shadow maintenance crews to record barriers to data capture and list opportunities for improvement, but this could not be achieved due to operations staff workloads and availability.

We recommend that the next phase of the work confirms the need for addressing the issues identified and assesses the feasibility of the options proposed.

References

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https://bipnz.org.nz/wp-content/uploads/2022/06/PipeDataPortal_WaterNZ_Sept20_Final.pdf

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Drinking Water Pipe Asset - Intervention Guide (Wellington Water, 2022)

Stormwater Pipe Asset - Intervention Guide (Wellington Water, 2022)

Wastewater Pipe Asset - Intervention Guide (Wellington Water, 2022)

New Zealand Gravity Pipe Inspection Manual 4th edition (Water NZ, 2021)

APPENDICES

Appendix A: Field Mapping - Gravity Pipe Inspection Manual to BIP Typology

Groups	Code	Defect	Description	BIP code	note on BIP code
Joint Codes	**JF**	Joint Faulty	Joint sealing defects or physical damage to joints, excluding open and displaced joints.	Joints Cracks/Holes/Fractures	
Joint Codes	**JO**	Joint Open	additional code to identify rotation or angular displacement at the joint	Joint pulled out	
Joint Codes	**JD**	Joint Displaced	The pipe segments have a vertical or horizontal displaced to each other.	Joint Misalignments	
Joint Codes	**W**	Weld Defect	A defect in a joint weld is evident. This includes welded joints in PE, Steel and PVC pipe materials	Joints Damaged Seal	
Joint Codes	**MHJ**	Manhole Joint Faulty	The bond or seal between the pipe and node structure (including chambers, catch pits, wingwalls, etc) is faulty, such that the seal between pipe and structure is broken or defective and there is a pathway to the outside of the pipe.	Joints Damaged Seal	
Lateral Codes	**L**	Lateral	Defect free lateral connection that would not attract a defect code of LF, LP or LX1.		NO MATCH, NOT NEEDED
Lateral Codes	**LF**	Lateral Sealing Faulty	Joint sealing defects or physical damage to lateral connections, excluding protruding laterals and defects within the lateral pipe. Physical damage relates specifically to occurrences up to the first joint, inside the lateral stub and an area of pipe wall around the lateral connection, that extends 50mm circumferentially fromthe internal face of the lateral connection pipe	Joints Damaged Seal	
Lateral Codes	**LP**	Lateral Protruding	The Lateral pipe is protruding into the inspected main pipe.		**NO MATCH. Suggested new BIP category: Defect/Hydraulic/ permanent obstruction**

Groups	Code	Defect	Description	BIP code	note on BIP code
Lateral Codes	**LX**	Lateral Problem (Defective)	There are defects visible in the lateral pipe, beyond the first joint with the main.		NO MATCH, NOT NEEDED
Masonry Codes	**MM**	Missing Mortar	All or part of the mortar from between the masonry units are missing	Pipe Internal Corrosion	
Masonry Codes	**MUS**	Massonary Unit Separation	the regularity of the original bond pattern has been disturbed with masonry courses separating along mortar joints	Pipe Fractures	
Masonry Codes	**DI**	Dropped Invert	A section of brickwork in the invert has dropped relative to the grade of the pipe forming a horizontal gap between the bricks near the invert of the pipe		**NO MATCH. Suggested new BIM category: Defect/Physical/ Deformed pipe**
Masonry Codes	**DMU**	Displaced Masonry Units	One or more masonry units moved from their original position	Pipe Fractures	
Masonry Codes	**MMU**	Missing Masonry Units	One or more masonry units are missing i.e. have fallen out	Pipe Fractures	
Masonry Codes	**MX**	Masonry Pipe Collapsed	full structural failure and the masonry pipe no longer functions as a free-flowing conduit, although water may still flow through the rubble of the collapsed pipe	Pipe Collapse	
Pipe Wall Codes	**CC**	Crack, Circumferential	Covers cracks that are at a right angle to the pipeline axis. If the crack extends more than 100mm along the length of the pipe then it is allocated a crack longitudinal "CL" code.	Pipe Cracks - circumferential	
Pipe Wall Codes	**CL**	Crack, Longitudinal	Refers to cracks that are parallel to the pipeline axis. The cracks can be located anywhere around the circumference of the pipe. If there are two or more unconnected longitudinal cracks, then each crack is seperately recorded.	Pipe Cracks - longitudinal	
Pipe Wall Codes	**CM**	Crack, Multiple	Multiple cracks that are running both in circumferential and longitudinal directions.	Pipe Cracks - multiple	

Assessing Wellington Water's Pipe condition data capture
Appendix A: Field Mapping - Gravity Pipe Inspection Manual to BIP Typology

Groups	Code	Defect	Description	BIP code	note on BIP code
Pipe Wall Codes	**DF**	Deformed Pipe	Refers to rigid pipe, such as earthenware, asbestos cement or concrete pipe, that has been deformed due by external pressure.		**NO MATCH. Suggested new BIM category: Defect/Physical/ Deformed pipe**
Pipe Wall Codes	**PB**	Pipe, Broken	The pipe still functions as a free-flowing conduit but pieces of it have broken out or are displaced to the extent that they may fall out.	Pipe Fractures	
Pipe Wall Codes	**PF**	Deformed Plastic Pipe	This code refers to plastic pipe that has been deformed due to external pressure or loading.		**NO MATCH. Suggested new BIM category: Defect/Physical/ Deformed pipe**
Pipe Wall Codes	**PH**	Pipe, Holed	A hole has been cut or punched into the pipe either to gain access to the pipe or during the construction of another underground service.	Pipe Fractures	
Pipe Wall Codes	**SD**	Surface Damage	Includes chips in of the pipe, spalling, abrasive erosion or chemical corrosion.	Pipe Internal Corrosion	Could be different, but expected most frequent.
Pipe Wall Codes	**PL**	Protective Linning Defective	The lining of a pipe is defective. This relates to liners installed within a pipe conduit for protection, sealing or rehabilitation.	Lining Scouring	Could be different, but expected most frequent.
Pipe Wall Codes	**PR**	Point Repair	A short section of pipe (≤2m) has been repaired with an internal sleeve or injected sealing material		NO MATCH, NOT NEEDED
Pipe Wall Codes	**LC**	Lining Change	The lining of the original pipe has changed		NO MATCH, NOT NEEDED
Pipe Wall Codes	**SV**	Soil Visible through Defect	the soil or trench material outside the pipe is visible through a defect	Pipe Holes	
Pipe Wall Codes	**DC**	Dimension Change	changes in diameter/dimensions of the pipe during the inspection. Can also be used for changes in shape.		NO MATCH, NOT NEEDED
Pipe Wall Codes	**MC**	Material Change	The pipe material has changed.		NO MATCH, NOT NEEDED

Groups	Code	Defect	Description	BIP code	note on BIP code
Pipe Wall Codes	**PC**	Pipe Length Change	This code is used where the joint spacing length has changed without the material (or lining) changing		NO MATCH, NOT NEEDED
Pipe Wall Codes	**PX**	Pipe, Collapsed	The pipe no longer functions as a free-flowing conduit, although water may still flow through the rubble of the collapsed pipe.	Pipe Collapse	
Pipe Wall Codes	**TM**	Tomo	A cavity is evident outside the pipe wall. The bedding or fill material from the outside of the pipe is depleted. Generally caused by a pipe break, pipe hole, or displaced joint that allows backfill material to be washed into the pipe.	Pipe Break	
Service Related Codes	**DE**	Debris, Silty	Silt and gravel deposited in the pipeline.	Sediments	
Service Related Codes	**DG**	Debris, Greasy	Refers to the presence of grease, fat, scale, and any other material that is adhered to the pipe wall, with the exception encrustation deposits.	Fog	
Service Related Codes	**DP**	Dipped Pipe	It is generally identified by changes in water level. Where a dip continues through a manhole and finishes on the far side of the manhole, it is recorded as two separate dips, the first finishing at the manhole and the second start at the manhole.		**NO MATCH. Suggested new BIM category: Defect/Physical/ Deformed pipe**
Service Related Codes	**ED**	Encrustation Deposits	Covers encrustation deposits on the pipe wall. These are generally the result of infiltration seepage bringing with it dissolved salts from the surrounding soil. The seepage moisture evaporates and leaves a precipitated salt behind. Encrustation is often an orange colour (probably due to a high proportion of iron oxide in many soils), and usually seen at joints. However it may occur anywhere there is a minor leak in the pipeline.		**NO MATCH. Suggested new BIM category: Defects/Hydrauli c/Encrustation**

Groups	Code	Defect	Description	BIP code	note on BIP code
Service Related Codes	**IP**	Infiltration Present	Visible infiltration through either the pipe wall or pipe joints.	Groundwater Infiltration	
Service Related Codes	**OP**	Obstruction, Permanent	An obstrcution in the pipeline caused by a fixed construction feature, an external object embedded in the pipe wall, or an object or material that is not able to be removed using standard cleaning equipment. This code covers mortar in the pipeline and weld beads in PE.		**NO MATCH. Suggested new BIM category: Defect/Hydraulic/ permanent obstruction**
Service Related Codes	**OT**	Obstruction, Temporary	An obstruction in the pipeline, which is potentially removable and is not attached or embedded in the pipe wall and can be removed with standard pipe cleaning equipment.	Debris	
Service Related Codes	**RI**	Root Intrusion	Refers to roots growing through the defects in the pipe wall or through joints. The severity of the defect depends on the amount of restriction caused by the roots.	Roots	
Service Related Codes	**B**	Pipe Blocked	refers to where Roots, greasy deposits, silty deposits or other obstructions reduce the pipe diameter by >50%	Roots	Could be different, but expected most frequent.
Service Related Codes	**EX**	Exfiltration	There is a visible flow of water out of the pipe through a pipe defect	Exfiltration	
Service Related Codes	**WL**	Flow (Water) Level	The presence and nature of water and changes in depth of water above the invert		NO MATCH, NOT NEEDED
Service Related Codes	**LD**	Line Deviates	the pipe alignment changes up/down or left/right		NO MATCH, NOT NEEDED

Appendix B: Field Mapping – Maximo to BIP Typology

Cause _code	Cause_description	BIP code	note on BIP code
C01	Rags-Wipes - fabrics (clothes-underwear etc) - baby wipes		**NO MATCH. Suggested new BIM category: Defect/Hydraulic/fabric**
C02	Accumulation of Residues	Fog	
C03	Tree Roots	Roots	
C04	Structural Collapse	Pipe Collapse	
C05	3rd Party Damage		NO MATCH. NOT NEEDED (too vague: is is a crack, a clean break or something else?) or maybe "Undetected Construction Damage".
C06	Age-Based Replacement		NO MATCH. NOT NEEDED
C07	Settlement		**NO MATCH. Suggested new BIM category: Defect/Physical/Deformed pipe**
C08	Parts Failure		NO MATCH. NOT NEEDED (too vague)
C09	Vandalism		NO MATCH. NOT NEEDED (too vague)
C10	Infiltration - Ground Water	Groundwater Infiltration	
C11	Overload - Beyond Capacity	Overflow	
C12	Extreme Weather Conditions		NO MATCH. NOT NEEDED
C13	Theft		NO MATCH. NOT NEEDED
C14	Design Failure		NO MATCH. NOT NEEDED (too vague)
C15	Corrosion	Pipe Internal Corrosion	Could be external. Suspected more frequent.
C16	Encrustation		**NO MATCH. Suggested new BIM category: Defects/Hydraulic/Encrustation**
C17	Silt-Sediment	Sediments	
C18	Joint Failure	Joints Cracks/Holes/Fractures	Could be different. Suspected more frequent.
C19	Seal - Gland Failure		NO MATCH. NOT NEEDED (water supply)
C20	Faulty Installation		NO MATCH. NOT NEEDED (too vague)

Cause _code	Cause_description	BIP code	note on BIP code
C21	Material Degraded	Pipe Internal Corrosion	Could be external. Suspected more frequent.
C22	Pollution - State pollutant	Surface Water Contamination	Could be different. Suspected more frequent.
C23	Operator Error		NO MATCH. NOT NEEDED
C24	Incorrect Control Settings		NO MATCH. NOT NEEDED
C30	Authorised Removal		NO MATCH. NOT NEEDED
C31	Accumulation of Fat Residues - Fat bergs	Fog	
C32	Compaction		**NO MATCH. Suggested new BIM category: Defect/Physical/Deformed pipe**
C33	Technical		NO MATCH. NOT NEEDED
C34	Parts Unavailable		NO MATCH. NOT NEEDED
C35	Service not required		NO MATCH. NOT NEEDED
C38	Switched Off		NO MATCH. NOT NEEDED
C39	Seized		**NO MATCH. Suggested new BIM category: Defect/Physical/Deformed pipe**
C40	Failure to close		NO MATCH. NOT NEEDED (suspected water supply)
C41	Failure to open		NO MATCH. NOT NEEDED (suspected water supply)
C42	Fair Wear and Tear	Scouring	
C43	Unnatural Wear and Tear	Scouring	
C49	Thermostat Failure		NO MATCH. NOT NEEDED
C51	Fuse Failure - Circuit Breaker Tripped		NO MATCH. NOT NEEDED
C56	Power Supply cut off		NO MATCH. NOT NEEDED
C57	Lack of Lubricant (State Lubricant type)		NO MATCH. NOT NEEDED
C59	Lack of Maintenance		NO MATCH. NOT NEEDED
C62	Incorrect Maintenance		NO MATCH. NOT NEEDED

Cause _code	Cause_description	BIP code	note on BIP code
C69	Low Pressure		NO MATCH. NOT NEEDED (suspected water supply)
C70	Low Water		NO MATCH. NOT NEEDED (suspected water supply)
C73	Overload	Overflow	
C76	Signal - System Fault		NO MATCH. NOT NEEDED
C80	Disease		NO MATCH. NOT NEEDED (too vague)
C81	Missed on Maintenance Schedule		NO MATCH. NOT NEEDED
C82	Environmental Location		NO MATCH. NOT NEEDED
C84	Vermin		NO MATCH. NOT NEEDED
C86	Illegal Dumping		NO MATCH. NOT NEEDED
C87	Asset Damage		NO MATCH. NOT NEEDED (too vague)
C88	Fault at Pump Station		NO MATCH. NOT NEEDED
C89	Fault at Reservoir		NO MATCH. NOT NEEDED
C90	Valve Settings		NO MATCH. NOT NEEDED
C91	No Issue Identified		NO MATCH. NOT NEEDED
C92	Incorrect Water Treatment		NO MATCH. NOT NEEDED
C93	Contamination		NO MATCH. NOT NEEDED (too vague)
C94	Degraded supply source		NO MATCH. NOT NEEDED
C95	Cracked or Split	Pipe Cracks - circumferential	Could be different. Suspected more frequent.
C96	Hole in Pipe	Pipe Holes	
C97	Found - Asset Buried		NO MATCH. NOT NEEDED
C98	Found		NO MATCH. NOT NEEDED
C99	Located - Underneath Building		NO MATCH. NOT NEEDED
C100	Located - Underneath Structure		NO MATCH. NOT NEEDED
C101	Asset Not Found		NO MATCH. NOT NEEDED

Cause _code	Cause_description	BIP code	note on BIP code
C102	Leak Confirmed - Unable to locate		NO MATCH. NOT NEEDED (suspected water supply)
C103	Debris and Rubbish	Debris	
C104	Flushing Required	Sediments	
C105	Isolate Service		NO MATCH. NOT NEEDED
C106	Test Valve Function		NO MATCH. NOT NEEDED
C107	Investigation Only		NO MATCH. NOT NEEDED
C108	No Work Found		NO MATCH. NOT NEEDED
C109	Lid-Cover Missing		NO MATCH. NOT NEEDED
C110	Required Refitting		NO MATCH. NOT NEEDED
C111	Buried - Sealed Over		NO MATCH. NOT NEEDED
C112	Out of level with pavement surface		NO MATCH. NOT NEEDED
C113	Traced to residential source		NO MATCH. NOT NEEDED
C114	Traced to commercial Premises		NO MATCH. NOT NEEDED
C115	Source not found		NO MATCH. NOT NEEDED
C116	Traced to Storm Water intake - Cause Unknown		NO MATCH. NOT NEEDED
C117	Traced to Incident (See work Log)		NO MATCH. NOT NEEDED
C118	Sanitary-toilet products - paper-pads-tampons		**NO MATCH. Suggested new BIM category: Defect/Hydraulic/fabric**
C119	Pipe defect affecting flow (snags, dips, deformation and breaks)		**NO MATCH. Suggested new BIM category: Defect/Physical/Deformed pipe**
C120	Other (Any issues which do not fit available selections)		NO MATCH. NOT NEEDED
C121	Request		NO MATCH. NOT NEEDED

Appendix C: BIP Typology and Data Capture Opportunity during Maintenance Work

Term	Class	Category	Group	Comment	Captured in GIS inventory (current or possible)	Captured during CCTV	Currently captured during maintenance (including reported / detected issues)	Could be captured during maintenance	Value for condition assessment (factors only)	Importance of capturing during maintenance (including reported / detected, color-coding for factors only as failures and defects are already captured)
Pipe Collapse	Failure	Physical			No	No	Yes but could be better	Yes, using current system		High, only source
Pipe Break	Failure	Physical			No	No	Yes but could be better	Yes, using current system		High, only source
Major leak (distribution)	Failure	Physical		Changed from Tizmaghz, added	No	No	Yes but could be better	Yes, using current system		High, only source
Overflow (drainage)	Failure	Hydraulic		Changed from Tizmaghz, detailed	No	No	Yes but could be better	Yes, using current system		High, only source
Odor	Failure	Quality			No	No	No code	Yes, add code		High, only source
Groundwater Contamination	Failure	Quality			No	No	Yes but could be better	Yes, using current system		High, only source
Land Contamination	Failure	Quality			No	No	Yes but could be better	Yes, using current system		High, only source
Surface Water Contamination	Failure	Quality			No	No	Yes but could be better	Yes, using current system		High, only source
Coastal Contamination	Failure	Quality			No	No	Yes but could be better	Yes, using current system		High, only source
Pipe Cracks - circumferential	Defect	Physical	Pipe	Changed from Tizmaghz, detailed	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe Cracks - longitudinal	Defect	Physical	Pipe	Changed from Tizmaghz, detailed	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe Cracks - multiple	Defect	Physical	Pipe	Changed from Tizmaghz, detailed	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe Holes	Defect	Physical	Pipe		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe Fractures	Defect	Physical	Pipe		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe Internal Corrosion	Defect	Physical	Pipe		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Pipe External Corrosion	Defect	Physical	Pipe		No	No	Yes but could be better	Yes, using current system		High, only source
Scouring	Defect	Physical	Pipe		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Undetected Construction Damage	Defect	Physical	Pipe		No	Yes	No code	Rarely		Low, not practical
Third-Party Damage	Defect	Physical	Pipe		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Joints Cracks/Holes/Fractures	Defect	Physical	Joint		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Joints Damaged Seal	Defect	Physical	Joint		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Joints Pulled Out	Defect	Physical	Joint		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Joints Extruding Seal	Defect	Physical	Joint		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Joint Misalignments	Defect	Physical	Joint		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Lining Tears/Breaks	Defect	Physical	Lining		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Lining Scouring	Defect	Physical	Lining		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Lining Corrosion	Defect	Physical	Lining		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Lining Delamination	Defect	Physical	Lining		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Lining Bulging	Defect	Physical	Lining		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Deformed pipe	Defect	Physical	Lining	Changed from Tizmaghz, added	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Voids	Defect	Hydraulic	Bedding		No	No code	No code	Yes, add code		High, only source
Sediments	Defect	Hydraulic	Deposits		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Fog	Defect	Hydraulic	Deposits		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info

Term	Class	Category	Group	Comment	Captured in GIS inventory (current or possible)	Captured during CCTV	Currently captured during maintenance (including reported / detected issues)	Could be captured during maintenance	Value for condition assessment (factors only)	Importance of capturing during maintenance (including reported / detected, color-coding for factors only as failures and defects are already captured)
Debris	Defect	Hydraulic	Obstructions		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Roots	Defect	Hydraulic	Obstructions		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Encrustation	Defect	Hydraulic	Obstructions	Changed from Tizmaghz, added	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Permanent obstruction	Defect	Hydraulic	Obstructions	Changed from Tizmaghz, added	No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Groundwater Infiltration	Defect	Hydraulic	Undesirable inflow		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Stormwater cross-connections	Defect	Hydraulic	Undesirable inflow		No	No code	No code	No		Not recommended during maintenance
Oil	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Fat	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Grease	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Wipes	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Paper	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Rubbish	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Sanitary Products	Defect	Quality	Release of undesirable substance		No	Yes	Yes but could be better	Yes, using current system		Medium, recent relevant info
Exfiltration	Defect	Quality	H2S production and release		No	No code	No code	Rarely		Low, not practical
Dissolved Sulphide	Defect	Quality	H2S production and release		No	No	No code	Maybe		To be investigated
Turbulence	Defect	Quality	H2S production and release		No	Yes	No code	Maybe		Low, not practical
Splashing	Defect	Quality	H2S production and release	Unclear	No	No code	No code	Rarely		Low, not practical
Land use	Factor	Design and construction	Planning and design		Yes	No	No	Yes, add field	No reference	Low, not practical
User connection density	Factor	Design and construction	Planning and design		Yes	No	No	No	Medium (BIP)	Not recommended during maintenance
Approach (combined/separate)	Factor	Design and construction	Planning and design		Yes	No	No	No	No reference	Not recommended during maintenance
Pipe layout	Factor	Design and construction	Planning and design		Yes	No	No	Yes, needs drawing	No reference	Low, not practical
Traffic load	Factor	Design and construction	Planning and design		Yes	No	No	No	No reference	Not recommended during maintenance
Construction load	Factor	Design and construction	Planning and design		Yes	No	No	No	No reference	Not recommended during maintenance
Interaction with other services	Factor	Design and construction	Planning and design		Yes	No	No	Yes, add field	No reference	Medium, recent relevant info
Shape	Factor	Design and construction	Pipe characteristics		Yes	No	No	Yes, add field	Uncertain (renewals framework)	Low, limited use cases
Diameter	Factor	Design and construction	Pipe characteristics		Yes	No	No	Yes, add field	High (renewals framework, BIP)	High, easy, high value
Section length	Factor	Design and construction	Pipe characteristics		Yes	Yes	No	Yes, add field	Medium (renewals framework, BIP)	Low, not practical
Material	Factor	Design and construction	Pipe characteristics		Yes	Yes	No	Yes, add field	High (renewals framework, BIP)	High, easy, high value
Lining	Factor	Design and construction	Pipe characteristics		Not always	Rarely	No	Yes, add field	No reference	High, only source
Coating	Factor	Design and construction	Pipe characteristics		Rarely	Rarely	No	Yes, add field	No reference	High, only source
Joint type	Factor	Design and construction	Pipe characteristics		Rarely	No	No	Yes, add field	Medium (renewals framework)	High, only source
Design life	Factor	Design and construction	Pipe characteristics		Rarely	No	No	No	Low (renewals framework)	Not recommended during maintenance
Installation date (or age)	Factor	Design and construction	Installation properties		Yes	No	No	No	High (renewals framework, BIP)	Not recommended during maintenance
Installation method	Factor	Design and construction	Installation properties		No	No	No	Rarely	Uncertain (renewals framework)	Low, not practical

Term	Class	Category	Group	Comment	Captured in GIS inventory (current or possible)	Captured during CCTV	Currently captured during maintenance (including reported / detected issues)	Could be captured during maintenance	Value for condition assessment (factors only)	Importance of capturing during maintenance (including reported / detected, color-coding for factors only as failures and defects are already captured)
Installation quality	Factor	Design and construction	Installation properties		No	No	No	Rarely	No reference	Low, not practical
Trench width	Factor	Design and construction	Installation properties		No	No	No	Maybe	No reference	Low, not practical
Slope	Factor	Design and construction	Installation properties		Yes	No	No	Maybe	High (BIP)	High, may not be practical
Cover depth	Factor	Design and construction	Installation properties		No	No	No	Yes, add field	High (BIP)	High, only source
Pipe bedding	Factor	Design and construction	Installation properties		No	No	No	Maybe	Uncertain (renewals framework)	To be investigated
Trench backfill	Factor	Design and construction	Installation properties		No	No	No	Yes, add field	No reference	Medium, only source, value uncertain
Restrainsts	Factor	Design and construction	Installation properties		No	No	No	Maybe	No reference	Low, rarely applicable
Maximum flow rate	Factor	Operational	Hydraulic operation	Changed from Tizmaghz, added	Yes	No	No	No	No reference	Not recommended during maintenance
Maximum pressure	Factor	Operational	Hydraulic operation	Changed from Tizmaghz, added	Yes	No	No	No	No reference	Not recommended during maintenance
Pressure range	Factor	Operational	Hydraulic operation	Changed from Tizmaghz, added	Yes	No	No	No	No reference	Not recommended during maintenance
Corrosive impurities	Factor	Operational	Sewage composition	Unclear what it is and how it is measured	No	No	No	Maybe	No reference	To be investigated (duplicate?)
Sediments	Factor	Operational	Sewage composition		No	Yes	No	Yes, add field	No reference	Low, only source, value uncertain, may not be practical
Acceptable FOG load	Factor	Operational	Sewage composition		No	No	No	No	No reference	Not recommended during maintenance
Inspection regime	Factor	Operational	Maintenance strategies		No	No	No	No	No reference	Not recommended during maintenance
Frequency of sewer cleaning	Factor	Operational	Maintenance strategies		No	No	No	No	No reference	Not recommended during maintenance
Sewer cleaning method	Factor	Operational	Maintenance strategies		No	No	No	No	No reference	Not recommended during maintenance
Quality of repairs	Factor	Operational	Maintenance strategies		No	No	No	No	No reference	Not recommended during maintenance
Temporary loading	Factor	Operational	Temporary loading	Unclear what it is and how it is measured	No	No	No	No	No reference	Not recommended during maintenance
Trees near system	Factor	Operational	Trees near system		Rarely	No	No	Yes, add field	No reference	High, only source, easy
Expansive properties	Factor	Environmental	Soil		Rarely	No	No	No	Medium (renewals framework, BIP)	Not recommended during maintenance
Moisture deficit index	Factor	Environmental	Soil		Rarely	No	No	No	No reference	Not recommended during maintenance
Corrosivity	Factor	Environmental	Soil	Unclear how it is measured	No	No	No	Maybe	No reference	To be investigated (duplicate?)
Sulfides	Factor	Environmental	Soil		No	No	No	Maybe	No reference	To be investigated (duplicate?)
pH	Factor	Environmental	Soil		Rarely	No	No	Yes, add field	No reference	Low, only source, value uncertain
Redox potential	Factor	Environmental	Soil		Rarely	No	No	Maybe	No reference	Low, only source, value uncertain, may not be practical
Moisture content	Factor	Environmental	Soil		Rarely	No	No	Yes, add field	No reference	Medium, only source, value uncertain, may not be practical
Groundwater level	Factor	Environmental	Soil		Rarely	No	No	Yes, add field	Medium (renewals framework, BIP)	High, only source
Wet/dry cycles	Factor	Environmental	Soil	Unclear what it is and how it is measured	Rarely	No	No	No	No reference	Not recommended during maintenance
Tidal influence	Factor	Environmental	Soil		Rarely	No	No	Rarely	No reference	Medium, only source, value uncertain, may not be practical
Movement	Factor	Environmental	Soil		Rarely	No	No	No	High (liquefaction, BIP)	Not recommended during maintenance
Frost penetration	Factor	Environmental	Soil		Rarely	No	No	No	No reference	Not recommended during maintenance
Sinkholes	Factor	Environmental	Soil		Rarely	No	No	No	No reference	Not recommended during maintenance
Rainfall	Factor	Environmental	Climate		Yes	No	No	No	No reference	Not recommended during maintenance
Temperature	Factor	Environmental	Climate		Yes	No	No	No	No reference	Low, only source, value uncertain
Earthquakes	Factor	Environmental	Catastrophic events		Yes	No	No	No	No reference	Not recommended during maintenance
Wildfires	Factor	Environmental	Catastrophic events		Yes	No	No	No	No reference	Not recommended during maintenance