INTUITIVE DECISION-MAKING FOR WASTEWATER NETWORK ASSET MANAGEMENT

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A thesis submitted for the degree of Master of Engineering

at the University of Canterbury, Christchurch

New Zealand

Abstract

This thesis argues that expert intuition is useful and even necessary for decision-making within the complex systems of wastewater network asset management (WNAM), and that opportunities for learning are introduced when this intuition is documented, leading to more skilled decision-making over time. A new methodology for documenting intuition is developed involving a survey of 43 wastewater industry experts with the results applied to a decision tree model to determine priorities for action.

Local Councils and other wastewater network asset owners face many challenges in their responsibility to maintain and expand infrastructure networks, subject to aging and degradation, in an environment of increasing public expectation for levels of service, sustainability and management of risks. The high public cost for wastewater infrastructure reinforces the need for effective decision-making and the relevance of targeted research in this area.

The literature review demonstrates that the high-level principles of advanced wastewater asset management are well understood and are provided in guidelines such as the International Infrastructure Management Manual and ISO 55000 Asset Management. However, the specific practical applications of these principles are variable and subjective.

This research examines the socio-technical nature and inherent complexity of WNAM, including the issues of interconnectedness, multiple perspectives, poor data availability and outcomes that are difficult to predict.

Intuition is a mode of decision-making that enables decisions to be made in the face of uncertainty. Further literature review shows that intuition is necessarily used within WNAM decision-making but can be subject to either skilled or unskilled application. Research literature in psychology is used to elaborate on the intuitive process and to demonstrate that unskilled intuition is subject to inherent bias and heuristics that distort decision judgements.

Documenting intuition can provide the learning opportunities needed to support the skilled application of intuitive decision-making. The literature review lastly looks at the various methods for documenting intuition within the context of WNAM decision-making.

Two case studies are used to find evidence of intuition decision-making within existing WNAM systems. The first case study examines two different methodologies employed by the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) and shows intuition used “up front” and at the “coal face”. The second case study looks more closely at how intuition is documented through the formal decision-making process adopted by the Waimakariri District Council for their wastewater inspection and renewal planning.

The remaining sections of this thesis detail original work developing a methodology for documenting intuition using a survey of 43 wastewater industry experts. A 1 – 5 Likert-type scale is used to capture the expert’s weighting of significance that they place on a range of factors relevant to WNAM. The results of the survey are analysed and fed into a decision tree model where the effect of each factor can be seen on the overall decision outcome.

When combined with factor scores, the documented significance from the survey enables prioritisation of decisions for WNAM. The process also identifies the factors to include or not include in decision-making and can be used to prioritise data collection or further work defining expert intuitive judgements.

The methodology provides a documentation trail so that the original decision model framework can be repeated or passed on. Wastewater network asset managers can use the documentation as a reference for future learning opportunities, therefore becoming more skilled in intuitive decision-making.

Acknowledgements

In submitting this thesis, I would like to extend special thanks to:

Dr Eric Scheepbouwer for his guidance and feedback as my academic supervisor,

Professor Emeritus David Elms for his wisdom offered at the early stage of my research,

Stronger Christchurch Infrastructure Rebuild Team (SCIRT) for case study resources,

Waimakariri District Council for case study resources,

Water New Zealand and the Institute of Public Works Engineering Australasia for assistance in circulating the industry survey,

My employer WSP Opus for the study opportunity,

And most of all my wife Hannah for her grace and support through the epic challenge of juggling research, thesis writing, ongoing work commitments, and being a dad.

Conference papers and presentations

This research includes components from the following conference papers and presentations:

J. A. Thorne, & E. Scheepbouwer, (2016), Asset Managers and intuitive decisions; how to compare apples with oranges, Presented at: *Institute of Public Works Engineering Australasia – New Zealand Conference*, Auckland, New Zealand.

J. A. Thorne, & E. Scheepbouwer, (2018), Data for next generation decision-making; Presented at: *Institute of Public Works Engineering Australasia – New Zealand Conference*, Rotorua, New Zealand.

J. A. Thorne, & E. Scheepbouwer, (2019), Intuitive decision-making for infrastructure strategists; Accepted as Hynds Paper of the Year Finalist to be presented in June at: *Institute of Public Works Engineering Australasia – New Zealand Conference*, Wellington, New Zealand.

J. A. Thorne, & E. Scheepbouwer, (2019), Trusting your expert gut in wastewater network renewal planning; Accepted paper to be presented in August at: *International Public Works Conference*, Hobart, Australia.

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Chapter 1 – Introduction

1.0 Background

Management of urban water systems (wastewater/stormwater/water supply) demands significant attention and financial commitment from local governments in New Zealand and around the globe (Alegre & Coelho, 2012). Councils face many challenges in their responsibility to maintain and expand infrastructure networks, subject to aging and degradation, in an environment of increasing public expectation for levels of service, sustainability and management of risks.

In the case of the Christchurch earthquake rebuild, approximately $2 billion was required to rebuild the city's horizontal infrastructure, of which the largest portion was associated with the wastewater network (Canterbury Earthquake Recovery Authority, 2015). The high cost to the public for wastewater infrastructure reinforces the importance and relevance of research targeted at informing and improving the effectiveness of asset management decision-making in this area.

The principles of integrated asset management are generally well understood and implemented. New Zealand and Australian local governments have together developed and published the International Infrastructure Management Manual (IIMM) which promotes a Total Asset Management Process. The IIMM forms an important benchmark for integrated asset management systems around the world and is regularly referenced in research and industry practice.

There are numerous standards, guidelines, computational models and support tools that assist the development of integrated asset management frameworks by describing the decision-making process from a rational and deterministic perspective (van Riel et al., 2014). For example, capital expenditure strategies may focus on the "hard" network data such as pipe size, age, material, and perhaps camera footage from inside the pipes. Reliance on this “hard” data for decision-making is problematic due to the complexity of wastewater networks and uncertainty regarding the relationships between data, performance and causality.

In contrast to these support tools using “hard” data, little formal guidance is available on how to appropriate operational deficiencies into the decision process (van Riel et al., 2014). And potentially more significant is the omission of formal methods to include intangible factors such as political, economic, environmental and social influences. These intangible influences have an important bearing on capital expenditure for wastewater networks.

A next step in wastewater asset management, perhaps, is to provide decision makers with practical guidance for processes to weigh up intangible and often competing influences to make transparent and robust decisions.

Investment decisions for wastewater networks are complex and consider a broad system of influences. Given this complexity, using only deterministic decisions based on “hard” data is not appropriate. Instead, decisions require the use of “intuition” to weigh up a range of factors to make a best-fit decision so that investment and construction actions can proceed. Good intuitive decisions rely on the relevant knowledge and experience of the decision maker(s) and on quality decision-making processes that reflect the complexity of the system (Elms & Brown, 2013). Local governments in New Zealand operating without well developed or formalised intuitive decision-making processes are exposed to risks of poor outcomes.

Both Van Riel et al. (2014) and Elms & Brown (2013) promote the use of intuition in complex engineering scenarios and conclude that further research in this area is required to enhance the quality of intuitive decision processes.

This study contributes to addressing this problem by investigating intuitive decision-making processes within wastewater network asset management and developing a new methodology to quantify and document decision data. The new methodology provides a formal tool to assist wastewater asset managers with the intuitive nature of their decisions. The new methodology could be adopted by industry organisations to enhance the long term quality of wastewater network asset management decisions.

1.1 Aim

Research Questions

The following questions are investigated in this research:

- How can intuitive decisions improve wastewater asset management decision-making?
- How is intuition manifest in the decision-making process?
- What methodologies can be used to quantify intuition?
- How does documenting intuition enhance the decision-making process?

Research Strategy

This research is explored through;

- Literature review of asset management principles, wastewater network systems, and intuitive decision-making
- Case study of existing wastewater network decision-making in two New Zealand organisations to examine how and where intuition is used
- Development of a new methodology for documenting intuitive decisions using a wastewater network pipe renewal decision tree and model, and an industry survey to support the decision model

The research is organised into the following chapters:

Chapter 2 – Literature Review; this chapter presents an overview of the current research and practice of wastewater asset management decision-making, and intuitive decision-making in general.

Chapter 3 – Case Studies; this chapter presents two New Zealand case studies of current decision-making systems that use intuition for wastewater network asset management.

Chapter 4 – Methodology; this chapter describes the steps taken in developing the new methodology for documenting intuition, and the associated industry survey.

Chapter 5 – Results; this chapter presents the results of the industry survey.

Chapter 6 – Analysis; in this chapter, the results of the industry survey are used in the decision model to identify the overall impact that each factor has on the overall decision objective.

Chapter 7 – Discussion; this chapter provides a discussion of the limitations and benefits provided by the new methodology for documenting intuition.

Chapter 8 – Conclusions; this chapter presents the conclusions of the literature research, case studies, and development of the new methodology for documenting intuition.

Chapter 2 - Literature Review

2.0 Introduction

This chapter presents an overview of the current research and practice of wastewater asset management decision-making and intuitive decision-making in general. The reviewed topics are presented in the following sections:

- Wastewater network asset management best practices
- The complex system of wastewater network asset management
- Intuitive decision-making vs deterministic decision-making
- Ways and methods to quantify and document intuition

Intuitive decision-making is not limited to wastewater networks or even the field of engineering in general. However, to provide a specific context, this thesis uses the discipline of wastewater asset management for examining intuitive decision-making. This context also allows the theory to be developed to a level of detail that can be applied by decision makers within the industry.

2.1 Wastewater network asset management best practices

Wastewater pipe networks are a major component of public infrastructure worldwide. As these wastewater assets age, their performance and reliability degrade until they require replacement or rehabilitation. McKinsey Global Institute (2013) predicted that an investment of $USD 11.7 trillion is required to meet global demands for water and wastewater infrastructure globally from 2013 to 2030.

In the last decade, there has been a shift to focus more strongly on the management of existing wastewater assets as greater quantities of assets reach the end of their useful theoretical lives (Local Government New Zealand, 2014). Modern asset management practices stem from an economic approach. Australia has been at the forefront of infrastructure asset management practices dating back to Byrnes et al. (1986) investigating the efficiency of various infrastructure ownership models. Since that time, public works institutes and advisory groups in Australia and New Zealand have joined forces under the Institute of Public Works Engineering Australasia (IPWEA) and have published the International Infrastructure Management Manual (IIMM, 2015).

The IIMM is an example of the integrated asset management approach where an overarching organisational strategy influences the decisions made at each operating level of the organisation.

The ISO 55000 Asset Management framework is another international standard that provides a defined system for managing assets. The standard provides an overview of asset management including principles, terminology, the requirements for implementing an asset management system and some guidelines on the application of these principles.

Significant research effort has been devoted to the high-level approaches of integrated infrastructure asset management. Three approaches for high-level description are detailed below;

Overall framework

Alegre & Coelho (2012) provide an overall framework for an integrated approach specifically for urban water and wastewater assets. Figure 1 below shows the interaction between organisational planning and decision levels, corporate competencies and the dimensions for analysis.

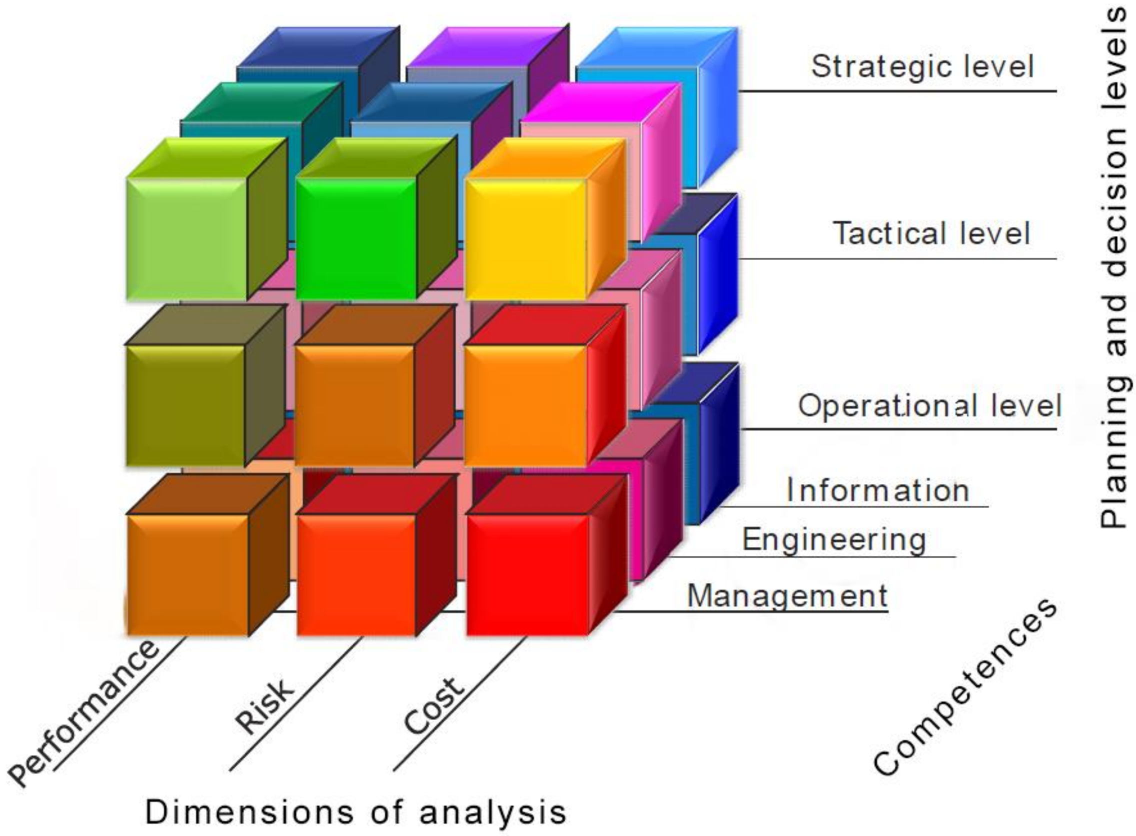


Figure 1 Integrated asset management framework (Alegre & Coelho, 2012)

The integrated framework uses the dimensions of **performance, risk and cost to** analyse infrastructure decisions. These dimensions require consideration from a number of different perspectives.

Four key perspectives

Younis & Knight (2014) propose the following four key perspectives for municipal infrastructure management:

> *Operational/Technical*
>
> Operational and technical perspectives include the understanding of systems' performance and prediction models, data quality, knowledge management practices, and staff education/training

Social/Political

Social and political perspectives consider the view of various stakeholders – customers, service providers, and governments, also considering issues such as public safety, environmental protection, and education

Financial

The financial perspective includes current budgets and the impact of decision on long term financial planning and stability

Regulatory

Regulatory perspectives include the compliance and understanding of present and future regulations that impact the infrastructure operation

Several other methods for splitting and defining these perspectives are made by Ugarelli et al. (2010), Alegre & Coelho (2012), CEN (2008), and Ashley et al. (2008). The common theme amongst them is that the management of wastewater infrastructure is a complex system of socio-technical dimensions that are difficult to measure with respect to each other. Without a common form of measurement, decision makers must reconcile the relative importance of the different perspectives. This key problem provides an opportunity for researching the use of intuition as a tool to create a pathway between these disparate perspectives.

Methodology guidance

These high-level approaches are generally well understood and have led to a common set of methodologies and terms that are adopted. This common guidance is provided below and allows some consistency for measuring the various elements under consideration within the integrated decision-making:

Level of service

The performance of infrastructure is intrinsically linked to the service quality and experience of those using, managing and paying for that infrastructure. Wastewater network levels of service cover reliability, function and dysfunction, environmental values, safety, efficiency and value for money (Ugarelli et al., 2010). Watercare Services Ltd, who manage water and wastewater infrastructures in the Auckland region, have identified their core customer values as quality, safety and sustainability (Watercare, 2011).

Key performance indicators (KPIs)

Performance indicators are quantitative and measure the effectiveness or efficiency of the activity (Alegre & Coelho, 2012).

KPIs can be aggregated and then compared to standardised performance indices. Performance indices can be used to judge performance (e.g. 0 - no function; 1 = minimum acceptable; 2 – good; 3 – excellent), although these indices have a subjective judgement component that is intrinsic to the standardisation process (Alegre & Coelho, 2012).

Condition assessment

Condition assessment requires collecting physical data to inform the analysis of current asset condition. Ugarelli et al. (2010) summarise that condition assessment is performed to “identify underperforming assets, predict failures, and decide on corrective actions”.

Before replacement or rehabilitation, correct actions can be determined, the condition assessment needs to be scored relatively in some way and then linked to the other attributes such as the KPIs or vulnerability to failure (Ugarelli et al., 2010).

Risk assessment

Within the vast field of risk analysis expertise, several mainstream frameworks have been developed for infrastructure-based problems (Alegre & Coelho, 2012). Risk is typically addressed as a risk cost or risk score that is the product of a probability score and consequence score (ISO/IEC Guide 73, 2002). In asset management practice, probabilities and consequences are often simplified into category levels defined by the assessor, for example; 1 – insignificant; 2 – low; 3 – moderate; 4 – high; 5 – severe (Alegre & Coelho, 2012). The resulting risk matrix is presented in Figure 2 below:

Figure 2 Risk assessment matrix (Alegre & Coelho, 2012)

The combination of high probability and high consequence leads to a high risk score, which is the area shown in red in the matrix. Medium risk is shown in yellow and low risk in green.

Risk assessment can be used as a method to bring together disparate socio-technical variables for comparison, such as service failure, cost, health and safety, or business reputation and image.

Individual wastewater network asset managers are concerned about their systems and the universal guidance described above falls short of providing specific information on how performance, risk and costs should be measured or traded off. For example, what impact does a single deteriorated pipe have on level of service and how can the risk of failure be determined from the condition assessment results?

Different infrastructure systems have their own qualities and complexities. Decision-making requires the combination of high-level asset management principles, technical knowledge of how performance, risks and costs interact, and a familiarity of the individual infrastructure system in question. The result is that the application of decision support systems for wastewater asset management is unique, varied, and subjective.

Table 1 below presents 13 different methods for applying wastewater pipe deterioration that were published in an eight year period.

Table 1 Classification of deterioration models adapted from Ana & Bauwens (2010). Refer to Ana & Bauwens (2010) for citations of model origins

Physical models	**Artificial intelligence models**	**Statistical models**
ExtCorr	**Neural networks** **Fuzzy set theory** **Rule-based simulation** **Expert system**, e.g. SCRAPS	**Cohort survival model** **Markov chain** **Semi-Markov** **Logistic regression analysis** **Multiple discriminant analysis**

The methods above focus on the technical perspective of pipe deterioration within wastewater network asset management. These technical contributions are useful. However, their practical application is limited in that they do not extend to address the socio-technical dimensions and the various complex systems that surround the technical perspective.

Finding universal methods that are both practical in their application and remain relevant across the various individually complex socio-technical systems is a current challenge for wastewater asset managers.

2.2 The complex system of wastewater network asset management

The performance and management of any single wastewater network depends on four perspectives; Operational/Technical, Social/Political, Financial and Regulatory. This requires consideration of the system as a whole so that the various parts can be analysed with respect to each other. With the varying perspectives, the system of WNAM has been described by Van Riel et al. (2014) as “socio-technical”.

Socio-technical: “a system containing both physical-technical elements and networks of interdependent actors, all with a high degree of interconnectedness” (Bar-Yam, 1997) (Bruijn & Herder, 2009).

A system diagram is shown below in Figure 3 that demonstrates the interconnectedness and socio-technical nature of WNAM:

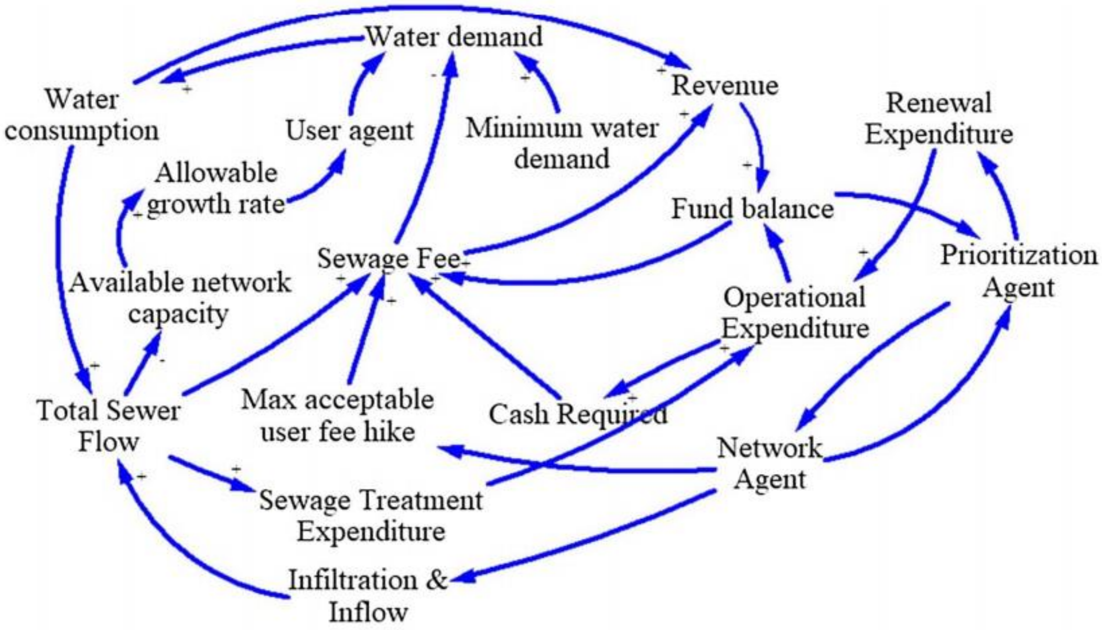


Figure 3 Interactions among network agent, user agent, and prioritisation agent for the wastewater system (Altarabsheh et al., 2019)

The systems view of WNAM is important so that meaningful developments can be made that go beyond just focussing on the technical elements and relationships of the system.

The systems view begins with the appropriate description of the WNAM system. A system is described sufficiently when it meets the requirements of a so-called "Healthy System", which has the following indicators (Elms, 1998):

- Balance
- Completeness
- Cohesion
- Consistency
- Clarity

The type of decision-making required to support a system will depend on the qualities, and the complexity, of the chosen system. A complex system is a special class of system and has identifiable characteristics.

Simon’s (1962) description of complex systems is used widely among many disciplines. A system is regarded as complex if it can be analysed into many components having relatively many relations among them so that the behaviour of each component depends on the behaviour of others.

The non-linear relationships within a complex system is another important identifier. Morowitz & Singer (1995) explain complex system non-linearity: "A system that involves numerous interacting agents whose aggregate behaviours are to be understood. Such aggregate activity is nonlinear. Hence it cannot simply be derived from the summation of individual components behaviour”.

Another way to understand complexity is the degree of difficulty in predicting outcomes (Elms & Brown, 2013) “the greater the difficulty, the greater the complexity”.

Given the lack of universal practical WNAM methods, it is clear from the earlier comments that it is difficult to predict the outcomes within the WNAM system reliably. In other words, it is a complex system. With respect to decision-making; the evaluation of alternate options for action within WNAM is difficult due to the challenge of predicting the corresponding expected benefits and costs holistically.

Three specific challenges in predicting WNAM system outcomes are described below;

Socio-technical challenge

There are numerous factors influencing wastewater asset management and performance. It is a socio-technical system and the contributing factors can be grouped by either their technical and/or social nature. Technical factors influencing the performance of a particular pipe network include pipe material, diameter, pipe gradient and pipe age.

Examples of social factors are the stakeholders’ willingness to pay, the expectations concerning the levels of service, the definitions of pipe criticality, and the relative importance of wastewater networks in comparison with surrounding infrastructure. The cross over between these traditionally different schools of thought makes the prediction of outcomes more difficult and adds to the WNAM system complexity.

Network complexity challenge

Wastewater infrastructure pipeline systems consist of an extensive network with sophisticated connectivities between pipes and manholes. Network outcomes are difficult to predict if only looking at the individual pipe or manhole elements without considering the impacts, influences and inter-dependencies on the surrounding parts of the network.

The connectivity creates a specific type of geometry and interdependence, which results in many non-linear interactions. That is the overall performance cannot be derived from a simple summation of its parts.

The complexity is also indicated by the high number of factors that influence WNAM. In the Van Riel et al. (2014) study, 18 sewer system managers provided a list of 21 factors that were actively evaluated in the planning of replacement wastewater pipelines.

Missing data challenge

Decisions are dependent on information sources. For WNAM there are a variety of data that provide useful information for decision-making. Core information on wastewater pipe networks includes pipe location, diameter, age and material. Beyond this core set, additional data such as maintenance records, condition assessment, hydraulic capacity and failure history are useful for informing the network's technical performance. And further, other data that informs the economic, social, environmental and political impacts of the network can also contribute.

However, due to several factors, these data sets are either incomplete or missing. The fact that the network is buried beneath the ground provides a physical barrier to data collection or validation. Pipe networks can have assets that are over 100 years old, and data was not captured in the same way as for new assets installed more recently.

This data completeness and reliability issue is commonly reported across WNAM research literature (Scheidegger et al., 2011). Most wastewater utilities lack accurate core data as well as cost characterisation. And when the data is available it is difficult to recover, combine and use (Cardoso et al., 2012, Ugarelli et al., 2007).

The lack of comprehensive, high quality, and reliable data for decision support systems are obstacles to the practical application of such tools. Where models are used with highly approximated inputs the results can be misleading. There is not a problem of having sufficient data management systems available, but instead of utilities failing to keep data up to date or to capturing data across their entire network (Ugarelli et al., 2008).

Together these combined issues highlight the inherent complexity of WNAM and the need for care in how the system is considered.

2.3 Intuitive decision-making vs deterministic decision-making

It is necessary at some point for the emphasis of WNAM to move from a focus on defining and understanding the system to a focus on decision-making. Asset managers need to make decisions and subsequently act so that pipes can be investigated, repaired or replaced.

The eight main components of the decision process according to Elms & Brown (2013) are:

- Problem clarification
- Choice of strategy
- Choice of action
- Alternative actions
- Information on the alternatives
- Values of the alternatives
- Constraints
- Context

Within each process component, there are broadly two distinct decision modes that can be used: deterministic decision-making or intuitive decision-making. Understanding the difference between these decision-making modes can be made easier by first examining the human thought process that leads to decisions. Psychology researcher Kahneman (2011) describes the two distinct modes of thinking, adopting the terms widely used by psychologists in this field: System 1 and System 2.

- System 1 operates automatically and quickly, with little effort and without the requirement of voluntary concentration. This mode of thinking draws on our relevant experience, knowledge and "gut", and is fundamentally important for intuitive decision-making.
- System 2 allocates attention to the effortful mental activities that demand it, including complex computations. These operations are trace mathematical and logical solutions to the question or task at hand. This mode of thinking is relied upon heavily when adopting deterministic decision-making processes.

Deterministic Decision-Making

Deterministic decision-making uses the methods of calculation borne of System 2 thinking and follows a process where the relevant factors and relationships are defined so that a correct answer can be found. The deterministic approach relies on data input, quantifiable relationships, and analysis of different calculated outcomes. The final decision can be made by examining which of the calculated scenarios provides the greatest expected outcome.

The field of engineering, and subsequently much of the asset management discipline, has a practical outlook and could be viewed as the application of science and mathematics to provide some societal need. It follows that these scientific and mathematical fundamentals require that engineers rely heavily upon the System 2 mode of thinking. Deterministic decision-making applies analytical reasoning to problems that are well defined and can be broken down, agreed upon, or well approximated to form a series of factors and relationships according to the mathematical System 2 approach.

The deterministic approach supports the decision-making process where there is:

- objective data
- full information about alternatives
- time, cognitive ability, computing power and resources to evaluate each choice against the others
- a formal understanding of the cost, benefits and utility of the various outcomes so that the calculations can be calibrated to ensure outcomes are optimised

Professionals in WNAM use deterministic approaches to support their decisions; such as estimating the restoration time of wastewater pipelines after earthquakes (Liu et al., 2017) and in the pipe deterioration modelling examples provided earlier in Table 1. The application, however, is limited to the extent that complete, objective data, causal information and formal evaluation of utility is known. The earlier described issues of the inherent socio-technical system nature, network complexity and problem of missing data constrain the deterministic approach. These constraints require certain assumptions to be adopted prior to the application of a deterministic approach.

System 2 thinking is less able to find appropriate solutions where problems or decision-making systems grow increasingly large, complex and less well understood (van Riel, 2014). System 1 thinking provides an alternative approach.

Work by Dijksterhuis et al. (2006) compared decision outcomes of System 1 thinking versus System 2 thinking. Engaging in the conscious, calculated thought process of System 2 was concluded to be more effective for simple decisions; however, the intuitive thought process associated with System 1 delivered high effectiveness for more complex decisions.

Intuitive Decision-Making

Intuitive decision-making uses System 1 thinking and relies on our innate ability to make sense of things without going through the effort of a calculated step by step thought process. Instead, the intuitive thought process enables humans to make judgements more quickly and under uncertainty (Kahneman, 2011). When faced with complex questions, System 1 can combine the relevant experience of the decision maker with a mechanism of simplifying the question into a similar problem with a more obvious answer. There are distinct processing modes at work within the fast thinking of System 1. Kahneman (2011) provides the example of an experienced chess player who after thousands of hours of practice comes to see the chess board in a unique way. Their ability to consider a complex chess position and to provide an intuitive yet accurate next move comes from their relevant expertise. This is the mode of System 1 thinking that comes from experience. A second mode within System 1 thinking is to answer a difficult question by reframing the question to something simpler that can be more easily contemplated and applying a heuristic, or rule of thumb. An example of this is Kahneman's description of a chief investment officer who had purchased tens of millions of dollars in stock of Ford Motor Company. His decision was not based primarily on stock pricing but instead on his intuitive "gut feeling" about the company; he liked the cars they made and liked the idea of owning shares in the company. The complex question of whether to buy shares in the company was substituted with a simpler question of whether the investor liked Ford cars and wanted to be associated with the company itself. These two examples of chess moves and stock picking illustrate both the marvels and flaws of intuitive thought. The pitfalls of intuition and helpful mitigations are presented in a following section.

The intuitive approach supports the decision-making process where there is:

- uncertainty
- complex decision systems
- correlation between the current decision and prior relevant experience
- no formal method of calculation
- limited time or resources

Elms & Brown (2013) conclude from the work of Dijksterhuis et al. (2006) that engineers should make increasing use of intuitive decision-making given their increasing call to deal with complex situations of socio-technical nature. Decision makers with WNAM are faced with challenges of uncertainty, complex systems and no formal method of calculating trade-offs between competing outcomes of social-technical nature.

Despite this complexity, it is however necessary for wastewater network asset managers to make investment and intervention decisions. In this the decision makers are effectively compelled to make use of their intuitive judgements to come to a decision at all. In practice, the decision makers are guided by their relevant expertise on which factors to consider in renewal planning and to what degree. The Van Riel et al. (2014) study provides an example of capturing this intuitive input. The following results in Figure 4 present the answers from a survey of Dutch municipalities asking which relevant information sources, or factors, are considered in wastewater pipe network renewal decision-making:

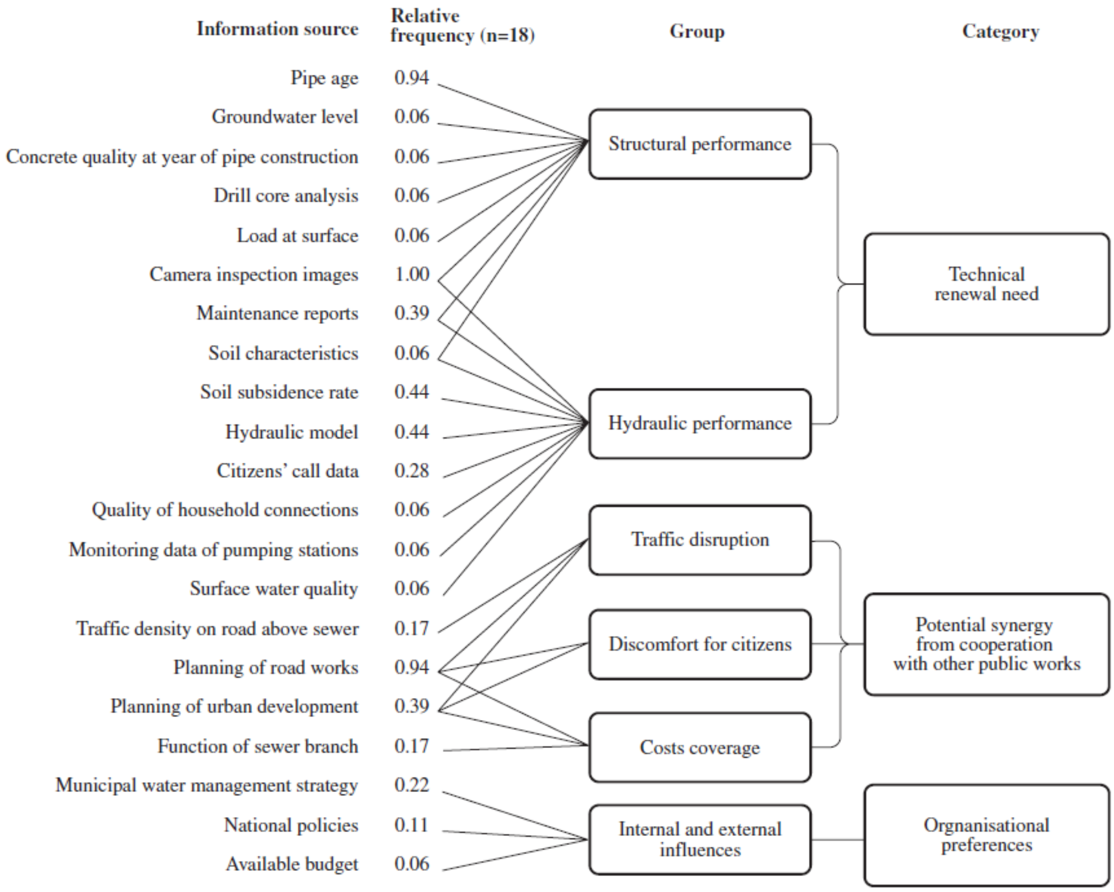


Figure 4 Identified information sources (grouped and categorised) consulted for sewer system replacement, obtained from eighteen interviews (van Riel et al., 2014)

This example shows a wide variety of factors under consideration and demonstrates that not all decision makers are referring to the same information sources. Some factors are more universally considered; pipe age (0.94 relative frequency), camera inspection images (1.00), and planning of road works (0.94). Other factors are included in fewer cases. These factors are more subjective and highlight the role of expert intuition as individual decision makers use their unique criteria for selecting what is relevant and useful.

The results also provide evidence that consideration is extended beyond the structural and hydraulic pipe factors to include the consideration of other infrastructure dependencies, alongside social, financial and organisational impacts. The social-technical nature of the decision system comes with the problem of how decision makers will trade off one disparate factor with another. Van Riel et al. (2014) describe this process as the intuitive combination of five simultaneous risk assessments covering:

- pipe collapse (insufficient structural performance),
- insufficient hydraulic performance,
- nuisance or discomfort for citizens and related reputation of the organisation,
- costs for excavation works and surface level reconstruction,
- traffic disruption due to excavation works.

In practise, this combined risk assessment was based on the intuitive judgements of the decision makers and did not have a formal step to quantify probabilities and consequences.

As earlier discussed, intuitive thinking is the combination of two processing modes, either the skilled harnessing of prior relevant expertise or the unskilled automatic simplification of the problem to a heuristic that can more easily be addressed. Van Riel et al. (2014) state two conditions that need to be met to make skilled intuitive judgements; sufficient regularity and learning opportunities.

There must be sufficient regularity of cues that relate the decision to the subsequently observed outcome. This condition can be easily observed in some aspects of WNAM such as the choice of pipe diameter and the subsequent observed performance during a period of high flow. However, this condition is unlikely to be met in pipe replacement decisions where pipes have asset lives of 100 years or more and renewal decisions are tracked over a period well beyond the career length of individual decision makers. Additionally, pipes can be replaced before reaching a point of continued performance failure. Pre-emptive replacement strategies promote continued service delivery but do however remove the opportunity for regular observation of failure data points that would otherwise justify the renewal decisions. The 100 years or more time frame and the pre-emptive renewal strategies also limit the learning opportunities needed to develop skilled intuition. Evaluation of the accuracy of prior intuitive decisions is limited in this WNAM pipe renewal context. Through these observations, Van Riel et al. (2014) conclude that while intuition is used necessarily in WNAM, it is likely to be applied in an unskilled manner and therefore subject to the pitfalls of intuition exercised outside the boundary of relevant expert knowledge.

Pitfalls of intuition

Tversky & Kahneman (1974) researched the presence of heuristics and biases when making intuitive judgements under uncertainty. The research revealed that the use of heuristics in intuitive decision-making is efficient and usually effective but also leads to systematic and predictable errors. They identified systematic and predictable pitfalls and three of these problematic heuristics are described below.

Representativeness or similarity heuristic

An assessment of representativeness or similarity can occur when determining the probable connection between two states. For example, how likely it is to for a person with a certain set of traits to be in a particular occupation. Where the set of personality traits is most associated with the occupational stereotype, the heuristic will influence people’s response without giving due consideration to other factors such as how likely is it for the general population to be in each particular occupation, even if these prior probabilities are known.

This representative heuristic will also influence decision makers to:

- insensitivity of sample size effect
- misconceptions of chance,
- overestimate predictive accuracy
- create an illusion of validity
- ignore natural regression towards the mean

Availability heuristic

An assessment of availability can occur when considering the likelihood of an event based on how easily instances of that event or scenario are brought to mind. For example, someone may assess the risk of heart attack for middle-aged people by recalling the instances of heart attacks from the people they know. The heuristic will influence decisions to favour an answer that is consistent with how easily the decision maker can recall memories or generate possible outcomes relevant to the question.

The availability heuristic will influence decision makers to be biased towards inputs or outcomes that:

- are familiar or prevalent in their memory due to recency or significance
- are easier to search for, mentally, or that appear in contexts that are easier to search for
- are easier to imagine or construct calculations for
- have an apparent associative bond which leads to an overpredicted that they are likely to co-exist

Adjustment and anchoring heuristic

The adjustment or anchoring heuristic occurs when an intuitive assessment is irrationally affected by some initial value or partial computation. For example, a subject's estimate of the percentage of African countries within the United Nations was affected by first exposing them to a randomly spun wheel with numbers 1-100 on it. Where the spun wheel landed on a small number the subjects underestimated the percentage of African countries and conversely overestimated when the wheel landed on a high number.

This adjustment and anchoring heuristic will influence decision makers to:

- insufficiently adjust from an unrelated initial mental prompt
- insufficiently adjust from a partially completed calculation
- underestimate the probabilities of failure in complex systems
- overestimate the probabilities of success in chain-like conjunction events
- poorly estimating the probability of some event occurring (either overly-tight or overly-wide) depending on how the question was constructed

These influences for bias can be evident in the responses of both experienced and naïve decision makers, although in many cases relevant experience can overcome the inaccuracy of heuristic bias. This experience provides a starting distinction between skilled and unskilled intuition.

In a 2016 interview, Professor Emeritus David Elms of the University of Canterbury provided an account of the following additional characteristics of intuitive decision-making:

- The more variable the historical situation, the more risk averse the decision maker becomes, therefore relying less on information
- The more experience someone has with making certain decisions, the more intuitive the decision becomes. This does not always lead to correct decisions

- People weigh losses more greatly than gains, which means decisions tend to be on the cautious, incremental, non-innovative, and risk averse side

Intuition cannot be expected to provide consistent accuracy without concerted effort to address inherent quality assurance issues. Given the number of different heuristics and adverse decision effects, a proactive awareness of whether a decision maker is applying intuition in an unskilled way is difficult to achieve. But there remain approaches of applying universal quality assurance to the decision-making process, such as that of sufficient regularity and learning opportunities, so that over time, skilled intuition is promoted over unskilled. A recommended starting point for this is for WNAM decision makers to document the argumentation for their renewal criteria and selection (van Riel et al., 2014). Documentation provides an opportunity to enhance the necessary intuitive decision-making process by:

- creating reference points so that assumptions and criteria can be tested and improved over time as feedback is acquired
- describing a particular decision process methodology that can be explicitly and consistently followed in future
- capturing expert judgements in a way that be shared with others to harness the power of multiple perspectives
- passing on institution knowledge from a qualified expert to a less experienced decision maker.

2.4 Methods to quantify and document intuition

Intuition within WNAM decision-making can be documented through a number of approaches. Perhaps the simplest starting place is a documented record of the steps taken in the decision process. An example of how a decision process may be documented is provided in Figure 5 below:

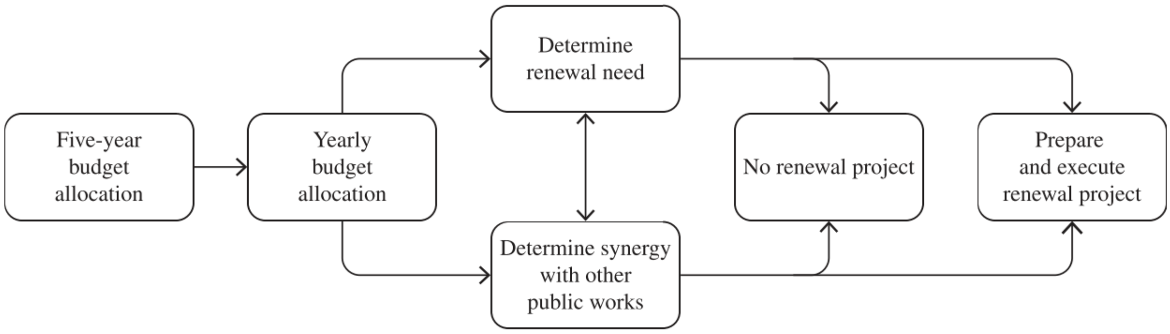


Figure 5 Decision-making process for wastewater pipe replacement (van Riel et al., 2014)

The next aspects to document are the individual factors or information sources that are used as inputs to inform the intuitive judgements. Figure 4 earlier provided an example of 21 factors used by Dutch municipalities in their wastewater renewal process. A similar example below documents specific factors, and their relative frequency, used as information sources to support 150 specific wastewater renewal projects (n = 150).

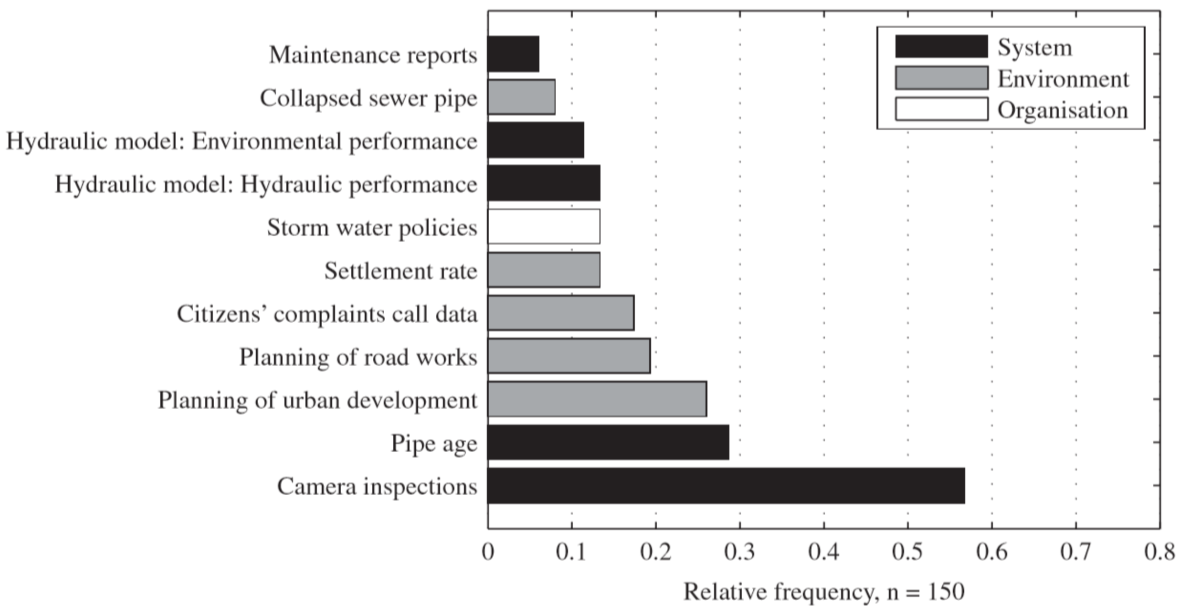


Figure 6 Indicated information sources for decision (van Riel et al., 2016)

The relative frequency provides some insight into the perceived relevance of each factor. The frequent use of the same factors, such as camera inspection, supports an assumption that these factors are widely recognised by experts to be significant.

More insight can be drawn and documented from experts by directly questioning the significance of each contributing factor. Two methodologies for quantifying this significance, or relative importance weighting, are the analytical hierarchy process (AHP) or the Likert scale.

AHP was introduced by Saaty (1980) to mathematically quantifying the relative importance or preference weighting of otherwise qualitative factors. AHP combines a series of pairwise comparisons wherein each case a relative weighting must be input from a user or group's perspective of the two factors in question. This pairwise comparison method is then continued to complete a matrix where the considered factors can be quantitatively measured against the others. The pairwise waiting is input based on the following fundamental scale in Table 2.

Table 2 The 1 – 9 "Fundamental Scale" (Saaty, 1980)

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

AHP provides a method for simulating decision models that have a hierarchy. That is where the final decision is placed at the top of the hierarchy and is influenced by several factors at a lower level, which in turn may be influenced by further factors at a lower level again. Each time the decision tree branches down another level, a normalised prioritisation score must be calculated by performing the series of pairwise comparisons on the subfactor. An example decision tree is shown in Figure 7 below that was part of applying AHP to an urban flood management decision.

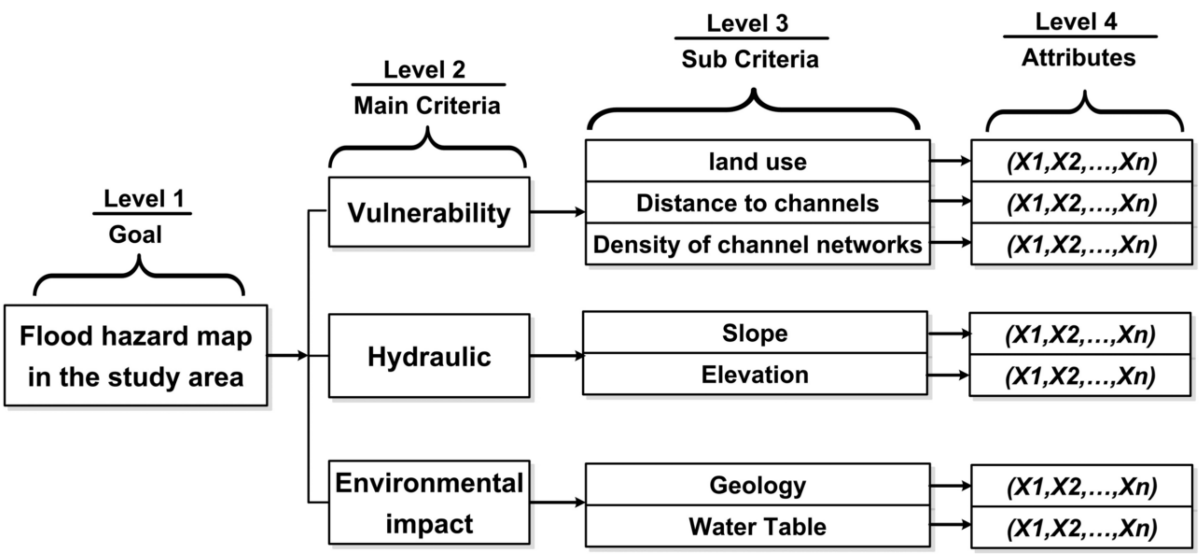


Figure 7 Hierarchical structure of urban flood management (Radmehr & Araghinejad, 2014)

This example has a basic hierarchy where there are never more than three subfactors contributing to a factor in an adjacent tier. If a decision model required several subfactors to be considered, then the computation effort increase exponentially. For example, to determine the relative weighting between seven subfactors the number of pairwise comparisons needed is 21 (= 1+2+3+4+5+6). This adds time and effort to the process of collecting the intuitively weighted inputs.

An alternative method of generating quantitative results of intuitive inputs is using a Likert-type scale from the method presented in by psychologist Likert (1932). Likert-type scales provide fixed choices on a scale designed to measure attitudes or opinions. Typically, five, seven or even nine pre-coded choices are provided on a continuum for participants to select. The recorded choices can be interpreted quantitatively based on the underlying assumption of the spacing between the ordinal continuum points. Generally, this assumption is that there is an equal linear spacing between the selected options. Table 3 below provides several typical examples of how Likert-type scoring is applied.

Table 3 Typical five-point Likert-type scales

Unimportant 1	Of little importance 2	Moderately important 3	Important 4	Very important 5
Not at all interested 1	Not very interested 2	Neutral 3	Somewhat interested 4	Very interested 5
Not satisfied 1	Slightly satisfied 2	Moderately satisfied 3	Very satisfied 4	Extremely satisfied 5
Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
Never 1	Rarely 2	Every once in a while 3	Sometimes 4	Almost always 5

Even in this small selection of examples, there are differences in how the five-point scale is applied. The terms “somewhat”, “very” and “extremely” are applied differently among the scales. The accuracy of quantitative analysis performed on data gathered in this way will be dependent on how responders interpret the words used in each category. Processes that sum, or relatively weigh the resulting scores are limited by the quality of the underlying assumption of the attached ordinal values.

Where data is collected from multiple sources, for example using a survey, the mean scores and standard deviation can be analysed to determine the measures of average and spread. An alternative methodology for analysing Likert-type scale survey data is using the Top 2 Box score. The Top 2 Box method provides a straightforward way to rank the results by reported significance level. For a 1 – 5 Likert scale, the Top 2 Box score is the calculation of the percentage of results that were reported as 4 or 5.

These described methods of documenting intuition can be applied to WNAM. Fundamentally, intuition can be documented during the following stages of the decision-making process:

- Capturing the overall process and steps followed
- Selecting the relevant factors that will be considered during the process
- Describing the hierarchical decision tree structure
- Quantifying the priority or relative weighting of the applied relevant factors.

Chapter 3 – Case Studies

3.0 Introduction

This chapter presents two case studies of current decision-making systems within local WNAM. The purpose of these case studies is to describe the role that intuition plays in the decisions methods that have been developed by these organisations and identify how it is documented.

3.1 Stronger Christchurch Infrastructure Rebuild Team (SCIRT)

Background

The SCIRT alliance was set up after the Christchurch earthquakes in 2010 and 2011 and was responsible for rebuilding the horizontal infrastructure; predominantly wastewater, stormwater, and water supply underground pipes, roads and bridges. SCIRT was made up of a number of organisations (Botha & Scheepbouwer, 2015). The owner and non-owner participants within the commercial model are the parties that all succeed or fail together. They were:

Owner participants – these are funding agencies and asset owners:

- New Zealand Central Government (CERA/Department of Prime Minister and Cabinet)
- Christchurch City Council (CCC)
- New Zealand Transport Agency (NZTA)

Non-owner participants – these are contracting firms:

- City Care
- Downer
- Fletcher
- Fulton Hogan
- McConnell Dowell

Supporting organisations providing professional services consultants to SCIRT as part of an Integrated Services Team that performed design, planning, coordination and technical services for the rebuild. The supporting organisations were not part of SCIRT but rather worked for the alliance.

The SCIRT rebuild

The earthquakes damaged approximately 528 km of the wastewater network, 31% of the total length of pipe assets owned by Christchurch City Council. The sudden damage to the wastewater network required a new condition assessment programme to be carried out. Remedial decisions were required for each pipe in the network based on condition assessment, asset information, geospatial data, and operational data. To facilitate a consistent approach to remedial decisions across the SCIRT organisation, a set of guidelines was developed; the Infrastructure Recovery Technical Standards and Guidelines (Scheepbouwer & Botha, 2016, Liu et al., 2016).

3.1.1 Infrastructure Recovery Technical Standards and Guidelines (IRTSG)

The IRTSG were the first new guidelines created after the Christchurch earthquakes and included decision pathways for assessing earthquake damage and determining remedial actions if any. The IRTSG were inclusive for all of the horizontal infrastructure rebuild, however only the aspects relating to the wastewater network are examined and discussed in this case study. For wastewater assets the overarching purpose of the IRTSG was to return the wastewater network to a condition that meets the levels of services prior to the 4 September 2010 earthquake.

Two significant characteristics of earthquake damage to wastewater pipes were

- Structural damage to the pipe wall or joints
- Change in the longitudinal profile of the pipes due to local dips or an overall loss in grade over the pipe length

For both of these damage categories below, the IRTSG provide a methodology for assessment and remedial action.

Structural damage

- Use CCTV records give the physical properties of the pipe
- Apply threshold levels for defects to identify required repairs
- Determine type of repair
- Apply threshold for pipe renewal/lining based on number of repairs needed

Change in longitudinal profile

- Use CCTV records, profilometer, or end manhole survey give longitudinal profile
- Apply threshold for dip magnitude as a percentage of pipe diameter
- Determine if pipe grade meets historical standards (manhole survey)
- Determine if the pipe can be fixed in one spot or over multiple pipe lengths

Intuition within the IRTSG

The IRTSG is prescriptive with the guidance of decision methodology, damage thresholds and repair strategies determined during the authors' development of the guideline. The authors' intuition has been used to determine which factors to concentrate on, and to what degree they affect the renewal decision.

This is intuition "up front". The subjectivity of decision-making has been worked through during the guideline development. This allows users who are applying the method to rely on the intuition of the authors. Since the balance of intuitive input is biased towards the guideline author, the guideline can be interpreted by a person of lower expertise since they are following a prescribed approach.

The users of the guideline are provided with a specific focus for their renewal decisions and do not have to consider the entire complex dynamic of wastewater network asset management each time.

This intuition "up front" also promotes a consistent approach for those using the guideline as the prescribed factors and weightings will be used similarly for all users.

Additionally, this prescription streamlines the decision-making process, speeding it up and allowing decisions of a similar and straightforward nature to be rapidly resolved. In the context of the SCIRT purpose and programme this method of applying intuition supported the urgency and the scale of the infrastructure recovery.

It is however difficult for a guideline of this nature to cover all the circumstances that could be encountered by the users. The adopted factors, weightings and thresholds may provide appropriate direction for the majority of cases but when applied to the entirety of a network, subject to a multitude of complex interactions, it is inevitable that some conditions do not suit the prescribed approach.

Intuition “up front” is also constrained by the ability of the expert authors to consider all the information that will be relevant in the future and account for it. Predictive capabilities are likely to be stronger in cases where prior experience can inform decision-making. Conversely, the ability to reasonably predict appropriate methodologies may be weaker where it is an entirely new event or circumstance that is being considered without the benefit of prior experience.

Technical guidelines are written at a certain time with a certain set of influencing socio-technical factors (i.e. economic/political). There may be a need to revisit the technical factors, weightings and thresholds as socio-technical factors change over time.

Auditing the intuitive judgements within the guideline provides a continuous improvement loop where the authors’ intuition can be tested with result feedback. Feedback is a form of quality assurance and mitigates pitfalls associated with utilising intuition. The feedback process was used within SCIRT and the IRTSG document received a number of updates and revisions.

3.1.2 Network Guidelines

In addition to the IRTSG, further guidelines were developed during the SCIRT rebuild programme to enhance the decision-making processes of wastewater network assessment and remedial action. A new “Network Guideline” was developed at a time when SCIRT had prioritised and dealt with the areas of Christchurch that had sustained the greatest earthquake damage and was now transitioning to focus on remaining assets where damage was less severe or where it was more localised in nature. The purpose of the Network Guideline was to further apply asset management principles to the decision-making methods. This modified the way that expert intuition was being applied to the decision-making model and is discussed here as a second method within the context of the SCIRT earthquake rebuild.

The Network Guideline was introduced as an additional decision layer on top of the already utilised IRTSG decision method. The IRTSG would continue to be used for the initial classification of damage thresholds to determine whether a remedy should be considered, with the Network Guideline providing additional decision-making support to increasingly refine what the remedial action should be.

The Network Guideline required an assessment of the existing or future impact of the earthquake damage for each individual asset. This impact assessment required users to take a risk-based approach to each asset to consider both the severity and the consequence of the damage. Categories to assess this risk were grouped as:

- Present-day impacts on the wastewater network performance
- Likelihood of pipe/network failure within 5 years
- Critical assets for network performance
- Critical locations of assets
- Critical impacts on operational and maintenance activities and expenditure
- Assets with an interdependence to other critical infrastructure

Users of this Network Guideline would conduct this risk-based assessment for each damaged asset before recommending a remedial action such as an excavated repair, trenchless patching or lining of the pipe, pipe replacement, or doing nothing.

Intuition within the Network Guidelines

Previously, the IRTSG method was shown to have intuition “up front” where the authors were prescribing the actual decisions themselves. The Network Guideline approach is different.

While it still relies on expert intuition by the guideline authors, they are only defining the framework and principles for decision-making. In this way, the expert intuitive input is shifted more towards the users of the guideline who are responsible for applying the framework and principles to create actual individual asset decisions.

Intuitive decisions made by individual users interpreting a set of guidelines could be referred to as intuition at the “coal face”.

The requirement for a risk-based assessment to be conducted for each damaged asset means that more time is spent by the guideline user prior to recommending remedial actions. However, since each asset’s remedial action is individually assessed to a deeper level, the outcomes are likely to be more tailored to each situation.

Also, as the Network Guideline method relies more heavily on the intuition of the user, the final decision will have an increased dependence on their subjective view. The user is responsible for conducting the risk assessment, so the quality of the outcome depends on their appropriate experience to do so.

Each user applying the Network Guideline will have their own interpretation when applying the risk-based assessment before recommending remedial action. For example, two people performing the same task may conform to a different definition of what makes an asset “critical” thus opening a degree of subjectivity. In the SCIRT case, the users were spread across four separate design teams and collaborated to unify their collective understanding of subjects such as “criticality”. This resulted in a subset of heuristics being developed by representatives from the design teams that could be applied universally. This subset of heuristics became a set of working guidelines borne from the discussions between the design team representatives. These discussions provided a forum for the intuitive interpretation of certain risk-based applications to be shared between the design team representatives.

3.2 Waimakariri District Council wastewater network prioritisation

This next case study examines a wastewater network decision-making tool and methodology developed by the Waimakariri District Council to prioritise network inspection, repair, and renewal.

Background

The Waimakariri District Council faced a similar situation to the SCIRT case where the condition and performance of their wastewater network were significantly affected by the 2010/2011 Canterbury earthquakes.

The response to earthquake damage in the wastewater network required an effort to prioritise recovery activities to ensure that expenditure was optimised toward recovery and enhancement.

Significant liquefaction occurred in the communities of Kaiapoi, Kaianga and Pines Beach within the Waimakariri District, resulting in localised ground damage affecting the performance of the wastewater network. Pipes were damaged through the shaking forces and the differential ground movement. Design pipe gradients were disrupted and adversely impacted the effectiveness of the wastewater network to convey flows via gravity. Through this earthquake event, the Waimakariri District Council were faced with a damaged network with now unknown condition and performance, requiring the need to begin planning a recovery response. It is through the investigation of the network and the planning of the response that the prioritisation methodology was developed.

Network renewal process

The scope of this prioritisation project was to provide a decision-making model to determine an optimum method of renewal for gravity sewers. The prioritisation is twofold and is used to optimise the scheduling of CCTV inspection works and to optimise the scheduling of pipe renewal works. Both scheduling optimisation methods use a risk-based methodology for wastewater mains to identify renewed based on the typically used measure of likelihood (of failure) multiplied by consequence (of failure).

3.2.1 CCTV inspection prioritisation

The CCTV inspection prioritisation method consists of the following steps:

- Determine whether existing CCTV footage exists
- For assets with existing CCTV survey, schedule reinspection depending on previous condition grading
- For pipes without existing footage, being a risk-based calculation using:
    - The theoretical useful remaining life and a vulnerability assessment to produce a score for the likelihood of failure
    - A criticality assessment to produce a score for the consequence of failure
- The likelihood score is multiplied by the criticality score to produce an overall prioritisation score.
- Pipes are scheduled for inspection or reinspection based on the risk-based scores above or existing condition grading records.
- The prioritisation list is manually checked and verified for appropriateness before final acceptance.

A flowchart illustrating the CCTV selection criteria is presented in Figure 8 below and is reproduced in a larger size in Appendix A.

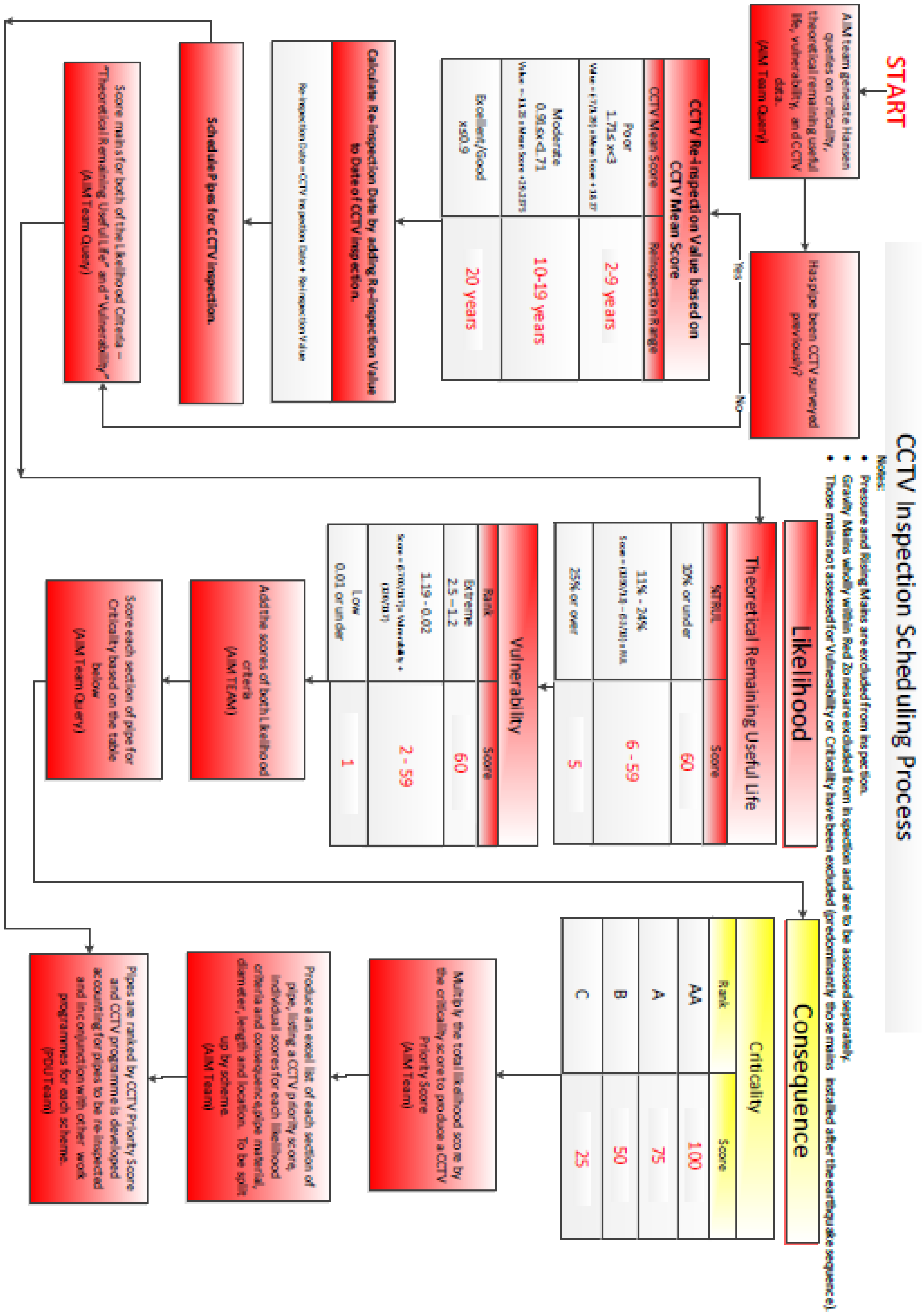


Figure 8 CCTV inspection scheduling process – taken from Waimakariri District Council operational documents (2016)

Intuition within CCTV inspection prioritisation

This method uses expert intuition to determine the likelihood of failure and the consequence of failure scores. The risk-based scoring system is subjective and depends on the importance level given to the factors used to determine the likelihood and consequence. Expert intuition is used to choose the relevant factors and the assignment of weightings.

Additionally, the breakpoints in the likelihood and consequence scale are determined using expert judgment. For example, the Theoretical Remaining Life scores of 5 – 60 split between the high, medium and low likelihood thresholds are subjectively set based on the relevant knowledge of the method's creators at Waimakariri District Council. The same applies to the consequence scores of 25 – 100 and the four corresponding breakpoints between AA and C.

There is a last step in the process where the prioritised list of pipes generated from the risk-based scoring is reviewed prior to any inspections taking place. Intuition is used at this stage to verify that the method has provided a priority that aligns with the expert judgement of the asset manager. It is also an opportunity for additional factors to be introduced and overlaid, such as the physical location and proximity of pipes, so that the actual inspection works are optimised geographically as well as according to the risk profile.

3.2.2 Pipe renewal prioritisation

Waimakariri District Council also developed a method for prioritising pipe renewals consisting of the following steps:

- Determine the blockage history of the wastewater pipe
- Use the CCTV inspection report mean structural score for each pipe
- Perform a vulnerability assessment to determine a theoretical vulnerability score
- Take the results of the three steps above and assign each a likelihood score. Add these three likelihood scores together to determine an overall likelihood score
- Perform a criticality assessment to produce a score for the consequence of failure

- The likelihood score is multiplied by the criticality score to produce an overall pipe renewal prioritisation score
- Pipes are scheduled for renewal based on the risk-based prioritisation scores above
- The prioritisation list is manually checked, and scheme maps produced showing the location of the target pipes
- The scheme maps are reviewed by the Asset Manager to determine the renewal technique to be used and whether further verification of the priority is needed using CCTV footage

A flowchart illustrating the pipe renewal scheduling process is presented in Figure 9 below and is reproduced in a larger size in Appendix B.

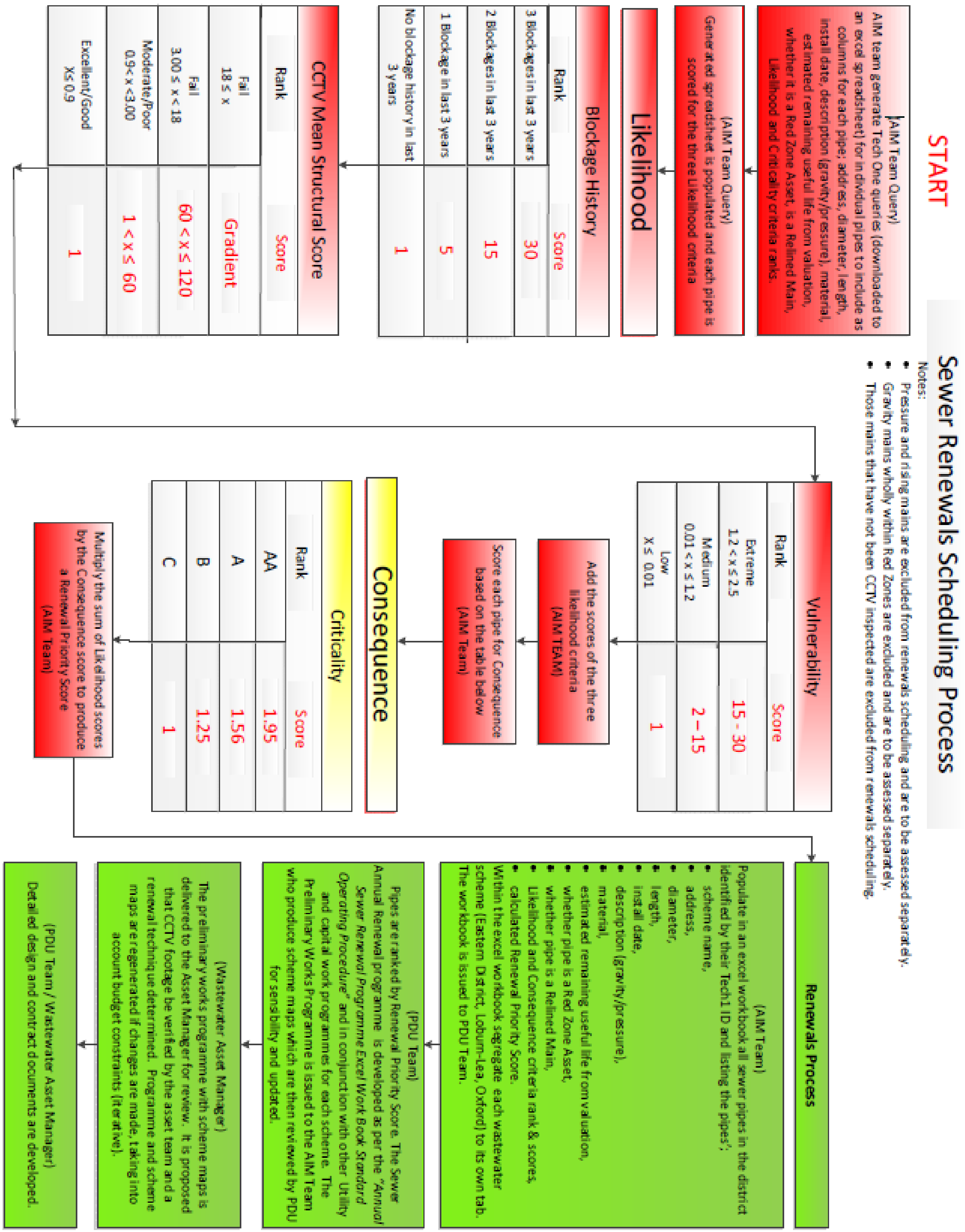


Figure 9 Sewer renewals scheduling process – taken from Waimakariri District Council operational documents (2016)

Intuition within the network renewal process

The Waimakariri District Council approach is a useful practical example of using intuition through a method of factors and risk-based weighted scores. Expert intuition is used to determine which factors will be considered and which will not. For example, their renewal process uses a theoretical value for vulnerability. There is not set definition of vulnerability within the industry, so the application requires the discretion of the user to choose which variables are considered. Waimakariri District Council has included pipe diameter, length, install date, description (gravity/pressure), material, estimated remaining useful life from valuation, whether a pipe is a Red Zone Asset, and whether the pipe has been lined in their assessment.

Intuition is also used to determine the scoring regime for adding or multiplying a range of factors together. Waimakariri District Council use a table where the factor weighting applies to a corresponding score. The setting of score values and corresponding thresholds, between high medium and low, involves expert intuition. In this case, the scores have been intuitively set for blockage history, CCTV mean structural ranking, vulnerability and criticality.

The determination of the factors and weightings is part of an "up front" intuitive input where the expert prescribes how the process is to be applied. Once this intuitive input is complete, the process can be applied by users according to its prescriptive nature.

A further use of intuition within the process is during the last step where the Asset Manager reviews the outputs and considers the suitability. This is effectively another expert intuition gate where someone with suitable experience vets the prioritisation process and scoring method to determine if the resultant renewal area maps make sense and are appropriate for action. This last step requires the input of an expert and verifies that the initial "up front" intuition was appropriate, and that the process has been applied by the user in a suitable way.

3.2.3 Documented intuition

The Waimakariri District Council approach provides clear documentation of how the decision -making process is applied. The process flow diagram shows the various steps to follow and describes the intuitive decision-making framework. This allows those not familiar with the process to understand the logic and how it is followed, and potentially how to perform the assessment themselves.

The documentation goes further and provides a list of the numerous factors that need to be collated into a spreadsheet to apply the process. These are listed in the green text box on the process diagram.

The intuitive scoring mechanism is also clearly documented. The relationships between the individual factor scores are shown with the corresponding likelihood or consequence scores to be used. Each score threshold is also shown within the tables to provide clear limits on how to interpret high, medium, and low scores. The clearly visible scoring mechanism provides a focal point for decision makers to audit and refine the process in future.

Chapter 4 – Methodology

4.0 Introduction

It is evident from the literature review and case studies that intuition forms a vital role in decision-making systems for wastewater network asset management. Since intuitive decisions are active in decision-making practice, effort can be directed towards the subsequent development of support systems that enable quality intuitive decisions. This thesis develops a new methodology to document intuition within the context of WNAM.

This chapter describes the steps taken in developing the methodology for documenting intuition.

An industry survey was chosen as part of the methodology to document intuition. An industry survey was used by Van Riel et al. (2014) in their research of wastewater network decision-making in the Netherlands. The research asked eighteen wastewater network managers from seven different Dutch municipalities for a description of the information sources that they used when prioritising wastewater network replacement. The collated research data provides a list of the information sources that these wastewater network managers provided as factors used within their decision-making processes. The information sources are those shown earlier in Figure 4. The relative frequency of each factor shows where multiple wastewater network asset managers responded with common answers.

Conclusions from the Van Riel et al. studies (2014, 2016) support the documentation of intuition as a next step and recommend the development of methods to solicit the various influence or weightings that experts place on the various factors. The new methodology developed in this thesis picks up this challenge of documenting the intuitive significance of various factors in the eyes of industry experts.

4.1 Purpose of survey

Intuitive responses from industry experts are subjective in nature. In ideal circumstances; given a large sample size, a common relevant knowledge system and a common interpretation of the survey question context, it may be that the expert responses converge to a common set of weightings. However even in this ideal case the weightings would not be either “right” or “wrong” but merely a depiction of expert understanding at a point in time. It is therefore important to note that the purpose of the industry survey is not to simply collect the resultant weightings from a set of wastewater network experts. Instead, and more importantly, the survey has been constructed to serve more widely as a method that could be adopted by various organisations who would wish to document intuitive decisions in a similar way. In this way, the purpose of the industry survey is as a pilot method to demonstrate how such a survey may be constructed, carried out and analysed. Aside from the survey results themselves, the resulting discussions and conclusions will focus on the suitability, usability, relevance, benefits and limitations of this documentation method.

The success of such a method depends on several human factors regarding the likelihood that different users would be able to buy into the approach and would see the value in them using their time to complete the inputs. The following characteristics of the survey were specifically considered in the development of the method to support the purpose of serving industry experts:

- Scope
- Relevance
- Alignment
- Familiarity
- User-friendliness
- Integration

These characteristics are explained in more detail in Appendix C.

4.2 The decision system model

The decision system model used is based on those factors identified in the Van Riel et al. studies (2014, 2016) and those factors within the case studies that were either the basis for asset manager decisions, or the inputs for pipe renewal intervention and risk-based assessments. The framed question is: “which pipe should I replace/repair?”.

The highest level of the decision system model is broad and includes components from the various socio-technical categories:

- Systemic improvement
- Coordination with other infrastructure planning
- Economic impact
- Environmental impact
- Political impact
- Ease of management
- **Network performance**

The option was taken to focus on gathering survey input data relating to just one of these overarching categories: network performance. Focussing the survey on this single category allows a demonstration of how this documentation method can be used in detail and provides proof of concept of how the survey could then be further developed for other categories and the entire decision tree eventually stitched together to represent the complete system. The category of network performance was chosen because it best represents the technical sphere of the decision-making tree and is where industry professionals in wastewater network operations and management are most confident in their expertise. The top level of the decision tree is shown in Figure 10 below:

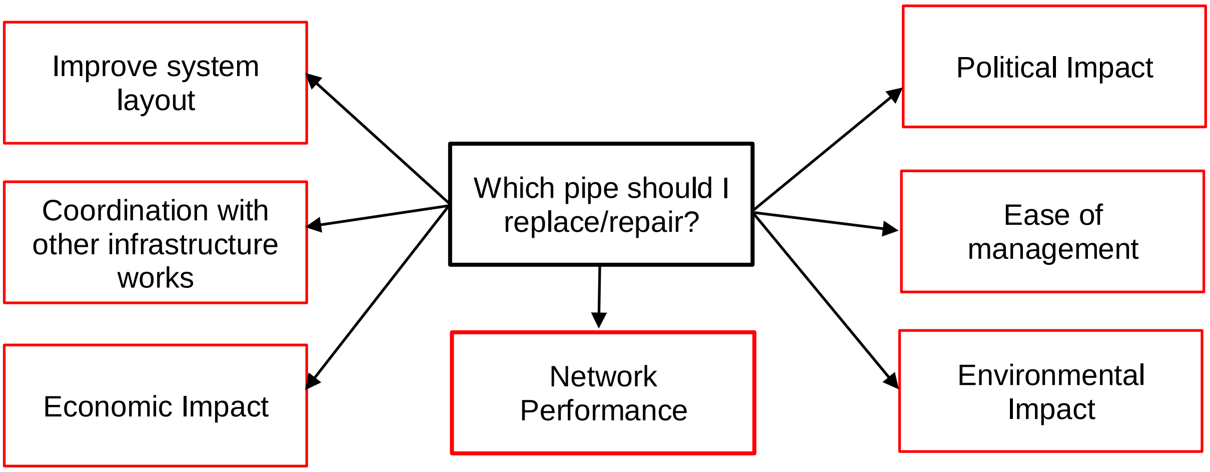


Figure 10 Top level of decision tree

To represent the category of network performance, further breakdown of the decision tree is required. This is another key step in the development of the survey because it is the author who decides how the category of network performance is broken down and what influencing factors will be included. As stated earlier, the 21 factors included in the Van Riel et al. studies (2014, 2016) and the prominent factors within the SCIRT and Waimakariri District Council case studies have been used as the reference. The sub-tree used to determine network performance has been developed around a risk- based approach considering the most likely failure modes. On this basis the five factors of greatest failure concern within the sub-tree of network performance were chosen to be:

- Ground damage
- Infiltration
- Overflow
- Losing service
- Exfiltration

This is shown below in the second level of the decision tree, Figure 11.

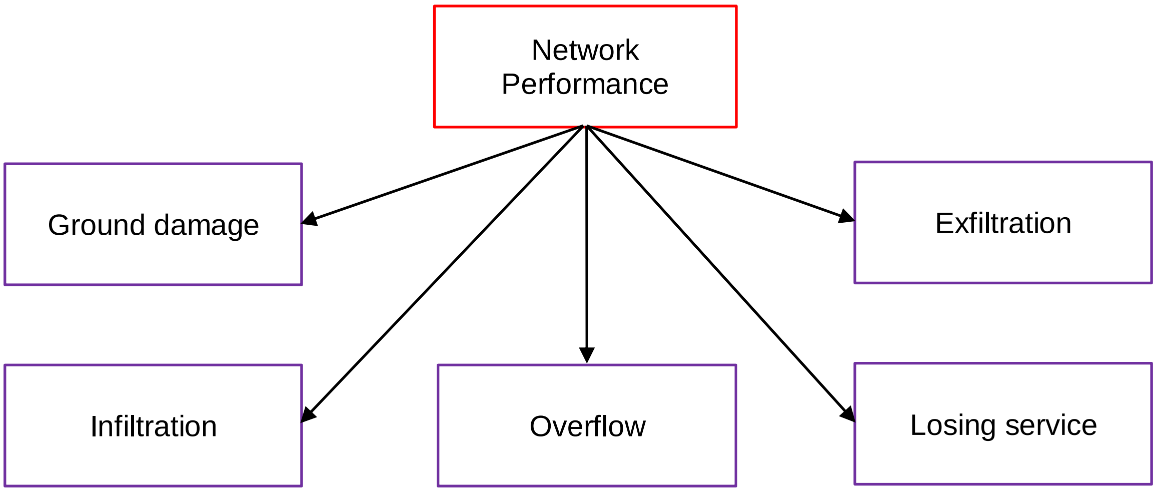


Figure 11 Second level of decision tree

Each of these sub categories were developed further by considering the factors that influence both the likelihood and the consequence of the failure mode.

Ground damage

This failure mode is where some problem relating to the buried wastewater pipes is causing the ground to be negatively affected in some way. For example, cracking on the ground surface, general subsidence or a sink hole forming. In this scenario the likelihood that such a failure would occur is broken down to show the typical influencing factors. The risk-based approach also needs to consider the negative consequence of ground damage occurring. A wastewater pipe network asset manager will want to prioritise their actions based on the overall risk which must consider the variable consequence level. For example, the difference in consequence between ground damage occurring in a busy intersection on a main road versus similar ground damage on a quiet cul-de-sac away from buildings of street features.

The development of the decision tree showing the ground damage factor is presented in Figure 12 below:

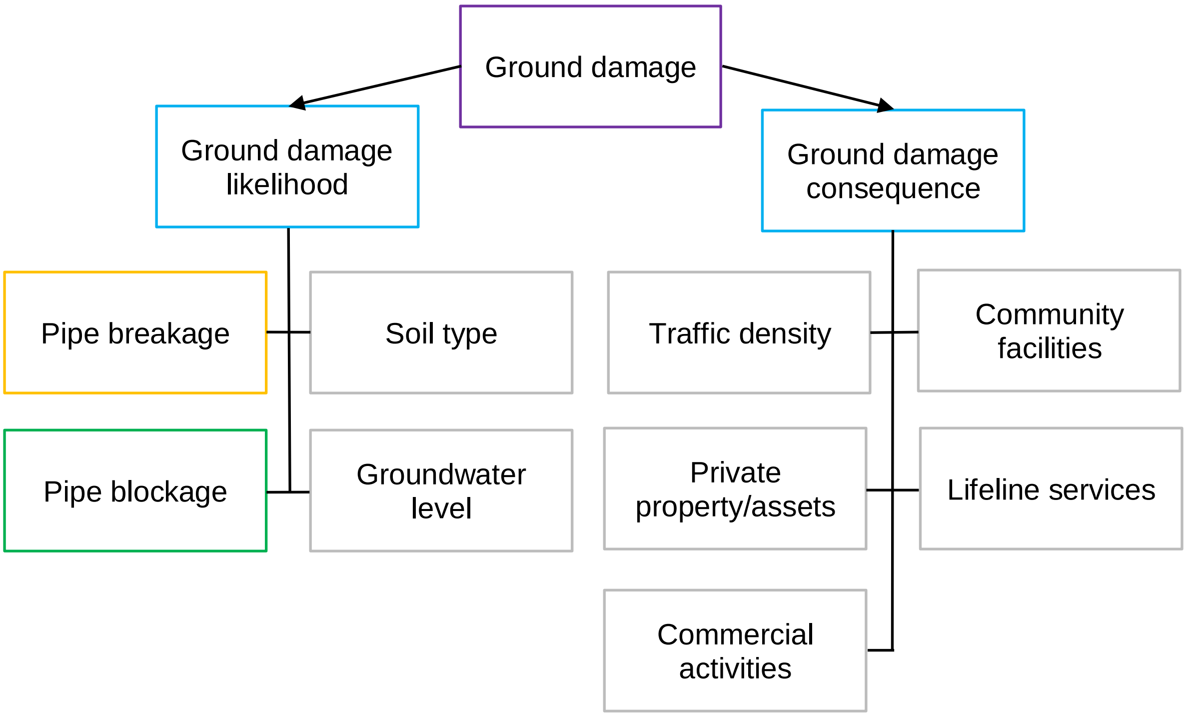


Figure 12 Ground damage in the decision tree

Infiltration

This failure mode is where some problem relating to the buried wastewater pipes is causing excess water to enter the pipes with a negative effect. This can cause several problems such as using up or exceeding the pipe network capacity, increasing daily flow volumes which impact pumping costs, wastewater treatment costs and disposal costs, and there is also the effect of dewatering the surrounding ground which lowers the groundwater level and can cause settlement of peat layers in the soil. Infiltration can be a diffuse effect where resulting negative affects to the network performance are caused by numerous infiltration defects spread across the entire network. The likelihood of infiltration failure is broken down in the decision tree to show the typical influencing factors. As before the risk-based approach used here also considers the negative consequences of infiltration. For example, areas of the network with high infiltration but where there is ample network capacity and low costs of conveyance (gravity pipe systems) and low costs of treatment (pond based treatment systems) will be of lower priority for the wastewater pipe network asset manager.

The development of the decision tree showing the infiltration factor is presented in Figure 13 below:

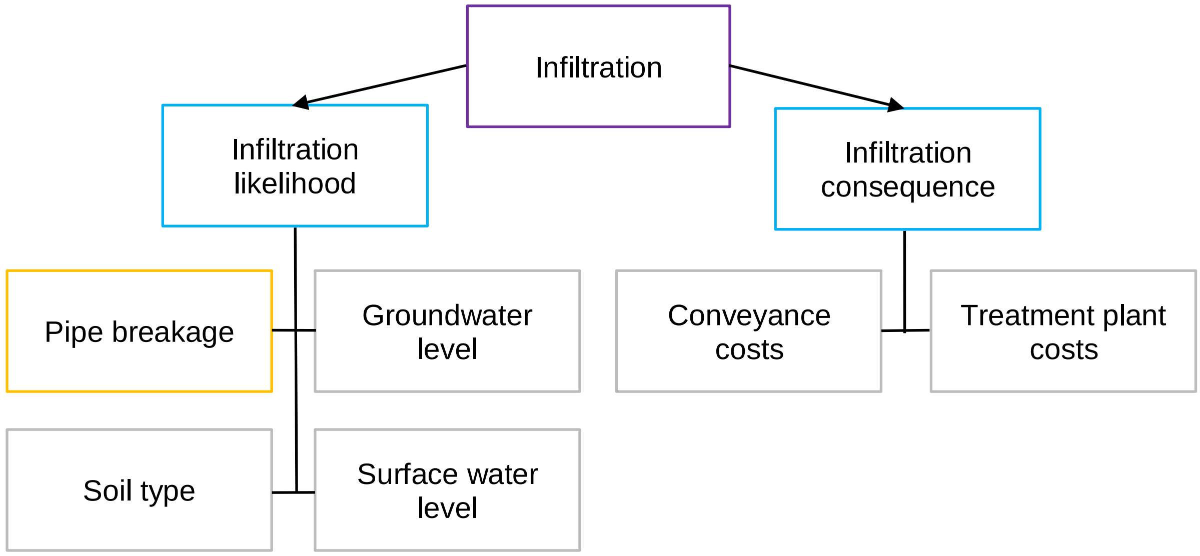


Figure 13 Infiltration in the decision tree

Overflow

This failure mode is where some problem relating to the wastewater pipe network is causing wastewater flows to overflow at ground level or into a waterway or enter into the stormwater system. Overflow in the wastewater network poses a significant public health risk and impacts negatively on water course ecology and other waterway values. Overflows also impact negatively on Maori water values *nga momo wai* (Water New Zealand, 2018) and how the different types of water should be treated. The likelihood of overflow failure is broken down in the decision tree to show the typical influencing factors. The risk-based approach is again used here to consider the negative consequences of overflow. For example, the impact of the overflow will be influenced by the activities occurring in the location or immediately downstream. Overflow occurring at a public recreational area or in a commercial business zone will be a higher priority than overflow in a low density neighbourhood area located away from any water bodies or stormwater network entry points.

The development of the decision tree showing the factor of wastewater network overflow is presented in Figure 14 below:

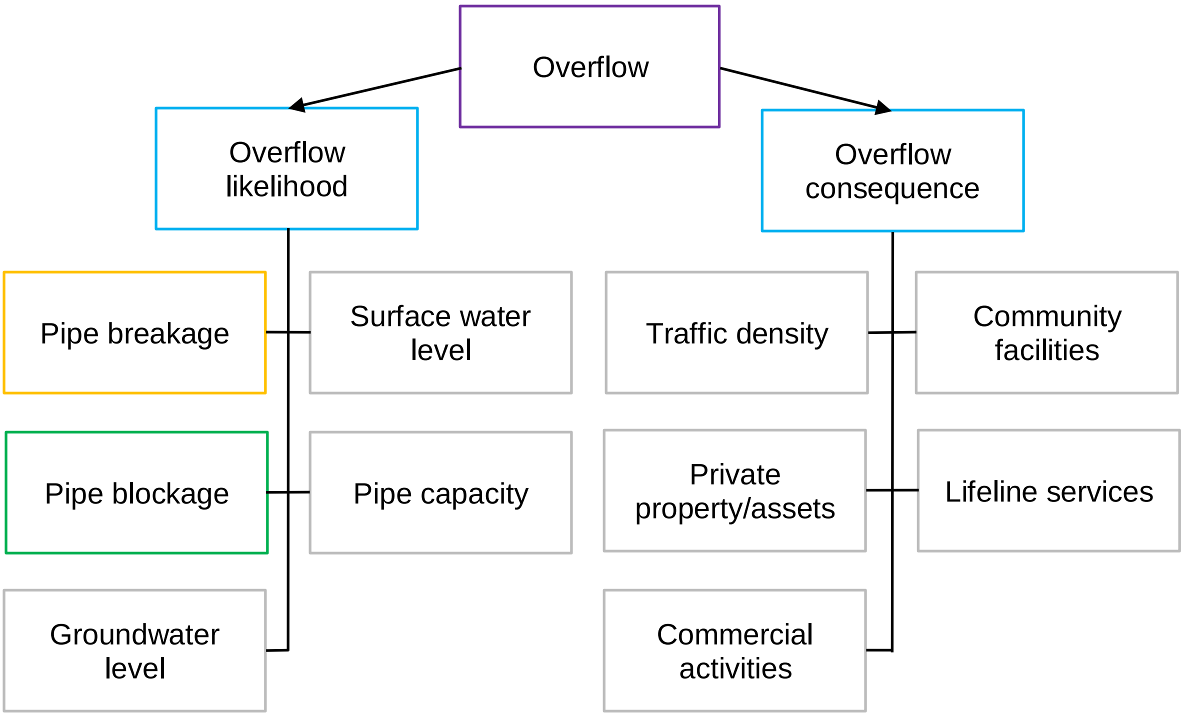


Figure 14 Overflow in the decision tree

Losing service

This failure mode is where some problem relating to the wastewater pipe network is causing network customers to be unable to use the wastewater service. Losing wastewater service means being typically unable to use toilet facilities, water in a kitchen, laundry and bathroom, and will affect businesses discharging trade waste. Customer service outage may vary in duration from a few hours to multiple days in length. Impacts will range from low level nuisance to forced closure of public facilities and institutions, or significant business interruption monetary impact. Loss of service may be related to other network performance failure categories, however there may be independent network events that result in a loss of service such as inspection, maintenance, repair or renewal activities.

The likelihood of losing customer service is broken down in the decision tree to show the typical influencing factors. As before the risk-based approach used here also considers the negative consequences of losing customer service. A low consequence loss of service may be of short duration where water use activities can be planned around the service outage. Another example may be an extended loss of service where flushing toilet use is replaced by chemical toilets or Port-A Loos, and having to dispose of laundry, shower or bath water into a back garden with minimal health risk. Further significant examples include the closure of a school due to no wastewater service, impacts to a hospital or health facility, or business interruption at a high water use industry resulting in monetary loss of revenue. A wastewater pipe network asset manager needs to be aware of the knock on effects that customers will experience if they lose wastewater service and have an appreciation of the differing needs of critical customers.

The development of the decision tree showing the loss of service factor is presented in Figure 15 below:

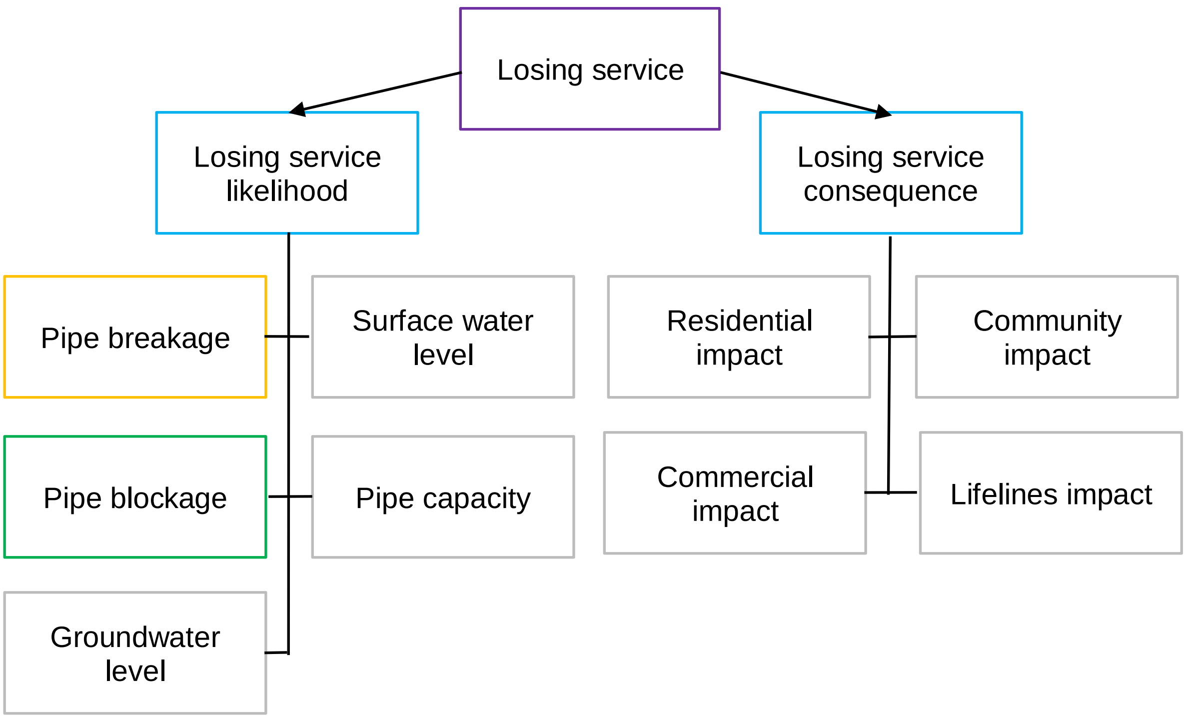


Figure 15 Losing service in the decision tree

Exfiltration

This failure mode is where some problem relating to the buried wastewater pipes is causing wastewater to leak out of the pipes and affect the surrounding ground in a negative way. There are two primary causes of concern for exfiltration; the loss of soil stability due to the presence of leaked wastewater, and the contamination issue of wastewater exiting the piped network into the soil. Exfiltration can cause fissures or slip planes on sloping ground and can also cause a lack of bearing strength in other soil types. Contamination caused by water that has exfiltrated from the piped network introduces public health risk and has adverse environmental impact to soil, groundwater and any nearby affected waterways. Exfiltration can be a diffuse effect where resulting negative affects to the network performance are caused by numerous exfiltration defects spread across the entire network. The likelihood of exfiltration failure is broken down in the decision tree to show the typical influencing factors. The negative consequences of exfiltration are presented under the risk-based approach. For example, ground stability or subsidence risk is greatest where exfiltration occurs in areas of high land value such as underneath buildings or infrastructure. Significant consequences of contamination in soil occur where soil is likely to be excavated and handled. Groundwater contamination can affect nearby watercourses or where groundwater is hydraulically connected to water sources from wells, the contamination can affect the use water for drinking and potable use.

The development of the decision tree showing the exfiltration factor is presented in Figure 16 below:

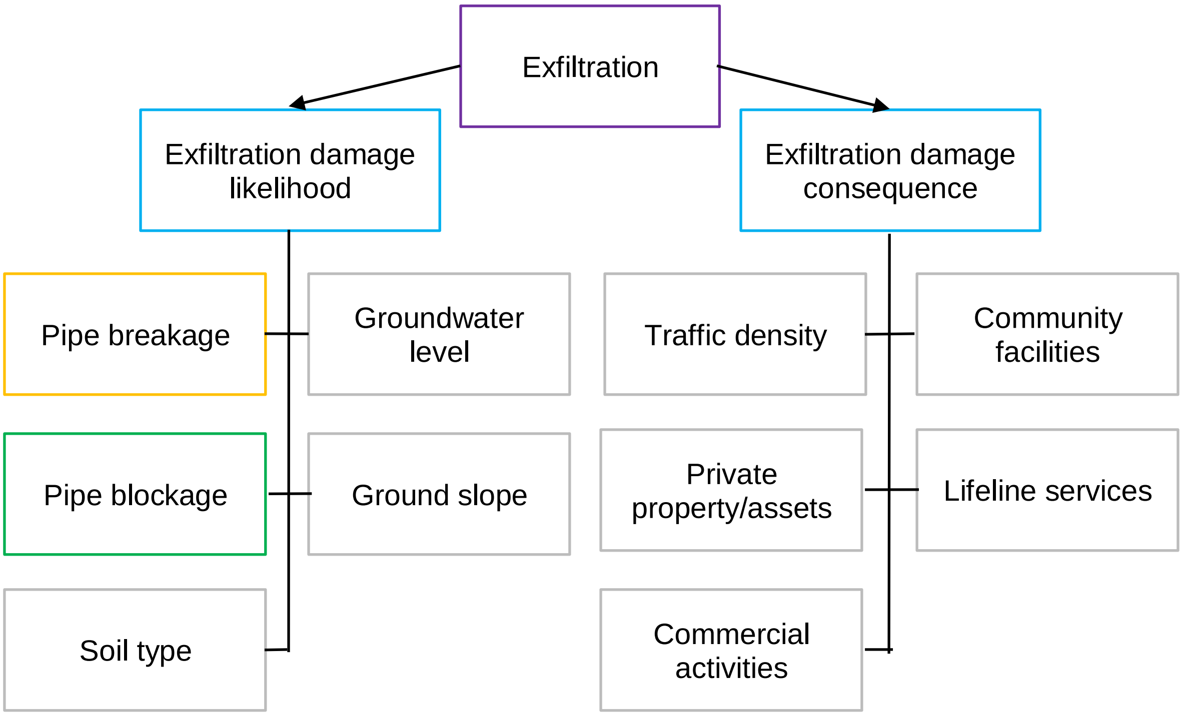


Figure 16 Exfiltration in the decision tree

Pipe breakage

The risk of pipe breakage is identified as a factor that is likely to contribute to a number of the different failure modes. There is not only a single criterion that leads to pipe break risk, so this factor has been further reduced to consider several of the most obvious factors that industry consider influence pipe break risk. These are:

- CCTV footage
- Pipe age
- Pipe diameter
- Pipe material
- Break history
- Soil type
- Pipe core analysis
- Surface loading
- Proximity to trees

These factors appear in the decision tree as shown in Figure 17 below:

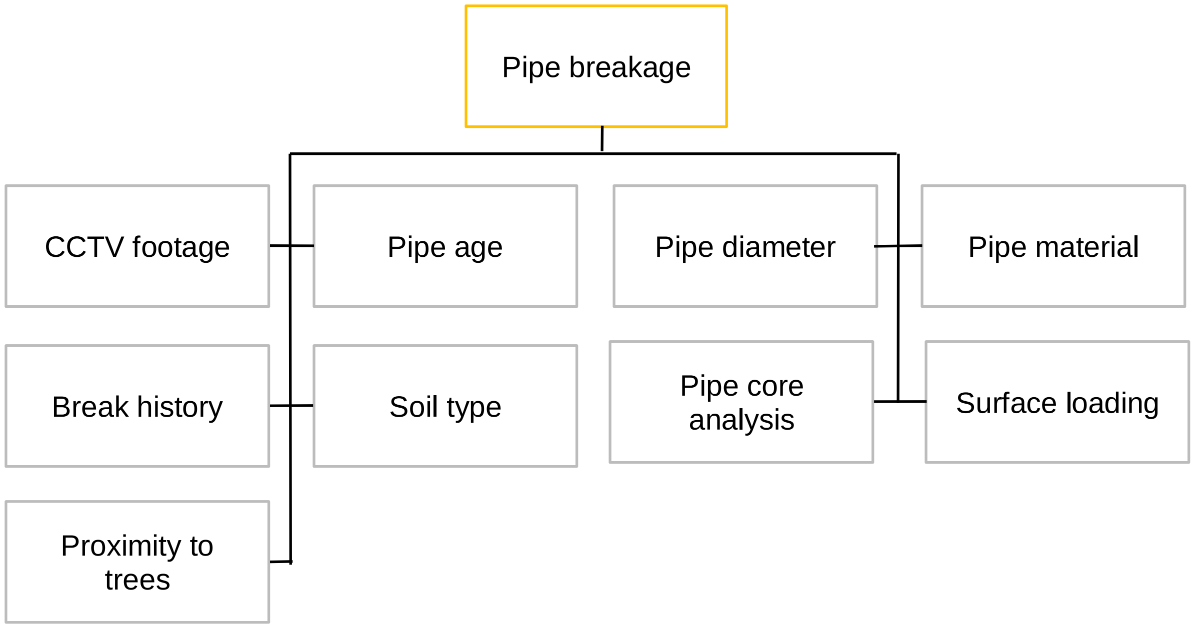


Figure 17 Pipe breakage in the decision tree

In this instance it is the likelihood of pipe breakage that is being quantified therefore the various subfactors are considered from the standpoint of how significant they are in influencing the likelihood that a pipe will break.

Pipe blockage

The risk of pipe blockage is also identified as a factor that is likely to contribute to a number of the different failure modes. The pipe blockage factor is reduced further to several of the most obvious factors that industry consider influence pipe blockage risk. These are:

- CCTV footage
- Pipe age
- Pipe diameter
- Pipe material
- Break history
- Blockage history
- Soil type

- Pipe grade
- Pipe dips
- Proximity to trees

These factors appear in the decision tree as shown in Figure 18 below:

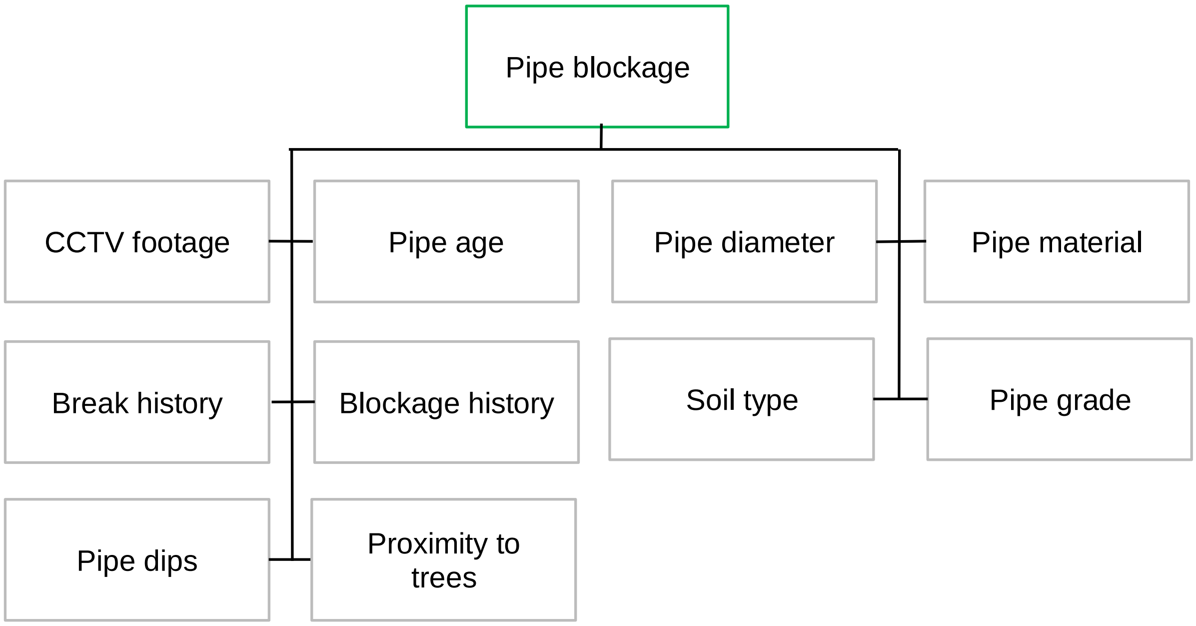


Figure 18 Pipe blockage in the decision tree

Again, it is the likelihood of pipe blockage that is being quantified therefore the various subfactors are considered from the standpoint of how significant they are in influencing the likelihood that a pipe will be blocked.

Decision tree connectivity

The decision tree has been laid out in a way that the significance of the various factors and subfactors can be determined from the expert intuitive inputs. For the case of this Master's research the input comes from the survey of industry professionals. This input forms the basis for the significance weighting.

For each factor a significance weighting is derived to provide a quantitative measure of how significant that particular is in terms of the overall decision tree. These significance weightings are applied according to basic decision tree analysis where the weightings at each step of the decision tree are normalised and add up to 1.0 as shown in Figure 19 below:

Decision tree level one:

Decision tree level two:

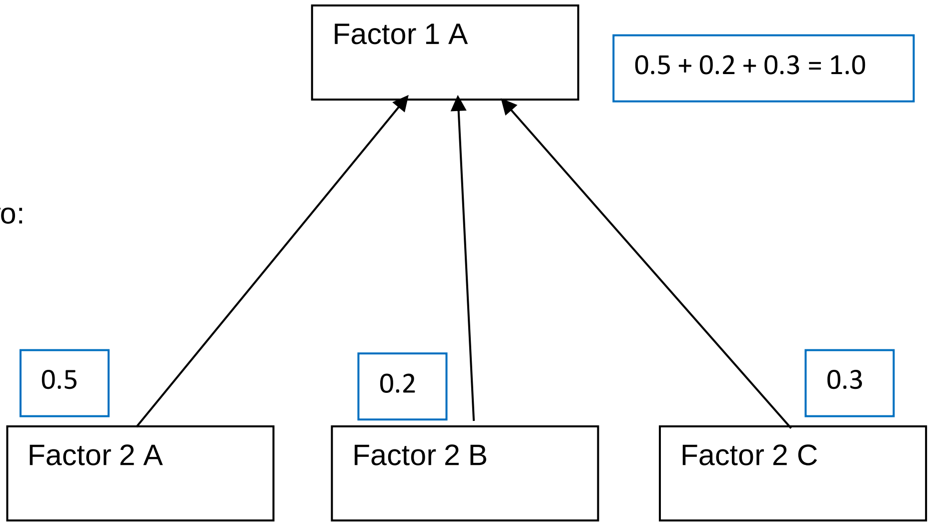


Figure 19 Example decision tree analysis

The significance weightings of each level two factor are shown with a blue border and adds to 1.0.

Once the significance weightings for the decision tree are determined from the expert intuitive input, they can be applied to generate quantitative decision analyses. Typically, this is done by multiplying the significance weightings with a numerical value for each factor, referred to as the factor score. These numerical values are free to be defined in any way by the decision maker but would typically be expressed as costs in dollars, or 1 – 5 scores. This research adopts a 1 – 5 score for the factor scores because this aligns with the quasi-quantitative assessments often performed within the wastewater network asset management industry (Land Information New Zealand, 2017). These 1 – 5 scores would be applied by the asset manager based on the available network data or otherwise their knowledge of the network and operating conditions. In this approach a factor score of 5 is bad and a factor score of 1 is good. “Bad” is also synonymous with high risk and “good” synonymous with low risk.

Example of typical user defined 1 – 5 factors scores are presented in Table 4 below for the factors positioned beneath the *Pipe breakage* factor in the decision tree. The classification of 1 - 5 scores is subjective and can be set in such a way that supports the decision analysis that the asset manager is trying to perform.

Table 4 Example factor scores

Factor	**Factor score = 1** **Good (i.e. low risk)**	**Factor score = 5** **Bad (i.e. high risk)**
CCTV footage	No defects, good pipe condition	Multiple significant pipe defects showing poor pipe condition
Pipe age	New pipe with >75% of expected remaining useful life left	Old pipe with <5% of expected remaining useful life left
Pipe diameter	Small pipe diameter (<150 mm) with a low impact to overall network performance in a failure event	Large pipe diameter (>450 mm) with a high impact to overall network performance in a failure event
Pipe material	Modern plastic material with flexibility	Brittle pipe material with vulnerability to deterioration
Break history	No break history	>3 breaks within the last 5 year period
Blockage history	No blockage history	>5 blockages within the last 5 year period

Soil type	Firm well drained soil	Soft ground conditions, liquefiable soil, corrosive soil
Pipe grade	Steeper than minimum gradients for tractive force gravity pipeline design	Flatter than minimum gradients for tractive force gravity pipeline design
Pipe dips	No pipe dips	Has pipe dips greater than 100% of pipe diameter
Proximity to trees	>25 m from trees	<5 m from trees

The multiplication of the significance weightings and the factor scores is applied in the manner shown in Figure 20 below:

Decision tree level one:

Decision tree level two:

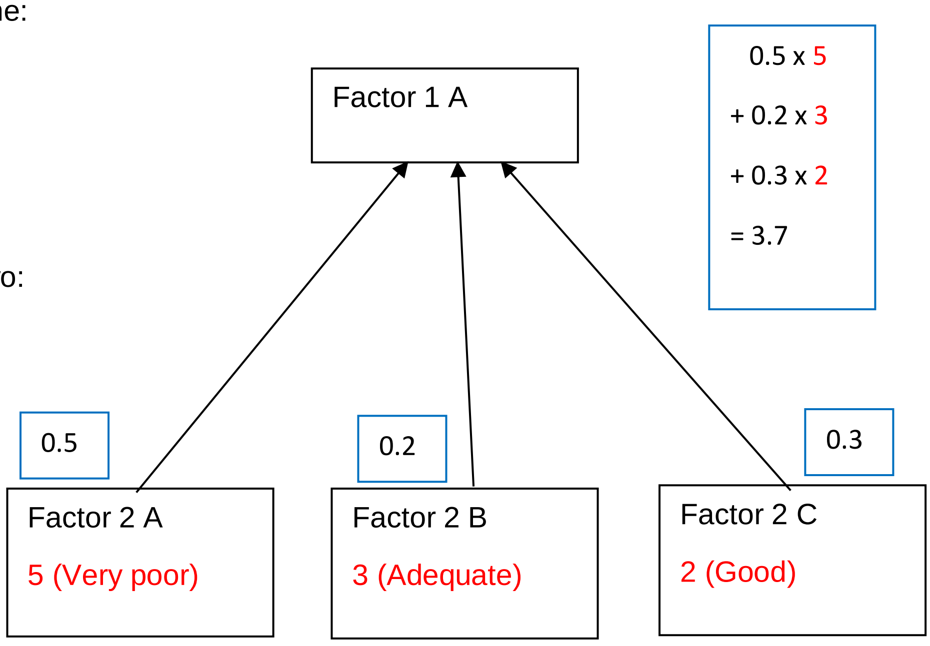


Figure 20 Example significance weighting analysis

So, the derived score for Factor 1A based on the significance weighting (from industry expert intuition) and factor score (from network data or knowledge) is 3.7. Applying this to the wastewater network assets, it might represent a scenario where a pipe asset has a pipe breakage score (Factor 1 A) of 3.7 based on having a very poor CCTV footage score (Factor 2 A), adequate pipe age score (Factor 2 B), and have a good pipe diameter score (Factor 2 C).

4.3 The industry survey

The industry survey is structured so that the questions being asked, and the gathered results, model the format of the decision tree. For each level of the decision tree within the examined category of network performance, the necessary expert intuition inputs are collected by asking survey participants to rank the significance of factor represented at that level.

For example, the top level within network performance requires expert intuition input for the subfactors of:

Network performance:

- Ground damage
- Infiltration
- Overflow
- Losing service
- Exfiltration

The survey frames the questions from the perspective of a wastewater network asset manager who is tasked with the situation of having to determine which pipes in their network to repair or replace. This creates the mental model to assist the survey participants to provide their expert input in a consistent manner. To develop consistency further and to reinforce this mental model a cover page of instructions was presented to participants and is included in Appendix D.

The cover page instructs participants to imagine they are responsible for choosing which pipes get renewed or repaired in a wastewater network and gives definitions of terms used in the survey, including examples of how to apply the significance scoring.

By framing the industry survey in this way, the significance weightings of the factors can be derived quantitatively using the Likert Scale where:

Table 5 Likert-type scale used in survey

Likert Scale	
Extremely significant	5
Very significant	4
Moderately significant	3
Slightly significant	2
Not at all significant	1

The Likert scale in Table 5 was adopted over the fundamental scale (Table 2) of the Analytical Hierarchy Process (AHP) to ensure the survey was short and easy to complete. AHP would have required many pairwise comparisons made by each survey participant compared to the more streamlined Likert scale approach. Results using the Likert scale can be analysed using the mean score, standard deviation and Top 2 Box score as explained in Chapter 2.

The full questions presented in the survey are provided with the survey in Appendix E. For each question the participants were required to rank (using the Likert Scale) each of the factors for that particular question within the decision tree model. The questions cover the following:

Table 6 Survey question topics

Q1	Likelihood of pipe breakage
Q2	Likelihood of pipe blockage
Q3	Likelihood of ground damage
Q4	Consequence of ground damage
Q5	Likelihood of infiltration
Q6	Consequence of infiltration
Q7	Likelihood of overflows
Q8	Consequence of overflows
Q9	Likelihood of losing customer service
Q10	Consequence of losing customer service
Q11	Likelihood of ground damage caused by exfiltration
Q12	Consequence of ground damage caused by exfiltration
Q13	Overall performance of pipes in the network

Allowing for one minute to read the cover page instructions and 30 seconds per question the estimated completion time for the survey was 8 minutes which aligns with the survey goal of being user-friendly.

Survey compliance

As a survey forming part of an academic programme at the University of Canterbury, approval was sought from the Human Ethics Committee prior to the release of the survey. The application to and approval from the University of Canterbury Human Ethics Committee is included as Appendix F. The survey was assessed to be low risk in nature and supporting evidence was provided in the application pertaining to:

- The nature of the research project
- Participants sought
- Selection and exclusion criteria
- Recruiting methods for participants
- Other interested parties
- Data collection
- Participant consent
- Confidentiality
- Risk
- Data storage and future use

Survey distribution

The survey was distributed online using the Qualtrics online survey software. A request to participate in the survey was sent via email or e-newsletters to memberships of the professional organisations: Water New Zealand and the Institute of Public Works Engineers of Australasia. Direct requests for participation were also sent out to wastewater engineers and asset managers within the Christchurch City Council, Waimakariri District Council, Stantec and WSP Opus engineer consultancies. It was requested within the survey invite that participants be people *with experience in wastewater network renewal decisions or investigations*. Beyond being in an organisation that received the survey invite, the survey participants were self-selecting. The survey was conducted in February 2017.

Chapter 5 – Results

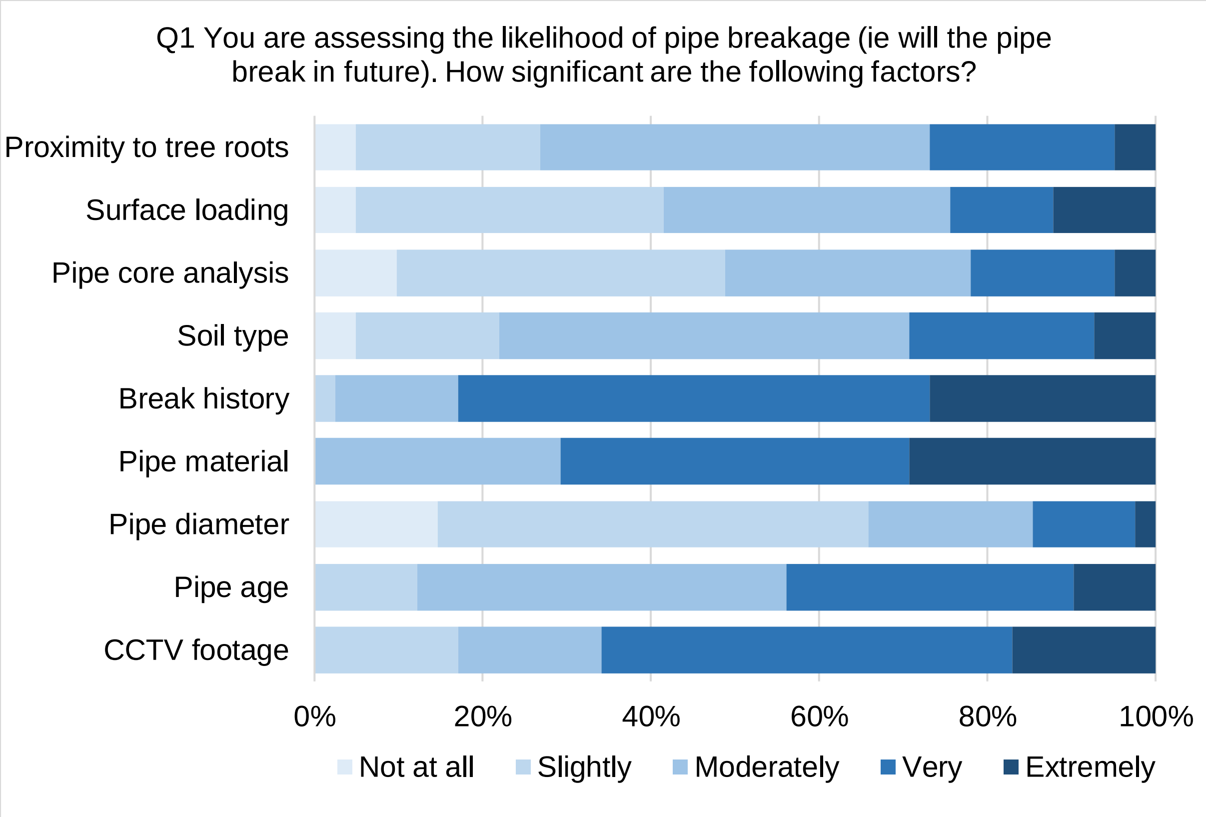
5.0 Introduction

This chapter presents the results of the industry survey. The survey was taken by 43 participants between 7 February 2017 and 27 February 2017. Of these 43 participants, 36 completed the survey in its entirety. 7 participants partially completed the survey and left the survey browser page before completing the questions to the end. The results and analysis include the answers to the partially complete surveys.

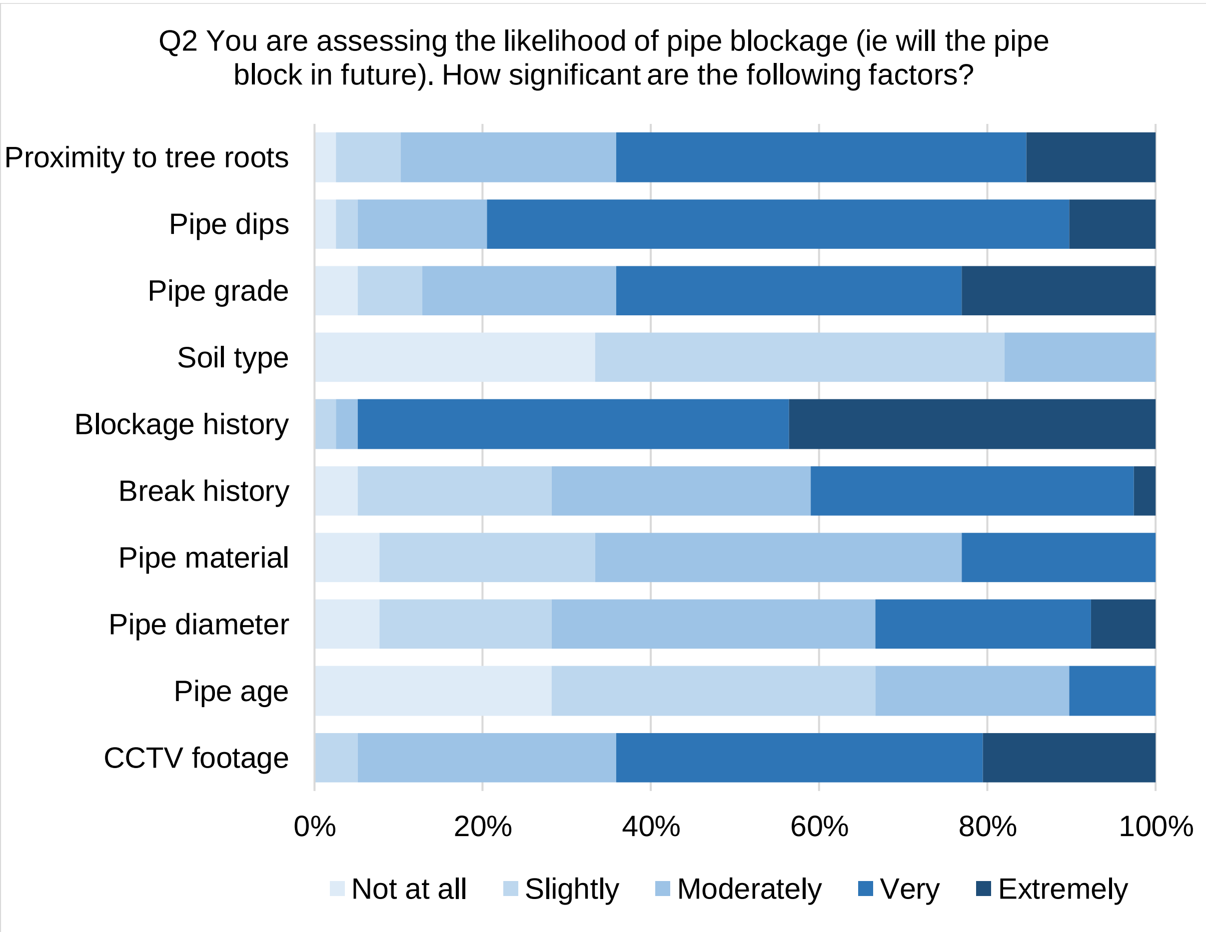
The collated results provide the significance weightings as answered by the individual survey participants for each of the listed factors associated with the survey questions. These significance weightings are recorded as a data set associated with each participant's anonymous unique identifier. To analyse the results, each of the significance weightings has been converted to a numeral according to the Likert Scale previous referenced in Table 5.

5.1 Presentation of results

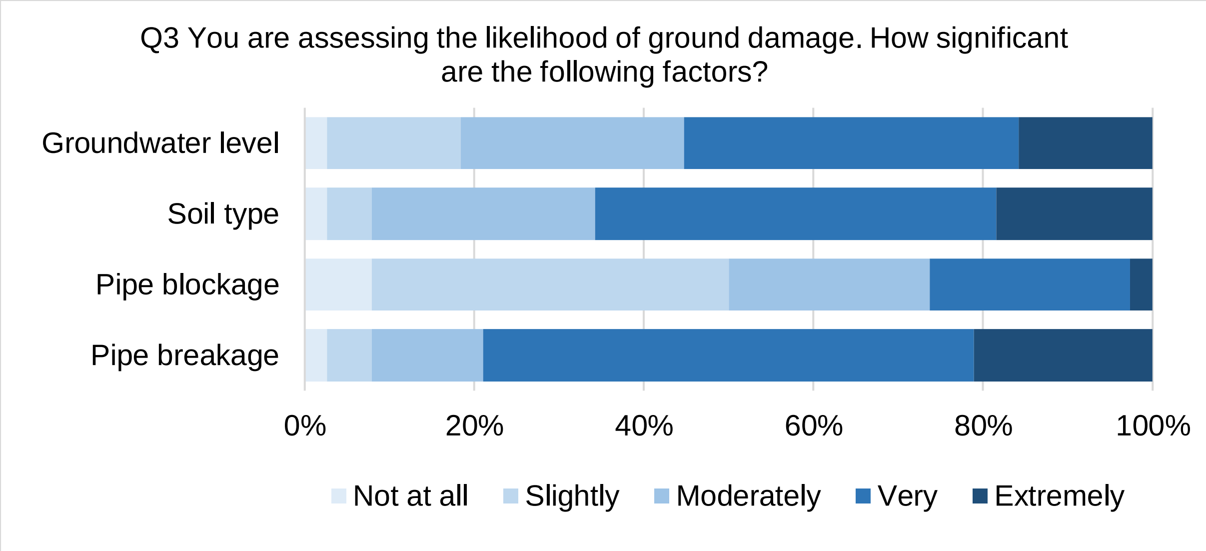
The results of the survey are provided in Appendix G and presented in the following set of figures.

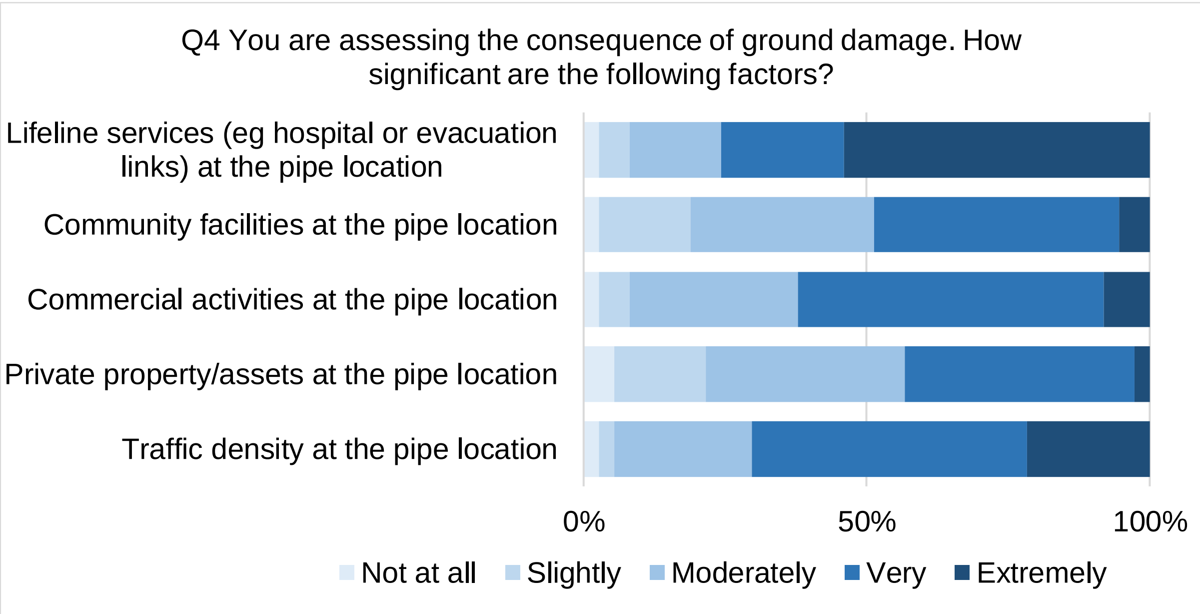


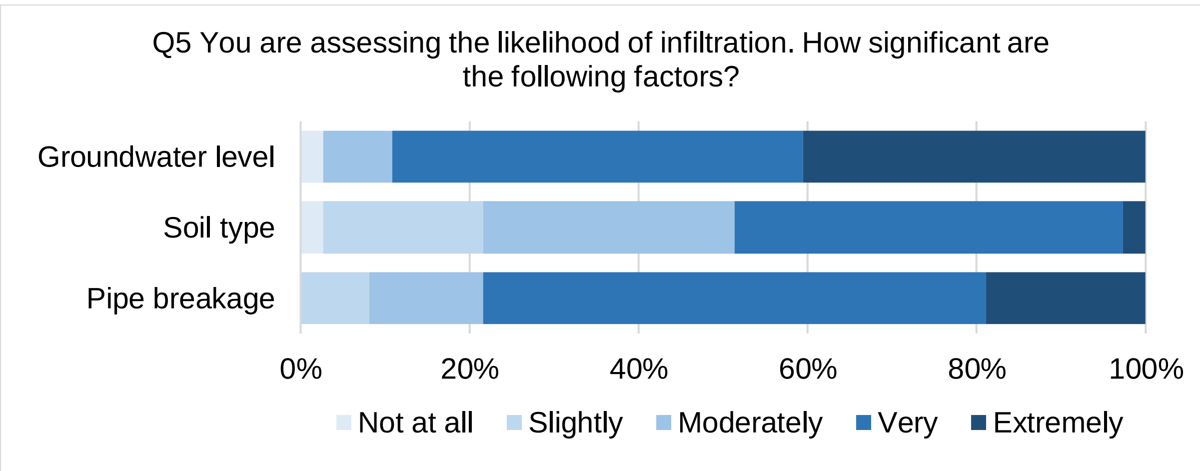
Q1 You are assessing the likelihood of pipe breakage (ie will the pipe break in future). How significant are the following factors?
Proximity to tree roots
Surface loading
Pipe core analysis
Soil type
Break history
Pipe material
Pipe diameter
Pipe age
CCTV footage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely

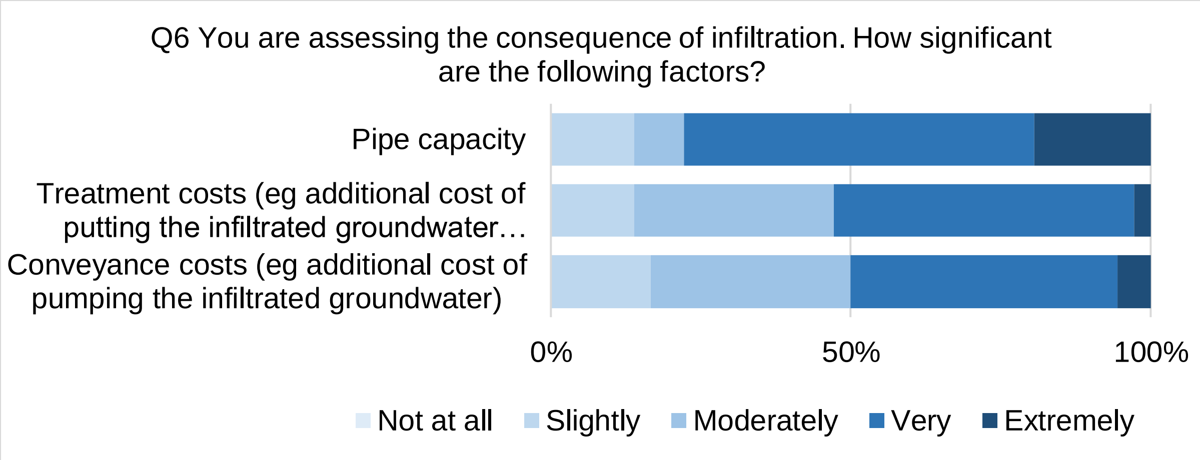


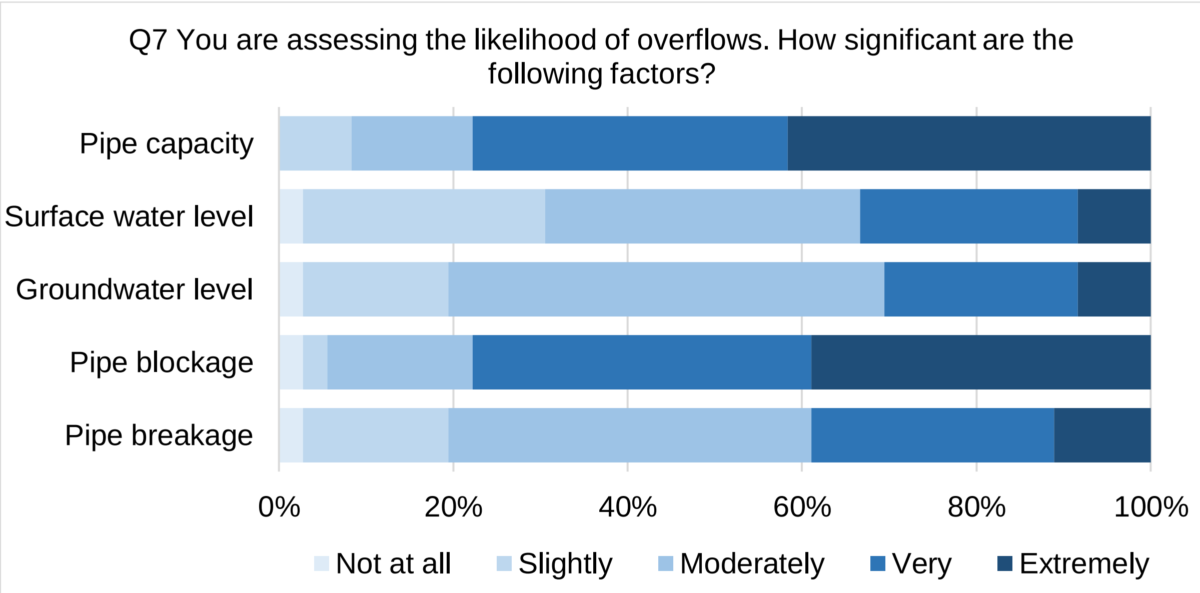
Q2 You are assessing the likelihood of pipe blockage (ie will the pipe block in future). How significant are the following factors?
Proximity to tree roots
Pipe dips
Pipe grade
Soil type
Blockage history
Break history
Pipe material
Pipe diameter
Pipe age
CCTV footage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely

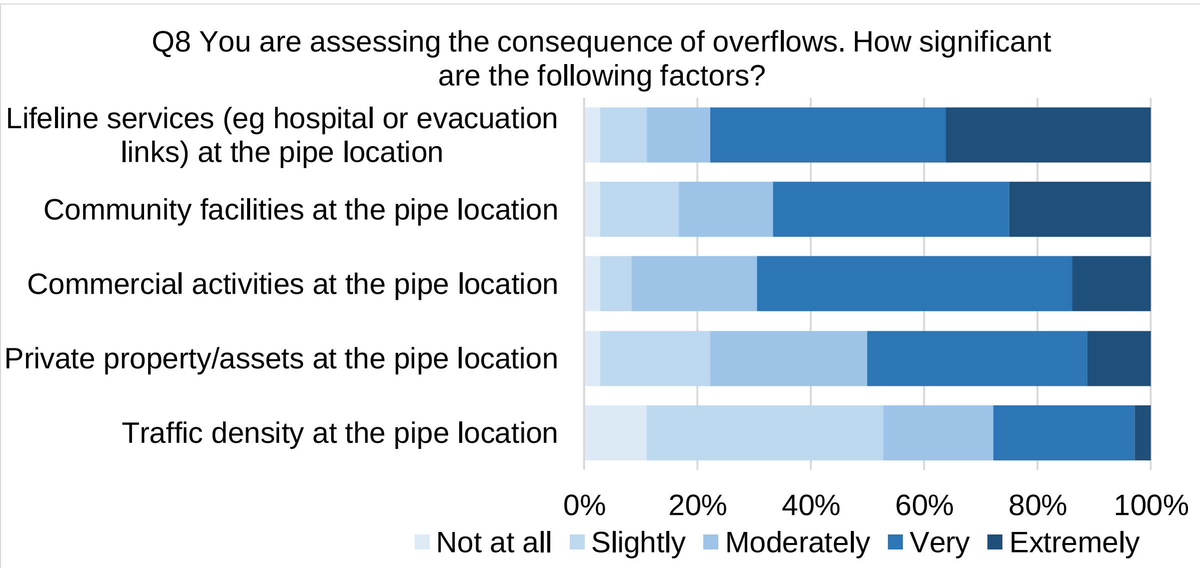

Q3 You are assessing the likelihood of ground damage. How significant are the following factors?
Groundwater level
Soil type
Pipe blockage
Pipe breakage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely

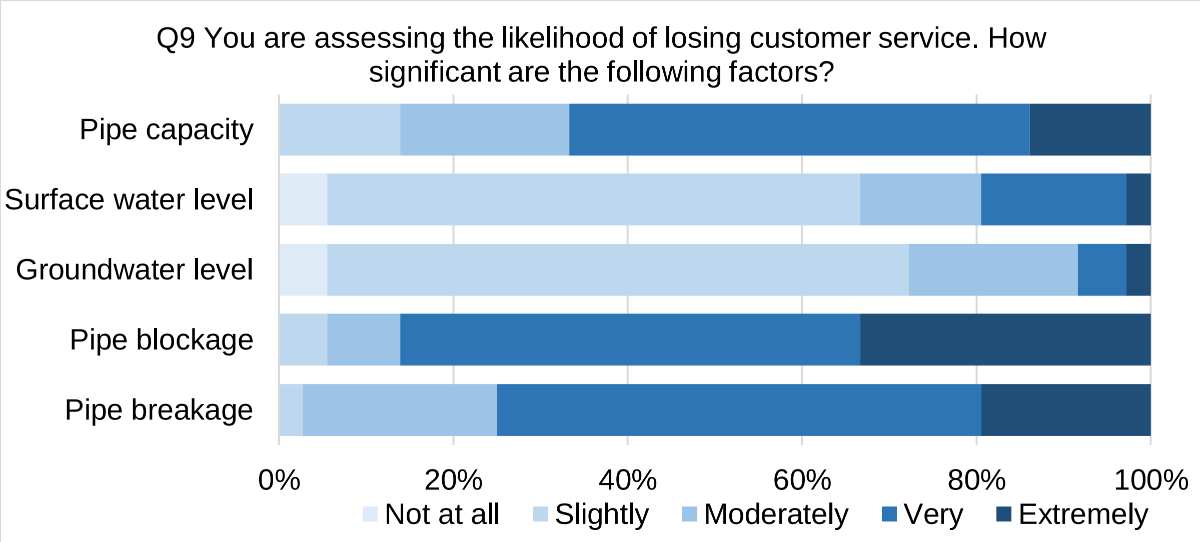

Q4 You are assessing the consequence of ground damage. How significant are the following factors?
Lifeline services (eg hospital or evacuation links) at the pipe location
Community facilities at the pipe location
Commercial activities at the pipe location
Private property/assets at the pipe location
Traffic density at the pipe location
0%
50%
100%
Not at all
Slightly
Moderately
Very
Extremely

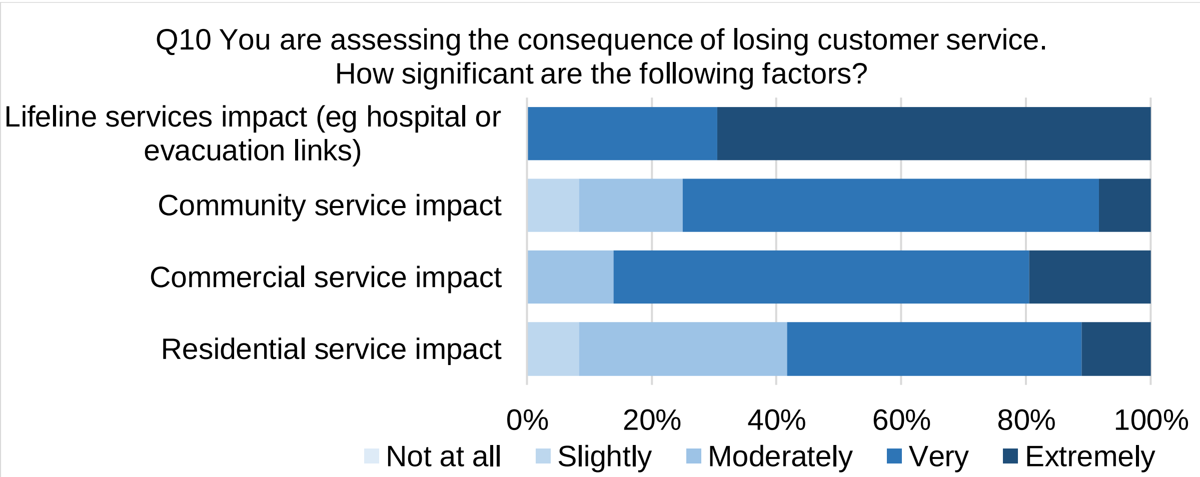

Q5 You are assessing the likelihood of infiltration. How significant are the following factors?
Groundwater level
Soil type
Pipe breakage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely

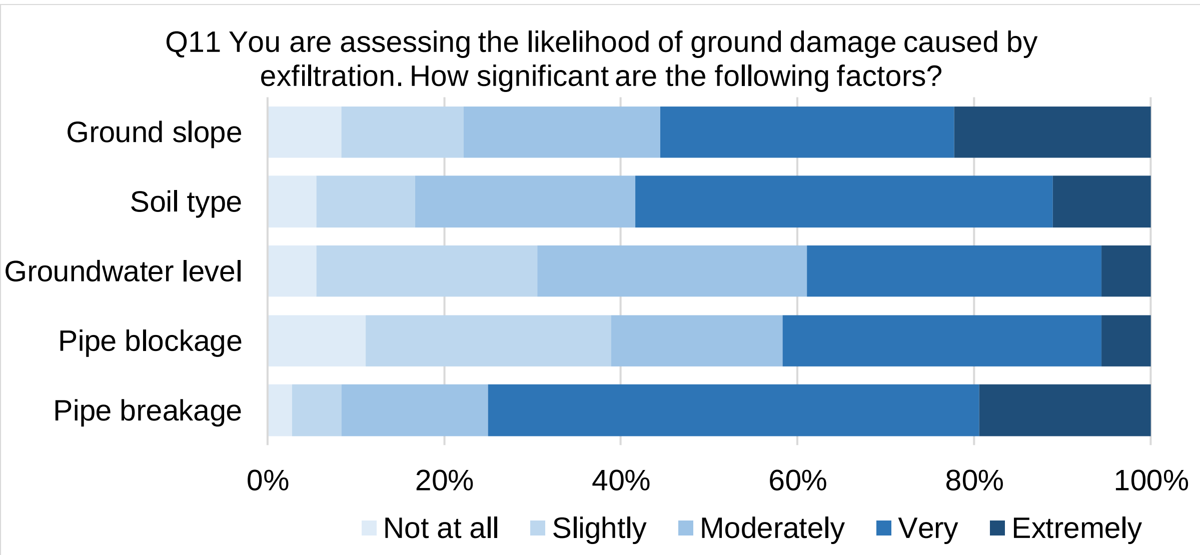

Q6 You are assessing the consequence of infiltration. How significant are the following factors?
Pipe capacity
Treatment costs (eg additional cost of putting the infiltrated groundwater…
Conveyance costs (eg additional cost of pumping the infiltrated groundwater)
0%
50%
100%
Not at all
Slightly
Moderately
Very
Extremely

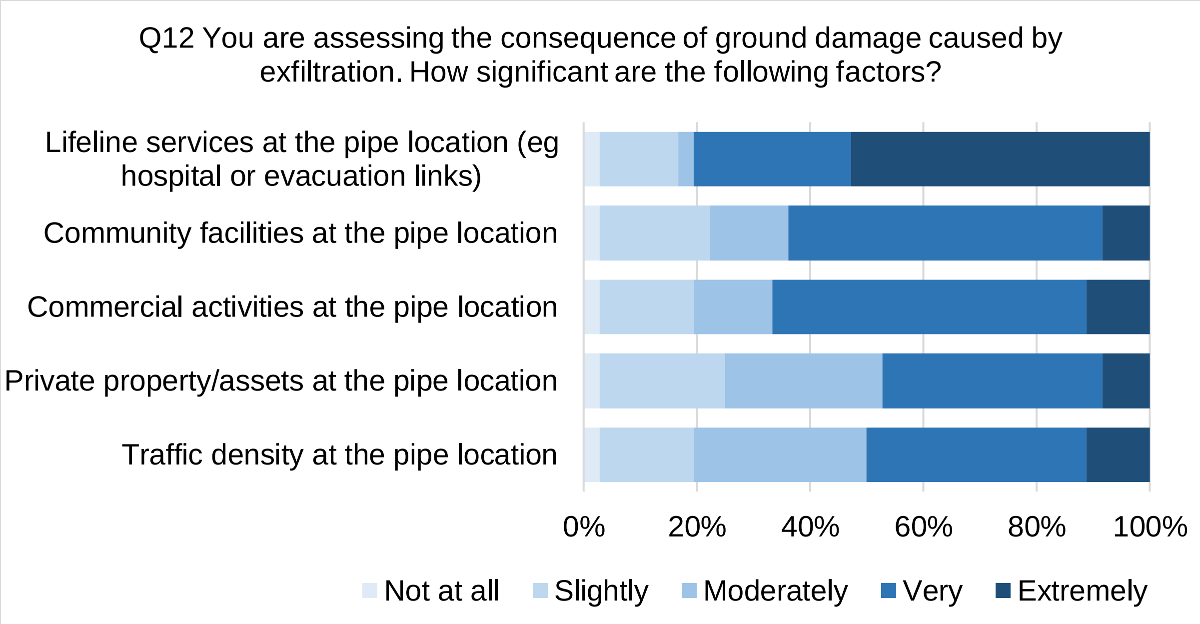

Q7 You are assessing the likelihood of overflows. How significant are the following factors?
Pipe capacity
Surface water level
Groundwater level
Pipe blockage
Pipe breakage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely


Q8 You are assessing the consequence of overflows. How significant are the following factors?
Lifeline services (eg hospital or evacuation links) at the pipe location
Community facilities at the pipe location
Commercial activities at the pipe location
Private property/assets at the pipe location
Traffic density at the pipe location
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely


Q9 You are assessing the likelihood of losing customer service. How significant are the following factors?
Pipe capacity
Surface water level
Groundwater level
Pipe blockage
Pipe breakage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely


Q10 You are assessing the consequence of losing customer service. How significant are the following factors?
Lifeline services impact (eg hospital or evacuation links)
Community service impact
Commercial service impact
Residential service impact
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely


Q11 You are assessing the likelihood of ground damage caused by exfiltration. How significant are the following factors?
Ground slope
Soil type
Groundwater level
Pipe blockage
Pipe breakage
0%
20%
40%
60%
80%
100%
Not at all
Slightly
Moderately
Very
Extremely



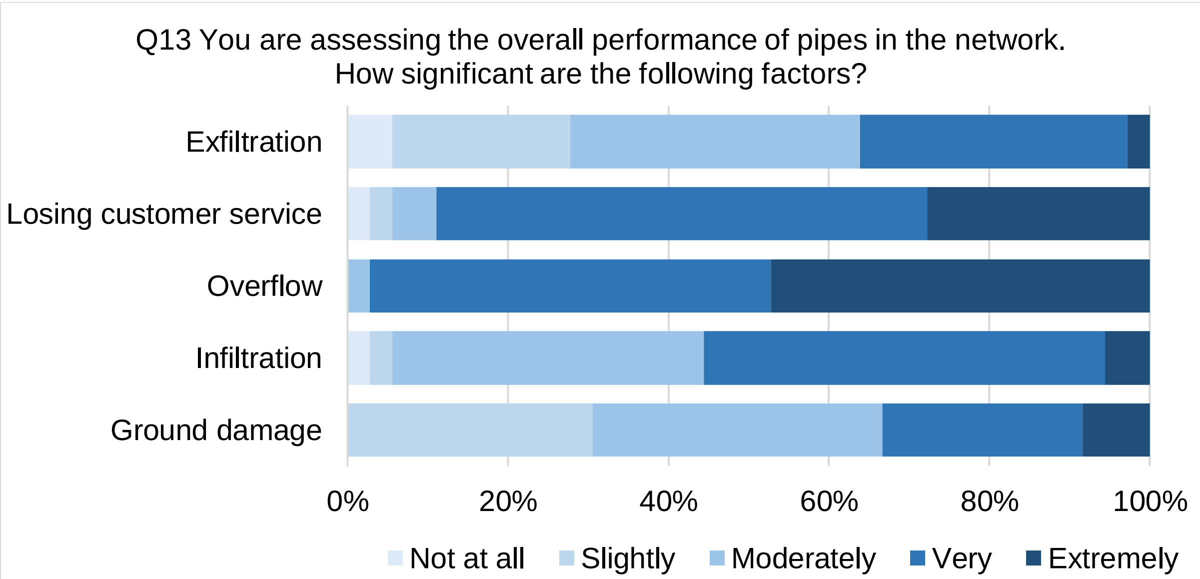


Figure 21 Industry survey question results

Measures of average

Most of the weighting mean values provided by survey participants were in the Significant (3) to Very Significant (4) range. The median value across all answers was 4, and the average of each question's median value was 3.54.

The mean scores for each answer are presented in Table 7 to Table 10 below.

Table 7 Mean significance scores for questions 1 and 2

Question ID	Factor	Mean significance score
1	CCTV footage	3.66
1	Pipe age	3.41
1	Pipe diameter	2.37
1	Pipe material	4.00
1	Break history	4.07
1	Soil type	3.10
1	Pipe core analysis	2.68
1	Surface loading	2.90
1	Proximity to tree roots	3.00
2	CCTV footage	3.79
2	Pipe age	2.15
2	Pipe diameter	3.05
2	Pipe material	2.82
2	Break history	3.10
2	Blockage history	4.33
2	Soil type	1.85
2	Pipe grade	3.69
2	Pipe dips	3.82
2	Proximity to tree roots	3.67

Table 8 Mean significance scores for questions 3, 4, 5 and 6

Question ID	Factor	Mean significance score
3	Pipe breakage	3.89
3	Pipe blockage	2.71
3	Soil type	3.74
3	Groundwater level	3.50
4	Traffic density at the pipe location	3.84
4	Private property/assets at the pipe location	3.19
4	Commercial activities at the pipe location	3.59
4	Community facilities at the pipe location	3.32
4	Lifeline services (e.g. hospital or evacuation links) at the pipe location	4.19
5	Pipe breakage	3.89
5	Soil type	3.27
5	Groundwater level	4.24
6	Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	3.39
6	Treatment costs (e.g. additional cost of putting the infiltrated groundwater through the wastewater treatment plant)	3.42
6	Pipe capacity	3.83

Table 9 Mean significance scores for questions 7, 8, 9 and 10

Question ID	Factor	Mean significance score
7	Pipe breakage	3.28
7	Pipe blockage	4.08
7	Groundwater level	3.17
7	Surface water level	3.08
7	Pipe capacity	4.11
8	Traffic density at the pipe location	2.67
8	Private property/assets at the pipe location	3.36
8	Commercial activities at the pipe location	3.72
8	Community facilities at the pipe location	3.72
8	Lifeline services (e.g. hospital or evac)	4.00
9	Pipe breakage	3.92
9	Pipe blockage	4.14
9	Groundwater level	2.33
9	Surface water level	2.50
9	Pipe capacity	3.67
10	Residential service impact	3.61
10	Commercial service impact	4.06
10	Community service impact	3.75
10	Lifeline services impact (e.g. hospital or evac)	4.69

Table 10 Mean significance scores for questions 11, 12 and 13

Question ID	Factor	Mean significance score
11	Pipe breakage	3.83
11	Pipe blockage	2.97
11	Groundwater level	3.08
11	Soil type	3.47
11	Ground slope	3.47
12	Traffic density at the pipe location	3.39
12	Private property/assets at the pipe location	3.28
12	Commercial activities at the pipe location	3.56
12	Community facilities at the pipe location	3.47
12	Lifeline services at the pipe location (e.g. hospital or evacuation links)	4.14
13	Ground damage	3.11
13	Infiltration	3.53
13	Overflow	4.44
13	Losing customer service	4.08
13	Exfiltration	3.06

The tables above show the mean significance weightings for the factors as reported at specific question points in the survey. This means that the scores are directly relatable to the other factors also associated with that question. However, they cannot be directly compared with the other mean significance weightings in other questions without considering the context in which the question was asked. For example, the factor *Pipe breakage* appears multiple times in the above table with different mean significance weightings associated with the separate survey questions, reproduced in Table 11 below. *Pipe breakage* was considered to have a higher significance score of 3.92 in response to Q9 and had a lower significance score in response to Q7.

Table 11 Example of factors appearing multiple times

Question ID	**Factor**	**Mean**
Q10: Consequence of losing customer service	Pipe breakage	3.92
Q3: Likelihood of ground damage	Pipe breakage	3.89
Q5: Likelihood of infiltration	Pipe breakage	3.89
Q11: Likelihood of ground damage caused by exfiltration	Pipe breakage	3.83
Q7: Likelihood of overflows	Pipe breakage	3.28

Measures of spread

The measures of spread of the industry survey results show the level of agreement from the survey participants in determining the significance of each factor. The standard deviation was calculated using the mean Likert scores for each question. Table 12 to

Table 15 below show the standard deviations for each survey question.

Table 12 Standard deviation for questions 1 and 2

Question ID	Factor	Standard Deviation
1	CCTV footage	0.96
1	Pipe age	0.84
1	Pipe diameter	0.97
1	Pipe material	0.77
1	Break history	0.72
1	Soil type	0.94
1	Pipe core analysis	1.04
1	Surface loading	1.09
1	Proximity to tree roots	0.92
2	CCTV footage	0.83
2	Pipe age	0.96
2	Pipe diameter	1.05
2	Pipe material	0.88
2	Break history	0.97
2	Blockage history	0.69
2	Soil type	0.71
2	Pipe grade	1.08
2	Pipe dips	0.76
2	Proximity to tree roots	0.93

Table 13 Standard deviation for questions 3, 4, 5 and 6

Question ID	Factor	Standard Deviation
3	Pipe breakage	0.89
3	Pipe blockage	1.01
3	Soil type	0.92
3	Groundwater level	1.03
4	Traffic density at the pipe location	0.90
4	Private property/assets at the pipe location	0.94
4	Commercial activities at the pipe location	0.83
4	Community facilities at the pipe location	0.91
4	Lifeline services (e.g. hospital or evacuation links) at the pipe location	1.08
5	Pipe breakage	0.81
5	Soil type	0.90
5	Groundwater level	0.83
6	Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	0.84
6	Treatment costs (e.g. additional cost of putting the infiltrated groundwater through the wastewater treatment plant)	0.77
6	Pipe capacity	0.91

Table 14 Standard deviation for questions 7, 8, 9 and 10

Question ID	Factor	Standard Deviation
7	Pipe breakage	0.97
7	Pipe blockage	0.97
7	Groundwater level	0.91
7	Surface water level	1.00
7	Pipe capacity	0.95
8	Traffic density at the pipe location	1.07
8	Private property/assets at the pipe location	1.02
8	Commercial activities at the pipe location	0.88
8	Community facilities at the pipe location	1.09
8	Lifeline services (e.g. hospital or evac)	1.04
9	Pipe breakage	0.73
9	Pipe blockage	0.80
9	Groundwater level	0.79
9	Surface water level	0.94
9	Pipe capacity	0.89
10	Residential service impact	0.80
10	Commercial service impact	0.58
10	Community service impact	0.73
10	Lifeline services impact (e.g. hospital or evac)	0.47

Table 15 Standard deviation for questions 11, 12 and 13

Question ID	Factor	Standard Deviation
11	Pipe breakage	0.91
11	Pipe blockage	1.16
11	Groundwater level	1.02
11	Soil type	1.03
11	Ground slope	1.23
12	Traffic density at the pipe location	0.99
12	Private property/assets at the pipe location	1.00
12	Commercial activities at the pipe location	1.00
12	Community facilities at the pipe location	1.00
12	Lifeline services at the pipe location (e.g. hospital or evacuation links)	1.17
13	Ground damage	0.95
13	Infiltration	0.77
13	Overflow	0.56
13	Losing customer service	0.84
13	Exfiltration	0.95

Chapter 6 – Analysis

6.0 Introduction

This chapter provides an analysis of the survey results with respect to the overall decision model.

The scores presented in Table 7 to Table 10 in the chapter above show the significance of the factors as judged by the participants for each survey question. The relative influence that each factor has on the factor above it in the decision tree hierarchy can be assessed with further modelling of the survey scores. This influence can be tracked through each level of the decision tree to determine how that influence is carried through to the highest level, i.e. *Network performance.*

This modelling was undertaken using a spreadsheet that replicated the decision tree hierarchy with input cells at each level to indicate the significance score is applied to each factor. The mean significance weightings from Table 7 to Table 10 were used as inputs.

6.1 Overall significance

The overall significance of each factor is derived by solving the decision tree using the significance scores from the survey. First, the mean scores were squared, the provide greater relative spread, and then normalised for each question. Solving along the branches of the decision tree followed the calculation method for solving a probability tree where progression along the branches of the tree are multiplied, and subfactors at each level add to 1.0. For example, Overall significance impact:

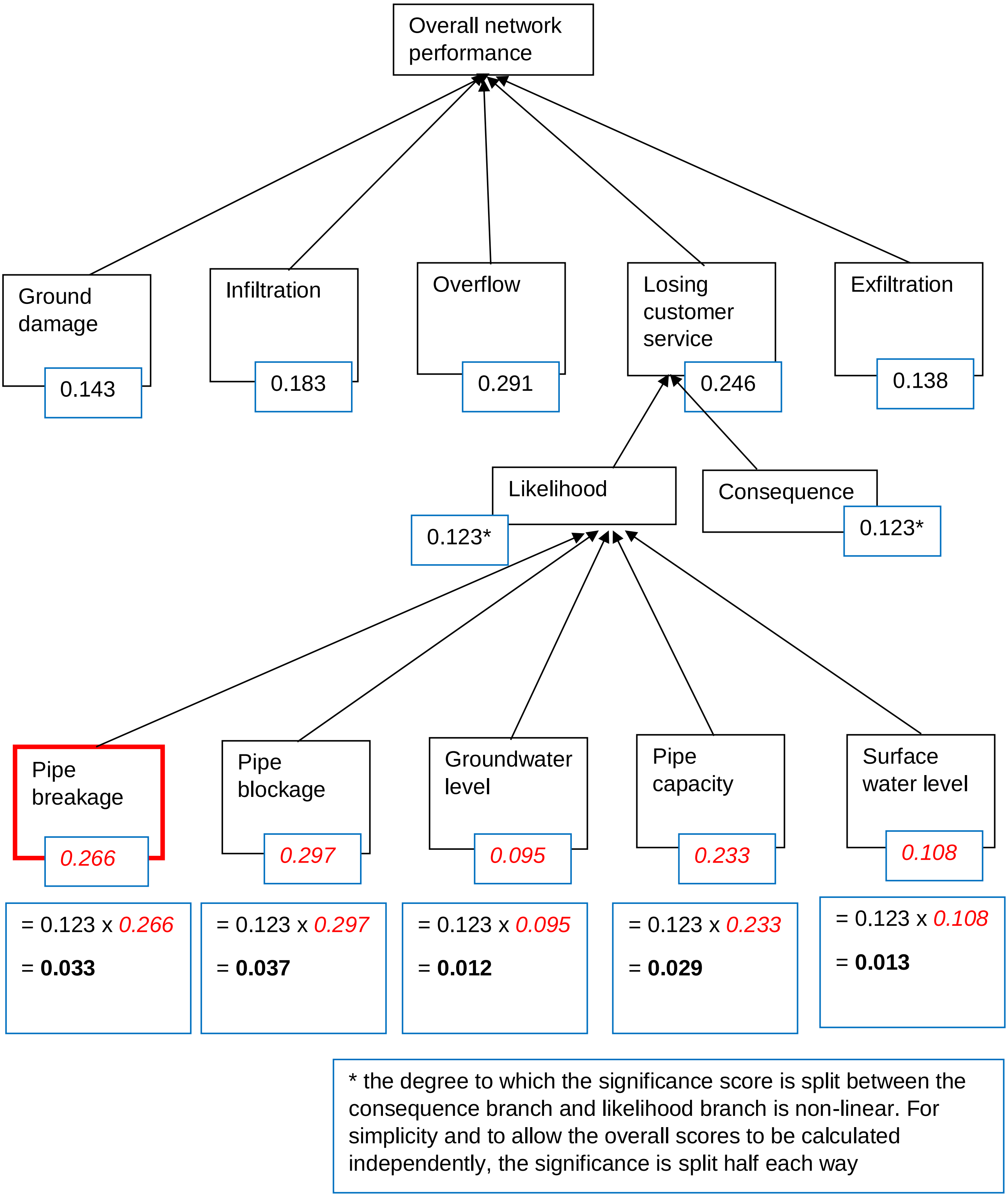


Figure 22 Calculating overall significance

As per the example above the overall significance impact of *Pipe breakage* (within the context of *Losing customer service*) is 0.065. However, the factor *Pipe breakage* appears in multiple locations within the decision tree, so the total overall significance impact score is the sum of all these as shown below.

= Pipe breakage (*Ground damage*) + Pipe breakage (*Infiltration*) + Pipe breakage (*Overflow)*+ Pipe breakage (*Losing customer service*) + Pipe breakage (*Exfiltration*)

= 0.022 + 0.032 + 0.025 + 0.033 + 0.018

= 0.129 Overall significance impact

Table 16 and Table 17 below show the overall significance impact scores for each factor derived in this way from the survey results from highest to lowest.

Table 16 Derived overall significance

Factor	Overall significance
Overflow	0.291
Losing customer service	0.246
Infiltration	0.183
Ground damage	0.143
Exfiltration	0.138
Pipe breakage	0.129
Pipe capacity	0.103
Groundwater level	0.101
Pipe blockage	0.096
Lifeline services (e.g. hospital or evacuation links) at the pipe location	0.075
Soil type	0.073
Commercial activities at the pipe location	0.060
Community facilities at the pipe location	0.057
Private property/assets at the pipe location	0.049
Traffic density at the pipe location	0.045
Lifeline services impact (e.g. hospital or evacuation links)	0.041
Surface water level	0.035

Table 17 Derived overall significance - continued

Factor	Overall significance
Commercial service impact	0.031
Break history	0.030
CCTV footage	0.030
Treatment costs (e.g. additional cost of the infiltrated groundwater)	0.028
Pipe material	0.028
Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	0.028
Community service impact	0.026
Residential service impact	0.024
Proximity to trees	0.024
Pipe age	0.019
Blockage history	0.016
Pipe diameter	0.016
Ground slope	0.015
Pipe dips	0.013
Pipe grade	0.012
Surface loading	0.011
Pipe core analysis	0.010

The overall significance of the factors ranged from 0.291 *(Overflow)* to 0.010 *(Pipe core analysis)*.

The ten factors with the highest overall significance are:

- Overflow
- Losing customer service
- Infiltration
- Ground damage
- Exfiltration
- Pipe breakage
- Pipe capacity
- Groundwater level
- Pipe blockage
- Lifeline services (e.g. hospital or evacuation links) at the pipe location

It is useful to also examine the impact of the factors depending on the level that they are present in the decision tree model. For example, it is logical that those factors appearing further up the decision tree will have a greater overall impact on the *Network performance* as these factors are positioned more closely and are directly linked. The following tables present the overall significance impact of scores split between those found in the decision tree level one, level two and level three.

Table 18 Decision tree level one derived overall significance

Factors – Level one of the decision tree	**Overall significance**
Overflow	0.291
Losing customer service	0.246
Infiltration	0.183
Ground damage	0.143
Exfiltration	0.138

Table 18 results show that *Overflow* is the most significant factor for wastewater asset managers when determining the overall performance of the network. *Losing customer service* also has a significant bearing on the overall performance score. Looking at just these level one factors; *Infiltration* has an average impact and *Ground damage* and *Exfiltration* have a low impact in comparison to the rest. A change in the factor score of one of these lower two factors has approximately half of the impact compared to a change in the *Overflow* factor score.

Table 19 Decision tree level two derived overall significance

Factors – Level two of the decision tree	**Overall significance**
Pipe breakage	0.129
Pipe capacity	0.103
Groundwater level	0.101
Pipe blockage	0.096
Lifeline services (e.g. hospital or evacuation links)	0.075
Soil type (T1/T2)	0.073
Commercial activities at the pipe location	0.060
Community facilities at the pipe location	0.057
Private property/assets at the pipe location	0.049
Traffic density at the pipe location	0.045
Lifeline services impact (e.g. hospital or evac)	0.041
Surface water level	0.035
Commercial service impact	0.031
Treatment costs	0.028
Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	0.028
Community service impact	0.026
Residential service impact	0.024
Ground slope	0.015

Table 19 shows that the level two factors have a broad range of impacts. There is a nine-fold difference in the overall significance of the highest factor *(Pipe breakage 0.129)* compared with the lowest rated factor *(Ground slope 0.015).* The table of results shows that *Pipe breakage* stands above the rest of the level two factors as the most important at 0.129. The next most important factors are grouped together with *Pipe capacity* 0.103, *Groundwater level* 0.101, and *Pipe blockage* 0.096.

Another observation from the overall significance scores seen in the table of level two factors above is that a few the factors appear more than once in the decision tree, which correlates with their overall significance. These factors appearing multiple times in the decision tree generally have higher overall significance. For example, *Pipe breakage* appears five times in the decision tree and has the highest overall significance of 0.129. Likewise, the other high scoring factors appear multiple times; *Groundwater level* appears five times (overall significance 0.101), *Pipe blockage* appears four times (overall significance 0.096), and *Pipe capacity* appears three times (overall significance 0.103).

Table 20 Decision tree level three derived overall significance

Factors – Level three of the decision tree	**Overall significance**
Break history	0.030
CCTV footage	0.030
Pipe material	0.028
Proximity to trees	0.024
Pipe age	0.019
Blockage history	0.016
Pipe diameter	0.016
Pipe dips	0.013
Pipe grade	0.012
Surface loading	0.011
Pipe core analysis	0.010

The level three factors in Table 20 have low overall significance compared to the other factors. These are all subfactors that are used to derive the *Pipe breakage* and *Pipe blockage* factors. The difference between the highest and lowest of these factors is a factor of three. Compared to the level two factors, this is a tighter distribution of more even significance scores.

This distribution of overall significance scores is linked to the decision tree model where a linear relationship is assumed where a factor score is the sum of its subfactor scores. The layout of the decision tree hierarchy and assumed linear relationship are topics discussed further in Chapter 8 – Discussion and Chapter 9 – Conclusions.

Top 2 Box

As discussed in Chapter 2, the Top 2 Box calculation is useful for survey methods such as the Likert scale and calculates the percentage of all results on the 1 – 5 scale that were reported as Very Significant or Extremely Significant**.** The Top 2 Box results are shown below in Table 21 to Table 24.

Table 21 Top 2 Box scores for questions 1 and 2

Question ID	Factor	Top 2 Box score
1	CCTV footage	66%
1	Pipe age	44%
1	Pipe diameter	15%
1	Pipe material	71%
1	Break history	83%
1	Soil type	29%
1	Pipe core analysis	22%
1	Surface loading	24%
1	Proximity to tree roots	27%
2	CCTV footage	64%
2	Pipe age	10%
2	Pipe diameter	33%
2	Pipe material	23%
2	Break history	41%
2	Blockage history	93%
2	Soil type	0%
2	Pipe grade	64%
2	Pipe dips	79%
2	Proximity to tree roots	64%

Table 22 Top 2 Box scores for questions 3, 4, 5 and 6

Question ID	**Factor**	**Top 2 Box score**
3	Pipe breakage	79%
3	Pipe blockage	26%
3	Soil type	66%
3	Groundwater level	55%
4	Traffic density at the pipe location	70%
4	Private property/assets at the pipe location	43%
4	Commercial activities at the pipe location	62%
4	Community facilities at the pipe location	49%
4	Lifeline services (e.g. hospital or evacuation links) at the pipe location	76%
5	Pipe breakage	78%
5	Soil type	49%
5	Groundwater level	89%
6	Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	50%
6	Treatment costs (e.g. additional cost of putting the infiltrated groundwater through the wastewater treatment plant)	53%
6	Pipe capacity	78%

Table 23 Top 2 Box scores for questions 7, 8, 9 and 10

Question ID	Factor	Top 2 Box score
7	Pipe breakage	39%
7	Pipe blockage	78%
7	Groundwater level	31%
7	Surface water level	33%
7	Pipe capacity	78%
8	Traffic density at the pipe location	28%
8	Private property/assets at the pipe location	50%
8	Commercial activities at the pipe location	69%
8	Community facilities at the pipe location	67%
8	Lifeline services (e.g. hospital or evacuation links)	78%
9	Pipe breakage	75%
9	Pipe blockage	86%
9	Groundwater level	8%
9	Surface water level	19%
9	Pipe capacity	67%
10	Residential service impact	58%
10	Commercial service impact	86%
10	Community service impact	75%
10	Lifeline services impact (e.g. hospital or evac)	100%

Table 24 Top 2 Box scores for questions 11, 12 and 13

Question ID	Factor	Top 2 Box score
11	Pipe breakage	75%
11	Pipe blockage	42%
11	Groundwater level	39%
11	Soil type	58%
11	Ground slope	56%
12	Traffic density at the pipe location	50%
12	Private property/assets at the pipe location	47%
12	Commercial activities at the pipe location	67%
12	Community facilities at the pipe location	64%
12	Lifeline services at the pipe location (e.g. hospital or evacuation links)	81%
13	Ground damage	33%
13	Infiltration	56%
13	Overflow	97%
13	Losing customer service	89%
13	Exfiltration	36%

This alternative Top 2 Box approach provides an opportunity for applying a different method to the decision tree. Table 25 below gives the overall significance scores when using the Top 2 Box scores compared with the overall significance scores from the mean significance weighting.

Table 25 Overall significance scores derived from different methods

Factor	Overall significance		
	Top 2 Box	Mean significance weighting	Difference
Overflow	0.414	0.291	0.123
Losing customer service	0.346	0.246	0.100
Pipe capacity	0.159	0.103	0.056
Pipe blockage	0.155	0.096	0.059
Infiltration	0.135	0.183	-0.048
Pipe breakage	0.113	0.129	-0.016
Lifeline services (e.g. hospital or evacuation links) at the pipe location	0.084	0.075	0.009
Lifeline services impact (e.g. hospital or evacuation links)	0.065	0.041	0.024
Commercial activities at the pipe location	0.065	0.060	0.005
Community facilities at the pipe location	0.058	0.057	0.001
Groundwater level	0.057	0.101	-0.044
Exfiltration	0.057	0.138	-0.080
Ground damage	0.049	0.143	-0.094
Commercial service impact	0.048	0.031	0.018
Break history	0.046	0.030	0.015
CCTV footage	0.044	0.030	0.014
Blockage history	0.043	0.016	0.027

Factor	Overall significance		
	Top 2 Box	Mean significance weighting	Difference
Community service impact	0.037	0.026	0.010
Private property/assets at the pipe location	0.033	0.049	-0.015
Soil type	0.032	0.073	-0.041
Pipe dips	0.032	0.013	0.019
Pipe material	0.030	0.028	0.002
Proximity to trees	0.025	0.024	0.001
Residential service impact	0.022	0.024	-0.002
Pipe grade	0.021	0.012	0.009
Traffic density at the pipe location	0.019	0.045	-0.026
Surface water level	0.018	0.035	-0.017
Treatment costs (e.g. additional cost of the infiltrated groundwater)	0.017	0.028	-0.012
Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	0.015	0.028	-0.013
Pipe age	0.011	0.019	-0.009
Pipe diameter	0.007	0.016	-0.009
Ground slope	0.006	0.015	-0.009
Surface loading	0.003	0.011	-0.008
Pipe core analysis	0.003	0.010	-0.007

Top 2 Box scores gave a greater spread in the results where the overall significance was accentuated for the highest ranked and lowest ranked factors. This pronounced effect is greatest in the responses to the Level 1 factors at the top of the decision tree. The high Top 2 Box score for *Overflow* (97%) and *Losing customer service* (89%) increased the overall significance impact of those factors and the subfactors associated with them. This had the interesting result of switching the relative order of *Pipe breakage* versus *Pipe blockage*. Under the first method of decision tree analysis *Pipe breakage* was the most significant, however, under the Top 2 Box approach, it was *Pipe blockage* that had a higher significance. This is linked to the rise in significance for *Overflow* and *Loss of customer service*, which are more focussed on *Pipe blockage*, and the corresponding diminishing of significance for *Infiltration*, *Ground damage* and *Exfiltration* which are more focussed on *Pipe breakage*. In general, the ranking of factors under the two different methods was similar, suggesting that either method would be suitable for reporting the result of the survey.

Both methods of calculating overall significance are from the "top-down" and start with *Network performance* and work down to the lower decision tree levels. A third method was tested to determine the impact of each factor on the overall *Network performance* score by calculating from "the bottom-up". This was performed as a sensitivity analysis.

6.2 Sensitivity Analysis

To conduct the sensitivity analysis the decision tree was modelled with inputs for the significance weightings, but this time also using factors scores (refer Chapter 4 - Methodology). The analysis was performed twice. Firstly, using the survey mean significance weightings and secondly with the Top 2 Box scores, along with hypothetical factor scores.

Initially, the decision tree sensitivity model was set up with every factor having a factor score of 1. Then a series of sensitivity tests were conducted where a single factor score was changed from a 1 to a 5 to observe the resulting *Network performance* score. Table 26 below shows the resulting *Network performance* score for each factor being individually changed from 1 to 5 ranked from highest impact to lowest.

Table 26 Network performance scores derived from different methods

Factor	Network performance score	
	Top 2 Box	Mean significance weighting
Overflow	2.65	2.16
Losing customer service	2.38	1.98
Infiltration	1.54	1.73
Pipe capacity	1.49	1.33
Pipe blockage	1.48	1.32
Pipe breakage	1.37	1.42
Lifeline services (e.g. hospital or evac links) at the pipe location	1.27	1.25
Exfiltration	1.23	1.55
Commercial activities at the pipe location	1.22	1.20
Lifeline services impact (e.g. hospital or evac)	1.20	1.13
Community facilities at the pipe location	1.20	1.20
Ground damage	1.19	1.57
Groundwater level	1.18	1.34
Break history	1.17	1.11
CCTV footage	1.16	1.11
Blockage history	1.16	1.06
Commercial service impact	1.16	1.10

Factor	**Network performance score**	
	Top 2 Box	**Mean significance weighting**
Community service impact	1.12	1.09
Private property/assets at the pipe location	1.12	1.17
Pipe dips	1.12	1.05
Pipe material	1.11	1.11
Soil type	1.11	1.24
Proximity to trees	1.09	1.09
Residential service impact	1.08	1.08
Pipe grade	1.08	1.05
Surface water level	1.07	1.13
Traffic density at the pipe location	1.07	1.16
Treatment costs (e.g. additional cost of the infiltrated groundwater)	1.06	1.09
Conveyance costs (e.g. additional cost of pumping the infiltrated groundwater)	1.05	1.09
Pipe age	1.04	1.07
Pipe diameter	1.03	1.06
Ground slope	1.02	1.05
Surface loading	1.01	1.04
Pipe core analysis	1.01	1.04

The sensitivity noted in the table above relates specifically to the change in the decision model when all factor scores are set to 1 except for the one factor being analysed which is set to 5. In a more usual setting when applying the method for decision-making, the factor scores would be varied and range from 1 – 5 depending on the decision makers network information and the subsequent sensitivity of *Network performance* following a 1 to 5 shift for a single factor would be different.

This “bottom-up” sensitivity method produces a ranking of factors that generally agrees with the earlier “top-down” methods and would be a suitable alternative for reporting the result of the survey.

The survey result data provides insight into how industry experts view the significance of a range of factors relevant to wastewater network decision-making. The results allow decision makers to now gauge the importance to place on each factor by using the significance score from the survey. The results also indicate whether there is agreement or variance across the group of industry experts about how significant they view each factor to be. Where the significance level is high, and the degree of variance is low, it is a clear indication that a factor is important for pipe renewal.

The following factors have a high Top 2 Box result and generally low variance:

Table 27 Factors with high significance and agreement from survey participants

Order	**Factor**	**Top 2 Box**	**Standard deviation**
10	Lifeline services impact (e.g. hospital or evacuation links)	100%	0.47
13	Overflow	97%	0.56
2	Blockage history	93%	0.69
5	Groundwater level	89%	0.83
13	Losing customer service	89%	0.84
10	Commercial service impact	86%	0.58
9	Pipe blockage	86%	0.80
1	Break history	83%	0.72
2	Pipe dips	79%	0.76
3	Pipe breakage	79%	0.89
5	Pipe breakage	78%	0.81
6	Pipe capacity	78%	0.91
7	Pipe capacity	78%	0.97
7	Pipe blockage	78%	0.97
9	Pipe breakage	75%	0.73
10	Community service impact	75%	0.73
11	Pipe breakage	75%	0.91

Chapter 7 – Discussion

7.0 Introduction

Several observations are possible when looking at the industry survey results and considering how this method of documenting intuition might be further applied. It is useful to look at both the benefits and the limitations of using the industry survey and decision tree method developed as part of this thesis work. This chapter provides firstly a thoughtful assessment of the limitations and then a similar examination of the potential benefits of the new methodology for documenting intuition.

7.1 Limitations

Similar significance scores from the raw data

Answers to questions were generally 3 = "Moderately Significant" or 4 = "Very Significant" on the 1 – 5 scale. Two thirds of the results had mean significance scores between 3.00 and 4.00 which resulted in small variations between recorded factors. The survey content was constructed using factors identified as relevant to WNAM in previous literature, therefore it was unlikely that respondents would give a score of 1 "Not at all Significant". This leaves only four realistic choices from 2 – 5 which would have contributed to these tight ranges of responses. Using a scale with greater division, such as a 1- 9 Likert scale, could have accentuated the relative differences in intuitive input.

Assumption that factors should be combined in a linear way

Each tier of the decision tree is made up of the combined weighted scores of the subfactors beneath it. This model provides analysis using the assumption of a linear relationship between factors and subfactors. An alternative method would need to be applied if modelling a non-linear relationship.

The results are tied to the specific decision tree chosen

The calculation of the overall significance scores are inherently linked to the format of the decision tree.

Firstly, the choice of included factors within the decision model has a bearing. Adding or subtracting factors will act to change the complete set of significance weighted results.

Secondly, the number of factors that appear at each level of the tree is important to the results. For example, a factor may be the sum of a high number (e.g. 6 to 7) of subfactors or a low number (e.g. 2 to 3) of subfactors. The subfactors coming from the set of 6 to 7 subfactors will tend to have a lower overall significance compared to the subfactor that is part of the smaller set of 2 to 3.

Thirdly, the construction of tier levels and placement of factors within has further bearing on the result. In general, the closer the factor is to the top of the decision tree the greater overall significance. Conversely, those factors at the lower tier of the decision tree will generally have a lower overall significance score. Each tier of the decision tree presents a point where the significance scores will be spread linearly between each of the factors at that level.

<u>*Further intuitive input is needed to determine factor scores*</u>

The major result of the developed method is to numerically represent the significance weightings of the numerous factors based on expert judgements. However, the application of the decision model requires these to be combined with the factor scores from 1 (very good) to 5 (very poor) to make an overall assessment. For example, when prioritising pipe renewal actions based on CCTV scores and soil condition, additional assessment is needed to determine how a very poor CCTV score will be traded off against a very poor soil condition score. There is no current industry standard for selecting 1 to 5 criteria for these CCTV or soil condition factor scores. The process of determining for example that sandy ground conditions equal 5 (very poor) and clay ground conditions equal 2 (good) is somewhat subjective. In determining the scale to be used for the factor scores a decision must be made about how the 1 to 5 scale will be applied to the network data, including determining the thresholds for each category, i.e. at what point a 1 (very good) becomes only a 2 (good). This process could be determined by applying and documenting expert intuition and would benefit from a thoughtful and standardised approach, which is beyond the scope of what was developed for this industry survey. It is likely that a variant of the method applied within this thesis may be appropriate; that is, soliciting and documenting the expert input to collectively determine where the various 1 to 5 thresholds might apply.

7.2 Benefits

There are several benefits that the developed decision-making system provides when looking at how intuitive decisions may be documented or improved upon.

Provides prioritisation scores

The method provides prioritisation scores once the significance weights are combined with the factor scores. The method is adapted from existing techniques and theories and provides a workable solution for determining significance weightings. Documenting this quantitative result adds immediate value to the improvement of intuitive decision-making over time.

Identification of the factors to include or not include in decision-making

The expert intuition is focussed on determining the significance weightings for each factor. Looking at either the mean scores or Top 2 Box results provides a clear indication of which factors are deemed significant or not significant for this renewal prioritisation decision. This insight is valuable in numerous ways. The obvious value is that the significance weightings are needed to fully apply the decision model, but beyond that the relative significance could be used to further refine or simplify the decision tree model when performing a subsequent analysis.

Targeted data collection

The significance weightings also draw attention to the most important factors for data collection within WNAM to ensure that the inputs from the network data are of an appropriate standard in the areas of greatest influence to the overall decision outcome.

Targeted effort for setting 1 to 5 factor score categories and thresholds

Similar logic also applies to the task of setting the 1 to 5 factor score thresholds. The knowledge of which factors are most significance can help to hone the effort applied when coming up with the 1 to 5 factor score categories and thresholds where the greatest scrutiny is given to those factors with a high significance weighting.

Qualitative decision-making and prioritisation

It may be that a purely numeric representation of the decision tree is beyond what the asset manager is capable of at a given point in time but nevertheless the significance weightings could still be referred to in their intuitive process where a qualitative high/med/low significance is used without necessarily attempting to calculate final prioritisation scores.

Testing the decision tree structure and hierarchy

The survey itself requires a pre-emptive assumption for what the decision tree composition and hierarchy is like so that the questions can be structured appropriately. The process of completing the survey and applying the method provides a chance to analyse the results and then go back and challenge what was originally assumed as the appropriate decision tree. For example, it may be that the number of tiers or subfactors chosen at a particular level resulted in certain factors having too little or too large of an effect on the end decision compared to what was expected by expert consensus or some other known correlation. The analysis of the survey results gives an opportunity to further refine the decision tree structure and hierarchy, continuing to test the shape of the decision model.

Can be applied across a network

The nature of a wastewater network is that many individual assets have a similar nature, but each requires their own assessment and management. The decision model can be applied across large numbers of assets consistently. Once set up, the method can be applied at scale, allowing the computational benefit of process repetition. The significance weights are assessed at a network level and are therefore appropriate to be applied across the network. It is a straightforward process to compute the combined prioritisation score for each individual asset by combining the significance score and factor score.

Provides a framework that is repeatable

The developed decision model provides a framework that is repeatable in either the collection of industry expert knowledge via survey or the application of the knowledge repeatedly over time or for different networks. The method has a distinct number of steps that can be followed.

Through repetition the method allows comparison over time and can be reapplied in the same way or with modification.

Provides a documentation trail

The method succeeds in generating a documentation trail for how intuitive decisions are applied to network prioritisation. The decision model, factors and weightings are all documented explicitly. The documentation allows auditing of the decision quality and gives a starting point for refining the method over time to facilitate continuous improvement.

Links individual factors with ultimate decision outcome

The nature of having an explicit decision tree with tiers branching from each individual factor to the overall outcome provides a visual representation of the model. For each factor, it is possible to see which other factors are influenced by it and to see how those factors ultimately affect the decision outcome. Linking distinct parts of the decision tree together provides useful insight into why certain factors and network information is critical and the way each underpin effective decision-making. Tasks and activities that are performed as part of an organisation's asset management function can be demonstrably linked to overall outcomes, justifying the reason for those tasks.

Used as a shortlist

The application of this method provides a prioritisation score for remedial actions to be carried out on wastewater pipes within a network. These remedies may vary from further inspection, data collection, condition monitoring, physical testing, repair, lining, renewal, abandonment or justification to do nothing. The degree to which the result informs the actual decision depends on the degree of comfort and certainty the user has in converting the scores to direct actions. It may be that the asset manager wishes to retain the autonomy of the ultimate decision-making, but even in this case, the method helps. The method could be used to shortlist pipes as candidates for action still allowing room for the asset manager to apply their own expert intuition at the end of the process. The numerical prioritisation might be used to quickly highlight those pipes of high, medium or low concern, providing a time-saving shortcut for the asset owner's own intuitive decision-making process.

Chapter 8 – Conclusions

8.0 Introduction

This chapter presents the conclusions drawn from the literature review, case studies and new methodology developed for documenting intuition within WNAM. Recommended future research steps are provided at the end of this chapter.

8.1 Background and literature review

The research background and literature review has shown that:

- Wastewater network asset management requires effective decision-making given the vast financial value of the assets and the essential community service provided.
- The principles of advanced asset management are well understood however the specific practical applications of the principles are variable and subjective.
- Wastewater asset management is a complex socio-technical decision system with interconnectedness, multiple perspectives, poor data availability and outcomes that are difficult to predict.
- Intuitive decision-making is useful for complex systems and is necessary for determining actions within the context of wastewater network asset management.
- Intuition can be applied in a skilled or unskilled manner. Skilled intuition benefits from the decision maker's experience, relevant knowledge and the opportunity to learn through feedback. Where these factors are absent, unskilled intuition is subject to inherent bias and heuristics that distort decision judgements.
- Documenting intuition within wastewater network asset management can improve the effectiveness of intuitive decision-making over time. Intuition can be documented in these specific elements: the decision process steps, the factors or sources of information, the relative weighting of factors, and the decision hierarchy.

8.2 Case studies

Two case studies have provided evidence of:

- Intuition used within existing wastewater network asset management decision systems.
- Intuition used principally at distinct stages of the decision process, either “up front” or at the “coal face”.
- Existing methods of documenting intuition through quantitative scoring systems used with the industry.

8.3 Decision tree model and industry survey

The development of a decision tree model and industry survey has shown that:

- Expert judgements were able to be collected and documented using a Likert-type scale to quantify the relative significance of a range of factors affecting wastewater network performance.
- The overall impact of each factor on the network performance was able to be determined by normalising the subfactor inputs at each tier of the decision tree. Two “top-down” approaches were identified to determine the overall impact; using either the mean significance scores or the Top 2 Box scores from the survey. One “bottom-up” approach was identified to determine how sensitive the network performance was to the changing of a single factor. Each method provided a generally similar ranking of factors.
- The results of the applied method are specific to the decision tree and factors used, and the assumption of linearity between subfactors.
- The 1 – 5 relative scale range generally resulted in low variation of the survey raw significance scores.

- When combined with factor scores, the significance scores derived from the methodology enable prioritisation of decisions that can be applied consistently across an entire network.
- The overall significance scores identify the factors to include or not include in decision-making and can be used to prioritise targeted data collection or a targeted approach for defining factor scoring categories and thresholds.
- The methodology provides a documentation trail so that the decision model framework can be repeated or passed on. Wastewater network asset managers can use the documentation as a reference for future learning opportunities, therefore becoming more skilled in intuitive decision-making.

8.4 Next steps for future research

The decision model has specifically examined the technical category of network performance. The same methodology could be expanded for the other elements within the high-level system such as the decision-making around improving the system layout, coordination with other infrastructure works, economic impacts, environmental impacts, ease of management, and political impacts.

Further research could examine the framework for defining factor scores, such as the categorisation and thresholds of what “poor” or “excellent” soil conditions or CCTV records mean in practice.

The results of the survey are tied to the single specific decision tree hierarchy, set of factors, and Likert 1 - 5 scale that were used in this research. A variety of decision trees, hierarchy arrangements, and relative scales could be tested in combination with a differing set of factors to determine whether a particular model is preferable.

Consideration could also be given to how the methodology could be adapted to allows for non-linearity between competing subfactors.

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Appendices

Appendix A

Waimakariri District Council CCTV inspection scheduling process

Appendix B

Waimakariri District Council sewer renewals scheduling process

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Appendix A

Waimakariri District Council CCTV inspection scheduling process

CCTV Inspection Scheduling Process

Notes:

- Pressure and Rising Mains are excluded from inspection.
- Gravity Mains wholly within Red Zones are excluded from inspection and are to be assessed separately.
- Those mains not assessed for Vulnerability or Criticality have been excluded (predominantly those mains installed after the earthquake sequence).

START

AIM team generate Hansen queries on criticality, theoretical remaining useful life, vulnerability, and CCTV data.
(AIM Team Query)

Has pipe been CCTV surveyed previously?

Yes

CCTV Re-inspection Value based on CCTV Mean Score

CCTV Mean Score	Reinspection Range
Poor 1.71≤ x<3 Value = (-7/1.29) x Mean Score + 18.27	2-9 years
Moderate 0.91≤x<1.71 Value = -11.25 x Mean Score + 29.2375	10-19 years
Excellent/Good x≤0.9	20 years

Calculate Re-inspection Date by adding Re-inspection Value to Date of CCTV inspection.

Re-inspection Date = CCTV Inspection Date + Re-inspection Value

Schedule Pipes for CCTV inspection.

No

Score mains for both of the Likelihood Criteria – "Theoretical Remaining Useful Life" and "Vulnerability"
(AIM Team Query)

Likelihood

Theoretical Remaining Useful Life

%TRUL	Score
10% or under	60
11% - 24% Score = (1350/13) – (53/13) x RUL	6 - 59
25% or over	5

Vulnerability

Rank	Score
Extreme 2.5 – 1.2	60
1.19 - 0.02 Score = (5700/117) x Vulnerability + (120/117)	2 - 59
Low 0.01 or under	1

Add the scores of both Likelihood criteria
(AIM TEAM)

Score each section of pipe for Criticality based on the table below
(AIM Team Query)

Consequence

Criticality

Rank	Score
AA	100
A	75
B	50
C	25

Multiply the total likelihood score by the criticality score to produce a CCTV Priority Score
(AIM Team)

Produce an excel list of each section of pipe, listing a CCTV priority score, individual scores for each likelihood criteria and consequence,pipe material, diameter, length and location. To be split up by scheme.
(AIM Team)

Pipes are ranked by CCTV Priority Score and CCTV programme is developed accounting for pipes to be re-inspected and in conjunction with other work programmes for each scheme.
(PDU Team)

Appendix B

Waimakariri District Council sewer renewals scheduling process

Sewer Renewals Scheduling Process

Notes:

- Pressure and rising mains are excluded from renewals scheduling and are to be assessed separately.
- Gravity mains wholly within Red Zones are excluded and are to be assessed separately.
- Those mains that have not been CCTV inspected are excluded from renewals scheduling.

START

(AIM Team Query)
AIM team generate Tech One queries (downloaded to an excel spreadsheet) for individual pipes to include as columns for each pipe; address, diameter, length, install date, description (gravity/pressure), material, estimated remaining useful life from valuation, whether it is a Red Zone Asset, is a Relined Main, Likelihood and Criticality criteria ranks.

(AIM Team Query)
Generated spreadsheet is populated and each pipe is scored for the three Likelihood criteria

Likelihood

Blockage History

Rank	Score
3 Blockages in last 3 years	30
2 Blockages in last 3 years	15
1 Blockage in last 3 years	5
No blockage history in last 3 years	1

CCTV Mean Structural Score

Rank	Score
Fail $18 \leq x$	Gradient
Fail $3.00 \leq x < 18$	$60 < x \leq 120$
Moderate/Poor $0.9 < x < 3.00$	$1 < x \leq 60$
Excellent/Good $X \leq 0.9$	1

Vulnerability

Rank	Score
Extreme $1.2 < x \leq 2.5$	15 - 30
Medium $0.01 < x \leq 1.2$	2 – 15
Low $X \leq 0.01$	1

Add the scores of the three likelihood criteria
(AIM TEAM)

Score each pipe for Consequence based on the table below
(AIM Team)

Consequence

Criticality

Rank	Score
AA	1.95
A	1.56
B	1.25
C	1

Multiply the sum of Likelihood scores by the Consequence score to produce a Renewal Priority Score
(AIM Team)

Renewals Process

(AIM Team)
Populate in an excel workbook all sewer pipes in the district identified by their Tech1 ID and listing the pipes';

- scheme name,
- address,
- diameter,
- length,
- install date,
- description (gravity/pressure),
- material,
- estimated remaining useful life from valuation,
- whether pipe is a Red Zone Asset,
- whether pipe is a Relined Main,
- Likelihood and Consequence criteria rank & scores,
- calculated Renewal Priority Score.

Within the excel workbook segregate each wastewater scheme (Eastern District, Loburn-Lea, Oxford) to its own tab. The workbook is issued to PDU Team.

(PDU Team)
Pipes are ranked by Renewal Priority Score. The Sewer Annual Renewal programme is developed as per the *"Annual Sewer Renewal Programme Excel Work Book Standard Operating Procedure"* and in conjunction with other Utility and capital work programmes for each scheme. The Preliminary Works Programme is issued to the AIM Team who produce scheme maps which are then reviewed by PDU for sensibility and updated.

(Wastewater Asset Manager)
The preliminary works programme with scheme maps is delivered to the Asset Manager for review. It is proposed that CCTV footage be verified by the asset team and a renewal technique determined. Programme and scheme maps are regenerated if changes are made, taking into account budget constraints (iterative).

(PDU Team / Wastewater Asset Manager)
Detailed design and contract documents are developed.

Appendix C

Survey characteristics

Survey Characteristics

To achieve the survey's purpose of usability the survey was prepared in a way that would increase the chances of it being picked up and used by industry professionals. The success of such a tool depends on a number of human factors regarding the likelihood that a number of different users would be able to buy in to the approach and would see the value in them using their time to complete the inputs. The following characteristics of the survey were specifically considered in the development of the method in order to support the purpose of serving industry experts:

- Scope
- Relevance
- Alignment
- Familiarity
- User-friendliness
- Integration

These characteristics are explained in more detail in the sections below.

Scope

Wastewater network asset managers in industry have a scope in which they operate. For example many will be from a civil engineering background and have knowledge of wastewater flow demand and calculation, technical pipeline design, hydraulic capacity, construction costs and operational activities. The scope that they operate in is largely technical. As discussed in the literature review, a systems view of the complex decision making environment revealed that the system is socio-technical. There are a number of factors outside of the traditional field of engineers such as service levels, willingness to pay, environmental outcomes, finance, and organisation preferences that fit more appropriately within the scope of social scientists, economists or politicians. Therefore the industry survey has been developed by taking a subset of the entire systems view and selected the factors that fit within the technical scope.

This narrowing of focus is necessary to align the survey to the scope of decision that the target participating experts operate in. The results from the survey and how these are used must be kept in the perspective of this technical scope, understanding that it sits as a sub-section of the entire, more complex, decision making system.

Relevance

The new methodology is used to weight or gauge the significance of various factors. Because the emphasis is on the weighting, the factors themselves must be presented consistently to all participants. That is, the same set of factors are required to be assessed by each industry expert so that a meaningful comparison of significance can be collated for each. This requires the set of factors to be determined from the outset, in the construction of the survey and not solicited from the industry experts at the time of survey.

This is an important distinction because it requires prior expert knowledge of the relevant factors that are typically used in the technical decision systems. In this case, the prior research from Van Riel et al. (2014) provided a grouping of 21 factors, described as information sources, that were relevant to the Dutch municipalities. The SCIRT and WDC case studies also provided local context for the various factors that were considered when deciding actions for wastewater network renewal.

The relevant factors from Van Riel et al. (2014), SCIRT and WDC fell into the following broad categories:

- Pipe breakage factors
- Pipe blockage factors
- Soil characteristics
- Groundwater characteristics
- Road use above pipe
- Pipe capacity factors

The combination of data from the Dutch municipalities and New Zealand case studies allowed a set of factors to be chosen.

Alignment

It was important that the core structure of the survey aligned with actual decisions that wastewater network asset managers are required to make. This is an issue of aligning the purpose of the survey with the purpose of decision makers in industry. The exercise of alignment required drilling down to the essence of the problem. A core issue for wastewater asset managers is “Which pipe should I replace/repair?”. The value of outputs gathered through the survey method depends on how well they align with this core issue.

This exercise requires the suitable framing of the problem so that each stage in the decision tree is leading towards a response to the core issue of “Which pipe should I replace/repair?”. Factors are only suitably aligned with the core issue when they contribute towards an answer to the problem. An example of this distinction is a factor that gives information about asset condition only. Asset condition is only aligned with the core issue when is can be converted to information about network performance. An asset manager is not necessarily concerned that pipes are old, discoloured, brittle, have minor cracks and leaks if the over performance of the network is meeting the main objectives. Therefore the survey structure has been developed so that each factor aligns with a key aspect of network performance.

Familiarity

The documentation of intuition via survey requires a familiarity of language used. The words written into the survey are the mechanism for conveying meaning to the participants in order for them to submit their weighted judgement. The language should be familiar and unambiguous. To capture familiarity, the survey has been developed reusing common words and terminology found in the literature review and case studies. The survey has been design such that participants will fill it out on their own without direct interaction with myself as the research author. It is therefore important that ambiguity is minimised since there will not be any chance to clarify the meaning of the questions or terms through discussions. Wherever possible the selected language is chosen because of the established meaning of the terms for professionals within wastewater network asset management. Jargon is used freely since the participants have the required relevant knowledge to quickly and consistently understand the meaning.

Also, the context for the questions should be familiar. Participants need to be provided with the context for how to approach the survey in a way that is familiar for professionals working in the wastewater network asset management arena.

User-friendliness

The industry survey required voluntary participation so effort was made to ensure that it was user-friendly. A correct pitch was needed so that participants could both see the value in taking part in the survey and not feel that it was overly onerous so that they would be comfortable giving their time to complete it. All of the survey questions could be answered in the same way by selecting a value for each factor. It was estimated that each question could typically be answered in 30 – 60 seconds. The total number of questions was limited to 13 making it easy for participants to take part in.

As well as being brief, the survey questions were each structured in the identical way. This makes it obvious with how the questions should be read and what type of answer mechanism is expected from the participants.

The effort required in answering each questions was made low by simply requiring a check box to be chosen from a possible five options for each factor. The mechanic for collecting answers should provide enough possibilities that the answer does not become so obvious for participants that their individual intuitive expression suppressed, while also being limited enough that the participant is not overwhelmed by choice and encounters difficulty in answering.

Integration

In order to be useful, the documented intuition needs to be based on a scenario that closely mimics real world problems that wastewater network asset managers face. The framework that ties the questions together should also integrate with decision systems used by the participants. The earlier case studies and literature researched showed the adoption of risk based assessments used in asset management. The risk model is an established mode of quantifying or prioritising various wastewater network asset management decisions. The same risks based approach has been adopted in the survey. Questions are framed in terms of determining the likelihood and consequence of various pipe network performance outcomes occurring. The benefit of this integration is twofold in that it allows participants to see how the separate parts of the survey fit together to achieve and overall understanding of the contextual problem, and also provides a real world application where the documented intuition can be applied to. This is especially important as it relates to the overall purpose of the survey to be used a method for documenting intuition used by relevant professionals in a way that provides ongoing value to the quality of their everyday decision making processes.

Appendix D

Survey cover page instructions

I’m piloting a method that records the importance of factors often used when experts in wastewater network asset management make decisions.

The purpose of the pilot is to understand how this method might support the process of documenting the intuition of those with knowledge and experience.

The scenario
Imagine you are responsible for choosing which pipes get renewed or repaired in a wastewater network.

You’ve already decided that your goal is to minimise the risks of:

- Losing service (eg users not able to flush toilets/discharge wastewater to the network)
- Overflow (eg wastewater egress onto ground surface, watercourses)
- Infiltration (eg groundwater ingress into the wastewater pipes)
- Exfiltration (eg wastewater egress out of the pipes into the surrounding soil)
- Ground damage (eg soil getting into wastewater pipes causing sink holes above the pipe)

The survey will have you rate the significance of a number of factors in the pursuit of your goal. The survey does not have an exhaustive list of factors, you will no doubt think of a number of your own. However, I’m limited by how many factors I can include and have carefully chosen them for the purpose of this pilot.

How to answer
For each factor you will be asked to rate the level of significance. The way to approach this is to imagine you have **NO INFORMATION** about that particular factor. Now consider how crucial it is for you to gather information or have a sophisticated understanding of that factor.

For example:

Extremely significant = information is crucial / you need a sophisticated understanding of this factor

Very significant = information is important / you need a reasonable understanding of this factor

Moderately significant = information is generally useful / you need a basic understanding of this factor

Slightly significant = information could be useful in some circumstances / understanding this factor could be useful in some circumstances

Not at all significant = information is not needed / understanding this factor is not needed

Please answer all questions the best that you can without leaving any blanks. I’m interested in your feedback so there is a place below each question to type comments if you wish.

Appendix E

Survey full questions

Wastewater Network Renewal & Repair: Gauging What's Important

Q1 You are assessing the likelihood of pipe breakage (ie will the pipe break in future). How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
CCTV footage (1)	❍	❍	❍	❍	❍
Pipe age (2)	❍	❍	❍	❍	❍
Pipe diameter (3)	❍	❍	❍	❍	❍
Pipe material (4)	❍	❍	❍	❍	❍
Break history (5)	❍	❍	❍	❍	❍
Soil type (6)	❍	❍	❍	❍	❍
Pipe core analysis (7)	❍	❍	❍	❍	❍
Surface loading (8)	❍	❍	❍	❍	❍
Proximity to tree roots (9)	❍	❍	❍	❍	❍

Q32 Comments

Q2 You are assessing the likelihood of pipe blockage (ie will the pipe block in future). How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
CCTV footage (1)	❍	❍	❍	❍	❍
Pipe age (2)	❍	❍	❍	❍	❍
Pipe diameter (3)	❍	❍	❍	❍	❍
Pipe material (4)	❍	❍	❍	❍	❍
Break history (5)	❍	❍	❍	❍	❍
Blockage history (6)	❍	❍	❍	❍	❍
Soil type (7)	❍	❍	❍	❍	❍
Pipe grade (8)	❍	❍	❍	❍	❍
Pipe dips (9)	❍	❍	❍	❍	❍
Proximity to tree roots (10)	❍	❍	❍	❍	❍

Q33 Comments

Q3 You are assessing the likelihood of ground damage. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Pipe breakage (1)	❍	❍	❍	❍	❍
Pipe blockage (2)	❍	❍	❍	❍	❍
Soil type (3)	❍	❍	❍	❍	❍
Groundwater level (4)	❍	❍	❍	❍	❍

Q34 Comments

Q4 You are assessing the consequence of ground damage. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Traffic density at the pipe location (1)	❍	❍	❍	❍	❍
Private property/assets at the pipe location (2)	❍	❍	❍	❍	❍
Commercial activities at the pipe location (3)	❍	❍	❍	❍	❍
Community facilities at the pipe location (4)	❍	❍	❍	❍	❍
Lifeline services (eg hospital or evacuation links) at the pipe location (5)	❍	❍	❍	❍	❍

Q35 Comments

Q5 You are assessing the likelihood of infiltration. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Pipe breakage (1)	❍	❍	❍	❍	❍
Soil type (2)	❍	❍	❍	❍	❍
Groundwater level (3)	❍	❍	❍	❍	❍

Q36 Comments

Q6 You are assessing the consequence of infiltration. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Conveyance costs (eg additional cost of pumping the infiltrated groundwater) (1)	❍	❍	❍	❍	❍
Treatment costs (eg additional cost of putting the infiltrated groundwater through the wastewater treatment plant) (2)	❍	❍	❍	❍	❍
Pipe capacity (3)	❍	❍	❍	❍	❍

Q37 Comments

Q7 You are assessing the likelihood of overflows. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Pipe breakage (1)	❍	❍	❍	❍	❍
Pipe blockage (2)	❍	❍	❍	❍	❍
Groundwater level (3)	❍	❍	❍	❍	❍
Surface water level (4)	❍	❍	❍	❍	❍
Pipe capacity (5)	❍	❍	❍	❍	❍

Q38 Comments

Q8 You are assessing the consequence of overflows. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Traffic density at the pipe location (1)	❍	❍	❍	❍	❍
Private property/assets at the pipe location (2)	❍	❍	❍	❍	❍
Commercial activities at the pipe location (3)	❍	❍	❍	❍	❍
Community facilities at the pipe location (4)	❍	❍	❍	❍	❍
Lifeline services (eg hospital or evacuation links) at the pipe location (5)	❍	❍	❍	❍	❍

Q39 Comments

Q9 You are assessing the likelihood of losing customer service. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Pipe breakage (1)	❍	❍	❍	❍	❍
Pipe blockage (2)	❍	❍	❍	❍	❍
Groundwater level (3)	❍	❍	❍	❍	❍
Surface water level (4)	❍	❍	❍	❍	❍
Pipe capacity (5)	❍	❍	❍	❍	❍

Q40 Comments

Q10 You are assessing the consequence of losing customer service. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Residential service impact (1)	❍	❍	❍	❍	❍
Commercial service impact (2)	❍	❍	❍	❍	❍
Community service impact (3)	❍	❍	❍	❍	❍
Lifeline services impact (eg hospital or evacuation links) (4)	❍	❍	❍	❍	❍

Q41 Comments

Q11 You are assessing the likelihood of ground damage caused by exfiltration. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Pipe breakage (1)	❍	❍	❍	❍	❍
Pipe blockage (2)	❍	❍	❍	❍	❍
Groundwater level (3)	❍	❍	❍	❍	❍
Soil type (4)	❍	❍	❍	❍	❍
Ground slope (5)	❍	❍	❍	❍	❍

Q42 Comments

Q12 You are assessing the consequence of ground damage caused by exfiltration. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Traffic density at the pipe location (1)	❍	❍	❍	❍	❍
Private property/assets at the pipe location (2)	❍	❍	❍	❍	❍
Commercial activities at the pipe location (3)	❍	❍	❍	❍	❍
Community facilities at the pipe location (4)	❍	❍	❍	❍	❍
Lifeline services at the pipe location (eg hospital or evacuation links) (5)	❍	❍	❍	❍	❍

Q43 Comments

Q13 You are assessing the overall performance of pipes in the network. How significant are the following factors?

	Not at all significant (1)	Slightly significant (2)	Moderately significant (3)	Very significant (4)	Extremely significant (5)
Ground damage (1)	❍	❍	❍	❍	❍
Infiltration (2)	❍	❍	❍	❍	❍
Overflow (3)	❍	❍	❍	❍	❍
Losing customer service (4)	❍	❍	❍	❍	❍
Exfiltration (5)	❍	❍	❍	❍	❍

Q44 Comments

Q46 The survey is complete! Thanks for your help. This is one final chance to provide any feedback or comments you have.

Appendix F

University of Canterbury Human Ethics Committee approval

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2016/70/LR

20 December 2016

James Thorne
CNRE
UNIVERSITY OF CANTERBURY

Dear James

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Intuitive Decision Making for Wastewater Networks".

I am pleased to advise that the application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 13th December 2016.

With best wishes for your project.

Yours sincerely

pp. R. Robinson

Associate Professor Jane Maidment
Chair, Human Ethics Committee

Low Risk Application Form

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

FOR STUDENT RESEARCH UP TO AND INCLUDING MASTERS LEVEL

Ethical approval of low risk research involving human participants reviewed by departments or schools in the College of Education

PLEASE read the important notes appended to this form before completing the sections below

Researcher's Name:	James Thorne
Name of Department or School:	College of Engineering.
Email Address:	~~[illegible]~~ james.thorne@pg.canterbury.ac.nz
Title of Project:	Intuitive Decision Making for Wastewater Networks
Projected Start Date of Project:	21/11/16
Staff member/supervisor responsible for project:	Dr Eric Scheepbauwer
Names of other participating staff and students:	N/A.
Status of Research: (e.g. Thesis)	Master thesis

Brief description of the project:

Please give a brief summary (approx. 300 words) of the nature of the proposal in lay language, including the aims/objectives/hypotheses of the project, rationale, participant description, and procedures/methods of the project:-

The project involves developing and testing a methodology for documention the expert knowledge that industry experts use when they prioritise which wastewater pipe in a network to repair or renew. The methodology is the survey that asks industry experts to weigh the significance of different factors that are typically considered during repair/renewal decision making.

(Version April 2012)

Why is this a low risk application? Description should include issues raised in the Low Risk Checklist (see below). Please give details of any ethical issues which were identified during the consideration of the proposal and the way in which these issues were dealt with or resolved.
Participants will be contacted via Water New Zealand (industry group) or through direct contact with organisations eg Opus consultants and Waimakariri District Council. The survey will be anonymous; participants will disclose how many years of relevant wastewater industry experience they have. In the results write up I will not mention which specific organisations participated. (instead will say "partipants from local council and engineering consultancies in NZ"). The survey is primarily about demonstrating a method that can be used to document intuition for this application, not to scrutenize the actual weightings of significant factors as reported by participants. The survey is voluntary. The data will be held for the sole purpose of completing the masters thesis.

Applicant's Name:	James Thorne		
Signature:	James Thorne	Date:	9/11/16.

LOW RISK CHECKLIST – ***PLEASE ALSO REFER TO THE NOTES AT THE BACK OF THIS DOCUMENT***

Please check that your application / summary has discussed:

- procedures for voluntary, informed consent
- privacy & confidentiality
- how much anonymity can be offered and how it will be maintained
- risk to participants
- obligations under the Treaty of Waitangi
- needs of dependent persons
- conflict of interest
- permission for access to participants from other individuals or bodies
- inducements
- dissemination of research findings
- storage and subsequent destruction of data

Please ensure that Sections A, B and C below are all completed

A SUPERVISOR DECLARATION:

1. I have made the applicant fully aware of the need for and requirement of seeking ERHEC approval for research involving human participants.
2. I have ensured the applicant is conversant with the procedures involved in making such an application.
3. The applicant has individually filled in this Low Risk application form which has been reviewed by me.

Signed (Supervisor):	E Schieepbower	Date:	22/11/2016

B Supported by the Departmental/School Research Committee:

Name:	Tom Cochrane AHMW	Signature:		Date:	23/11/2016

C Supported by the Head of Department/School:

Name:	Ricardo Bello-Mendoza	Signature:		Date:	15 Nov 2016

Please attach copies of any Information Sheets, Consent Forms and/or Questionnaires as appropriate.
Forward two copies of all documents to:

The Secretary
Educational Research Human Ethics Committee
Level 5 Matariki South

All queries will be forwarded to the applicant within 10 working days of receipt of the application by the Secretary of the committee.
Please include a copy of this form as an appendix in your thesis or course work

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Action taken by Educational Research Human Ethics Committee

☐	Added to Low Risk Reporting Database	☐	Referred to full ERHEC
☐	Referred to another Ethics Committee - Please specify:		
Approved by:		Date:	

NOTES CONCERNING LOW RISK APPLICATIONS

1. ***Procedures:***

   This **Low Risk** application form should **only be used** for proposals which are **Low Risk** as defined in the University of Canterbury Educational Research Human Ethics Committee Principles and Guidelines policy document.

   In consultation with the ERHEC, Departments or Schools will develop a process for review and approval. Departments or Schools will advise ERHEC if there are any subsequent changes to the process.

   The staff making application must sign a declaration that students:

   - undertaking those research projects are being made fully aware of the need for and the requirement of seeking ERHEC approval for all research involving human participants,
   - are conversant with the procedures involved in making such an application,
   - have individually filled in the required applications submitted to the concerned staff.

   A low risk notification form should be filled out and forwarded to the secretary of the ERHEC. Attachments should include a sample of the information and consent forms that will be used.

2. Low risk applications would involve the same risk as might be encountered in normal daily life. For example,

   a. Master's theses where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals.

   b. Master's level supervised projects undertaken as part of specific course requirements where the projects do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals.

   c. Undergraduate and Honours class research projects which do not raise any issue of deception, threat, invasion of privacy, mental, physical or cultural risk or stress, and do not involve gathering personal information of a sensitive nature about or from individuals, but do not have blanket approval as specified in Section 4 below.

3. No project, regardless of level, may be considered as low risk if it involves any of the following.:
   a. invasive physical procedures or potential for physical harm
   b. procedures which might cause mental/emotional stress or distress, moral or cultural offence
   c. personal or sensitive issues
   d. vulnerable groups
   e. Tangata Whenua
   f. cross cultural research
   g. investigation of illegal behaviour(s)
   h. invasion of privacy
   i. collection of information that might be disadvantageous to the participant
   j. use of information already collected that is not in the public arena which might be disadvantageous to the participant
   k. use of information already collected which was collected under agreement of confidentiality
   l. participants who are unable to give informed consent, including children
   m. conflict of interest e.g. the researcher is also the lecturer, teacher, treatment-provider, colleague or employer of the research participants, or there is any other power relationship between the researcher and the research participants
   n. deception
   o. audio or visual recording without consent
   p. withholding benefits from "control" groups
   q. inducements
   r. risks to the researcher

   The only exception to this is that research with children and young people in educational settings may be included in applications made within blanket approval category, *provided the skills and strategies being learned are those that would be expected to be part of normal teaching practice on completion of the qualification.*

   This list is not definitive but is intended to sensitise the researcher to the types of issues to be considered. Low risk research would involve the same risk as might be encountered in normal daily life.

In some circumstances research that appears to meet low risk criteria may need to be reviewed by the ERHEC. This might be because of requirements of:

- The publisher of the research
- An organisation which is providing funding resources, existing data, access to participant, etc.
- Research which meets the criteria for a review by a Health and Disability Ethics Committee (see HRC website).

4. A separate low risk form should be completed for each teaching or research proposal which involves human participants and for which ethical approval has been considered or given at Departmental or School level.
5. The completed form, **together with two copies of any Information Sheet or Consent Form**, should be returned to the Secretary, Educational Research Human Ethics Committee, Okeover House, **as soon as the proposal has been considered at departmental or school level.**
6. The Information Sheet and Consent Form should NOT include the statement "This proposal has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee" as this is inappropriate for low risk proposals. A statement such as "This proposal has been reviewed and approved by the Department/School of ..... University of Canterbury" must, however, be used.
7. Please ensure the Consent Form and the Information Sheet has been carefully proofread; the institution as a whole is likely to be judged by them.
8. ERHEC aims to notify applicants for low risk approval within ten working days of receiving the application from the Head of Department/School.
9. The research must be consistent with the UC ERHEC Principles and Guidelines. Refer to the appendices of the UC ERHEC Principles and Guidelines for guidance on information sheets and consent forms.
10. Please note that if the nature, procedures, location or personnel of the research project changes after departmental/school approval has been given in such a way that the research no longer meets the conditions laid out in Section 5 of the Principles and Guidelines, a full application to the ERHEC must be submitted.
11. Ensure that the reference is made to the ERHEC complaints procedure which should be included in the body of the information as follows: Complaints may be addressed to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch, Email: human-ethics@canterbury.ac.nz.
12. This form is available electronically at the following web address: http://www.canterbury.ac.nz/humanethics/erhec/apply.shtml
13. **Responsibility:**

    Supervisors are responsible for:

    a. Theses where the projects do not raise any issues listed.
    b. Masters level supervised projects undertaken as part of specific course requirements where the projects do not raise any issues listed.
    c. Undergraduate and Honours class research projects which do not raise any issues listed but do not have blanket approval as specified in the Principles and Guidelines.

    HODs are responsible for:

    a. Giving departmental or school approval in principle for the low risk application.
    b. Ensuring a copy of all applications is kept on file in the Department/School.
    c. Ensuring one hard copy and one electronic copy of the application are sent to the secretary of the ERHEC.
    d. Advising the applicant that the project may not commence before the Secretary of the ERHEC has advised final approval (see item 8 above).

The Educational Research Human Ethics Committee is happy to give advice on the appropriateness of research for low risk review.

Appendix G

Survey full results

Q1_7	Q1_8	Q1_9	Q2_1	Q2_2
You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho
{"ImportId":"QID2_7"}	{"ImportId":"QID2_8"}	{"ImportId":"QID2_9"}	{"ImportId":"QID3_1"}	{"ImportId":"QID3_2"}
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Slightly significant
Slightly significant	Moderately significant	Slightly significant	Moderately significant	Slightly significant
Slightly significant	Slightly significant	Moderately significant	Extremely significant	Not at all significant
Slightly significant	Slightly significant	Moderately significant	Very significant	Very significant
Not at all significant	Slightly significant	Not at all significant	Very significant	Moderately significant
Very significant	Moderately significant	Moderately significant	Extremely significant	Moderately significant
Very significant	Moderately significant	Moderately significant	Moderately significant	Slightly significant
Extremely significant	Very significant	Very significant	Extremely significant	Slightly significant
Moderately significant	Slightly significant	Slightly significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Moderately significant
Slightly significant	Moderately significant	Moderately significant	Moderately significant	Slightly significant
Slightly significant	Extremely significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Extremely significant	Not at all significant
Not at all significant	Very significant	Moderately significant	Very significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Slightly significant
Not at all significant	Not at all significant	Not at all significant	Slightly significant	Slightly significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Not at all significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Very significant	Moderately significant	Moderately significant	Very significant	Slightly significant
Slightly significant	Very significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Extremely significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Not at all significant
Not at all significant	Not at all significant	Moderately significant		
Very significant	Extremely significant	Very significant	Moderately significant	Not at all significant
Moderately significant	Slightly significant	Slightly significant	Extremely significant	Slightly significant
Moderately significant	Very significant	Slightly significant	Very significant	Not at all significant
Slightly significant	Extremely significant	Moderately significant	Very significant	Not at all significant
Very significant	Extremely significant	Very significant	Very significant	Moderately significant
Moderately significant	Moderately significant	Moderately significant	Slightly significant	Slightly significant
Moderately significant	Slightly significant	Slightly significant	Very significant	Moderately significant
Moderately significant	Very significant	Very significant	Moderately significant	Not at all significant
Slightly significant	Moderately significant	Slightly significant	Very significant	Slightly significant
Very significant	Slightly significant	Slightly significant	Very significant	Not at all significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Moderately significant
Moderately significant	Slightly significant	Moderately significant	Very significant	Slightly significant
Very significant	Extremely significant	Extremely significant	Extremely significant	Moderately significant
Slightly significant	Moderately significant	Moderately significant	Very significant	Not at all significant
Extremely significant	Moderately significant	Very significant	Extremely significant	Not at all significant
Moderately significant	Moderately significant	Very significant		

Q2_3	Q2_4	Q2_5	Q2_6	Q2_7
You are assessing the likelihoo	You are assessing the likelihoo	You are assessing the likelihoo	You are assessing the likelihoo	You are assessing the likelihoo
{"ImportId":"QID3_3"}	{"ImportId":"QID3_4"}	{"ImportId":"QID3_5"}	{"ImportId":"QID3_6"}	{"ImportId":"QID3_7"}
Moderately significant	Moderately significant	Very significant	Very significant	Slightly significant
Not at all significant	Slightly significant	Slightly significant	Very significant	Slightly significant
Slightly significant	Moderately significant	Slightly significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Extremely significant	Slightly significant
Slightly significant	Very significant	Not at all significant	Very significant	Not at all significant
Moderately significant	Very significant	Moderately significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Moderately significant
Very significant	Moderately significant	Very significant	Extremely significant	Moderately significant
Very significant	Slightly significant	Slightly significant	Very significant	Moderately significant
Extremely significant	Moderately significant	Moderately significant	Extremely significant	Not at all significant
Moderately significant	Moderately significant	Slightly significant	Moderately significant	Slightly significant
Very significant	Moderately significant	Moderately significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Very significant	Extremely significant	Moderately significant
Very significant	Slightly significant	Moderately significant	Extremely significant	Slightly significant
Slightly significant	Very significant	Extremely significant	Extremely significant	Slightly significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Not at all significant
Slightly significant	Slightly significant	Slightly significant	Slightly significant	Not at all significant
Moderately significant	Moderately significant	Very significant	Very significant	Slightly significant
Moderately significant	Very significant	Very significant	Very significant	Slightly significant
Very significant	Slightly significant	Very significant	Very significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Slightly significant
Extremely significant	Very significant	Slightly significant	Very significant	Moderately significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Not at all significant
Not at all significant	Not at all significant	Moderately significant	Very significant	Not at all significant
Very significant	Slightly significant	Very significant	Very significant	Not at all significant
Moderately significant	Slightly significant	Moderately significant	Very significant	Slightly significant
Very significant	Not at all significant	Not at all significant	Very significant	Not at all significant
Very significant	Slightly significant	Very significant	Extremely significant	Slightly significant
Slightly significant	Moderately significant	Very significant	Extremely significant	Moderately significant
Very significant	Moderately significant	Moderately significant	Very significant	Slightly significant
Slightly significant	Not at all significant	Moderately significant	Extremely significant	Not at all significant
Moderately significant	Slightly significant	Very significant	Very significant	Not at all significant
Moderately significant	Moderately significant	Very significant	Extremely significant	Not at all significant
Slightly significant	Moderately significant	Slightly significant	Extremely significant	Slightly significant
Moderately significant	Very significant	Very significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Very significant	Very significant	Slightly significant
Extremely significant	Very significant	Slightly significant	Extremely significant	Moderately significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Not at all significant
Not at all significant	Very significant	Very significant	Extremely significant	Not at all significant
			Moderately significant	

Q2_8	Q2_9	Q2_10	Q3_1	Q3_2
You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho
{"ImportId":"QID3_8"}	{"ImportId":"QID3_9"}	{"ImportId":"QID3_10"}	{"ImportId":"QID4_1"}	{"ImportId":"QID4_2"}
Extremely significant	Very significant	Very significant	Very significant	Slightly significant
Very significant	Very significant	Moderately significant	Extremely significant	Very significant
Very significant	Very significant	Moderately significant	Extremely significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Slightly significant
Moderately significant	Moderately significant	Slightly significant	Moderately significant	Not at all significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Very significant	Very significant	Very significant	Slightly significant	Moderately significant
Moderately significant	Very significant	Very significant	Very significant	Moderately significant
Extremely significant	Very significant	Moderately significant	Extremely significant	Very significant
Extremely significant	Extremely significant	Very significant	Very significant	Slightly significant
Moderately significant	Very significant	Very significant	Moderately significant	Slightly significant
Moderately significant	Very significant	Very significant	Extremely significant	Very significant
Moderately significant	Very significant	Extremely significant	Extremely significant	Slightly significant
Moderately significant	Moderately significant	Very significant	Very significant	Slightly significant
Very significant	Very significant	Moderately significant	Slightly significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Moderately significant
Not at all significant	Not at all significant	Not at all significant	Not at all significant	Not at all significant
Moderately significant	Moderately significant	Very significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Extremely significant	Moderately significant
Slightly significant	Very significant	Very significant	Very significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Slightly significant
Extremely significant	Very significant	Very significant	Very significant	Moderately significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Not at all significant	Very significant	Very significant	Very significant	Slightly significant
Extremely significant	Extremely significant	Very significant	Very significant	Moderately significant
Very significant	Very significant	Extremely significant	Very significant	Slightly significant
Very significant	Very significant	Moderately significant	Moderately significant	Slightly significant
Very significant	Very significant	Moderately significant	Very significant	Slightly significant
Slightly significant	Moderately significant	Very significant	Very significant	Slightly significant
Extremely significant	Very significant	Moderately significant	Very significant	Not at all significant
Extremely significant	Extremely significant	Extremely significant	Moderately significant	Slightly significant
Moderately significant	Moderately significant	Slightly significant	Moderately significant	Moderately significant
Extremely significant	Extremely significant	Moderately significant	Very significant	Moderately significant
Extremely significant	Very significant	Extremely significant	Extremely significant	Very significant
Very significant	Very significant	Moderately significant		
Moderately significant	Moderately significant	Extremely significant	Extremely significant	Extremely significant

Q3_3	Q3_4	Q4_1	Q4_2	Q4_3
You are assessing the likeliho	You are assessing the likeliho	You are assessing the consequ	You are assessing the consequ	You are assessing the consequ
{"ImportId":"QID4_3"}	{"ImportId":"QID4_4"}	{"ImportId":"QID5_1"}	{"ImportId":"QID5_2"}	{"ImportId":"QID5_3"}
Extremely significant	Very significant	Moderately significant	Moderately significant	Moderately significant
Extremely significant	Very significant	Moderately significant	Very significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Moderately significant
Moderately significant	Moderately significant	Very significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Moderately significant	Slightly significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Very significant	Slightly significant	Slightly significant
Very significant	Very significant	Extremely significant	Very significant	Extremely significant
Very significant	Slightly significant	Very significant	Slightly significant	Moderately significant
Extremely significant	Extremely significant	Extremely significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Very significant
Extremely significant	Very significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Extremely significant	Slightly significant	Moderately significant
Moderately significant	Moderately significant	Very significant	Slightly significant	Very significant
Slightly significant	Moderately significant	Moderately significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Very significant	Very significant
Not at all significant	Not at all significant	Not at all significant	Not at all significant	Not at all significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Slightly significant	Slightly significant	Slightly significant
Very significant	Very significant	Very significant	Moderately significant	Moderately significant
Extremely significant	Extremely significant	Very significant	Moderately significant	Very significant
Extremely significant	Extremely significant	Very significant	Very significant	Very significant
Moderately significant	Slightly significant	Extremely significant	Extremely significant	Extremely significant
Very significant	Moderately significant	Extremely significant	Very significant	Extremely significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Very significant	Moderately significant	Very significant	Moderately significant	Very significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Very significant
Very significant	Moderately significant	Moderately significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Moderately significant	Very significant	Very significant
Very significant	Slightly significant	Very significant	Very significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Very significant	Extremely significant	Moderately significant	Slightly significant	Moderately significant
Very significant	Very significant	Moderately significant	Not at all significant	Moderately significant
Very significant	Slightly significant	Extremely significant	Very significant	Very significant
Very significant	Very significant			

Q4_4	Q4_5	Q5_1	Q5_2	Q5_3
You are assessing the conseq	You are assessing the conseq	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho
{"ImportId":"QID5_4"}	{"ImportId":"QID5_5"}	{"ImportId":"QID6_1"}	{"ImportId":"QID6_2"}	{"ImportId":"QID6_3"}
Moderately significant	Moderately significant	Moderately significant	Very significant	Extremely significant
Very significant	Extremely significant	Very significant	Moderately significant	Moderately significant
Moderately significant	Extremely significant	Extremely significant	Moderately significant	Extremely significant
Very significant	Extremely significant	Extremely significant	Moderately significant	Extremely significant
Slightly significant	Extremely significant	Slightly significant	Very significant	Very significant
Moderately significant	Moderately significant	Extremely significant	Very significant	Very significant
Slightly significant	Extremely significant	Moderately significant	Slightly significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Very significant
Slightly significant	Extremely significant	Slightly significant	Slightly significant	Moderately significant
Very significant	Extremely significant	Extremely significant	Very significant	Extremely significant
Very significant	Extremely significant	Very significant	Moderately significant	Extremely significant
Moderately significant	Very significant	Extremely significant	Very significant	Extremely significant
Moderately significant	Extremely significant	Extremely significant	Slightly significant	Extremely significant
Very significant	Extremely significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Very significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Not at all significant	Not at all significant	Moderately significant	Not at all significant	Not at all significant
Very significant	Extremely significant	Very significant	Slightly significant	Very significant
Slightly significant	Slightly significant	Very significant	Slightly significant	Moderately significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Moderately significant	Extremely significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Very significant
Extremely significant	Extremely significant	Very significant	Moderately significant	Very significant
Very significant	Extremely significant	Slightly significant	Slightly significant	Extremely significant
Very significant	Very significant	Very significant	Very significant	Very significant
Moderately significant	Extremely significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Extremely significant
Moderately significant	Moderately significant	Extremely significant	Very significant	Very significant
Very significant	Extremely significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Moderately significant	Extremely significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Extremely significant
Very significant	Extremely significant	Moderately significant	Very significant	Extremely significant
Slightly significant	Slightly significant	Very significant	Slightly significant	Extremely significant
Slightly significant	Very significant	Very significant	Very significant	Extremely significant
Extremely significant	Very significant	Very significant	Extremely significant	Extremely significant

Q6_1	Q6_2	Q6_3	Q7_1	Q7_2
You are assessing the consequ	You are assessing the consequ	You are assessing the consequ	You are assessing the likelihoo	You are assessing the likelihoo
{"ImportId":"QID7_1"}	{"ImportId":"QID7_2"}	{"ImportId":"QID7_3"}	{"ImportId":"QID8_1"}	{"ImportId":"QID8_2"}
Slightly significant	Moderately significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Slightly significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Extremely significant	Moderately significant	Extremely significant
Slightly significant	Very significant	Very significant	Moderately significant	Moderately significant
Moderately significant	Very significant	Moderately significant	Moderately significant	Extremely significant
Very significant	Very significant	Slightly significant	Slightly significant	Moderately significant
Moderately significant	Very significant	Very significant	Extremely significant	Extremely significant
Moderately significant	Moderately significant	Very significant	Slightly significant	Slightly significant
Very significant	Very significant	Very significant	Extremely significant	Very significant
Moderately significant	Moderately significant	Extremely significant	Moderately significant	Extremely significant
Very significant	Very significant	Very significant	Moderately significant	Extremely significant
Extremely significant	Very significant	Moderately significant	Extremely significant	Extremely significant
Very significant	Very significant	Very significant	Very significant	Very significant
Moderately significant	Slightly significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Moderately significant	Moderately significant
Very significant	Very significant	Moderately significant	Not at all significant	Not at all significant
Very significant	Moderately significant	Very significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Moderately significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Very significant	Slightly significant	Extremely significant
Slightly significant	Slightly significant	Extremely significant	Slightly significant	Extremely significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Moderately significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Extremely significant	Very significant	Extremely significant
Very significant	Moderately significant	Very significant	Extremely significant	Extremely significant
Moderately significant	Moderately significant	Very significant	Slightly significant	Very significant
Very significant	Very significant	Extremely significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Very significant	Very significant	Moderately significant
Moderately significant	Moderately significant	Slightly significant	Very significant	Moderately significant
Very significant	Very significant	Extremely significant	Slightly significant	Extremely significant
Very significant	Moderately significant	Very significant	Moderately significant	Extremely significant
Moderately significant	Moderately significant	Slightly significant	Moderately significant	Very significant
Extremely significant	Extremely significant	Very significant	Very significant	Very significant

Q7_3	Q7_4	Q7_5	Q8_1	Q8_2
You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the consequ	You are assessing the consequ
{"ImportId":"QID8_3"}	{"ImportId":"QID8_4"}	{"ImportId":"QID8_5"}	{"ImportId":"QID10_1"}	{"ImportId":"QID10_2"}
Moderately significant	Very significant	Extremely significant	Slightly significant	Very significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Very significant
Very significant	Moderately significant	Extremely significant	Very significant	Moderately significant
Very significant	Extremely significant	Extremely significant	Very significant	Very significant
Moderately significant	Very significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Very significant	Moderately significant	Moderately significant	Slightly significant	Slightly significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Very significant
Slightly significant	Slightly significant	Extremely significant	Slightly significant	Slightly significant
Extremely significant	Moderately significant	Extremely significant	Slightly significant	Moderately significant
Moderately significant	Moderately significant	Extremely significant	Moderately significant	Extremely significant
Moderately significant	Moderately significant	Extremely significant	Slightly significant	Slightly significant
Moderately significant	Very significant	Moderately significant	Slightly significant	Moderately significant
Moderately significant	Very significant	Extremely significant	Slightly significant	Moderately significant
Moderately significant	Slightly significant	Extremely significant	Slightly significant	Moderately significant
Moderately significant	Very significant	Very significant	Very significant	Very significant
Not at all significant	Moderately significant	Moderately significant	Not at all significant	Not at all significant
Moderately significant	Very significant	Very significant	Slightly significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Slightly significant	Slightly significant
Moderately significant	Very significant	Very significant	Not at all significant	Moderately significant
Moderately significant	Moderately significant	Very significant	Moderately significant	Moderately significant
Moderately significant	Slightly significant	Slightly significant	Slightly significant	Very significant
Moderately significant	Slightly significant	Extremely significant	Extremely significant	Extremely significant
Slightly significant	Not at all significant	Extremely significant	Slightly significant	Very significant
Very significant	Moderately significant	Very significant	Moderately significant	Moderately significant
Very significant	Moderately significant	Very significant	Very significant	Very significant
Slightly significant	Very significant	Very significant	Moderately significant	Extremely significant
Moderately significant	Slightly significant	Very significant	Slightly significant	Slightly significant
Moderately significant	Very significant	Very significant	Slightly significant	Very significant
Very significant	Moderately significant	Extremely significant	Very significant	Very significant
Very significant	Moderately significant	Extremely significant	Not at all significant	Moderately significant
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Moderately significant
Moderately significant	Slightly significant	Slightly significant	Not at all significant	Slightly significant
Very significant	Slightly significant	Moderately significant	Slightly significant	Slightly significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Extremely significant

Q8_3	Q8_4	Q8_5	Q9_1	Q9_2
You are assessing the conseq	You are assessing the conseq	You are assessing the conseq	You are assessing the likeliho	You are assessing the likeliho
{"ImportId":"QID10_3"}	{"ImportId":"QID10_4"}	{"ImportId":"QID10_5"}	{"ImportId":"QID11_1"}	{"ImportId":"QID11_2"}
Moderately significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Extremely significant	Very significant	Very significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Very significant	Slightly significant	Very significant	Moderately significant	Slightly significant
Very significant	Extremely significant	Extremely significant	Extremely significant	Extremely significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Extremely significant	Very significant	Extremely significant	Very significant	Very significant
Very significant	Slightly significant	Very significant	Very significant	Slightly significant
Very significant	Extremely significant	Very significant	Extremely significant	Extremely significant
Extremely significant	Extremely significant	Extremely significant	Moderately significant	Extremely significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Extremely significant
Very significant	Extremely significant	Very significant	Extremely significant	Extremely significant
Very significant	Very significant	Extremely significant	Extremely significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Not at all significant	Not at all significant	Not at all significant	Very significant	Very significant
Very significant	Extremely significant	Extremely significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Moderately significant	Slightly significant	Extremely significant
Extremely significant	Extremely significant	Extremely significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Moderately significant	Extremely significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Extremely significant	Very significant	Moderately significant
Extremely significant	Extremely significant	Very significant	Very significant	Extremely significant
Slightly significant	Slightly significant	Slightly significant	Extremely significant	Extremely significant
Moderately significant	Moderately significant	Very significant	Moderately significant	Very significant
Extremely significant	Very significant	Extremely significant	Extremely significant	Extremely significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Extremely significant	Very significant	Very significant
Very significant	Slightly significant	Slightly significant	Very significant	Extremely significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Extremely significant	Extremely significant	Extremely significant

Q9_3	Q9_4	Q9_5	Q10_1	Q10_2
You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho	You are assessing the consequ	You are assessing the consequ
{"ImportId":"QID11_3"}	{"ImportId":"QID11_4"}	{"ImportId":"QID11_5"}	{"ImportId":"QID12_1"}	{"ImportId":"QID12_2"}
Slightly significant	Slightly significant	Very significant	Extremely significant	Very significant
Slightly significant	Slightly significant	Moderately significant	Very significant	Very significant
Moderately significant	Slightly significant	Very significant	Very significant	Very significant
Moderately significant	Very significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Extremely significant	Slightly significant	Moderately significant
Slightly significant	Slightly significant	Slightly significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Extremely significant	Very significant	Very significant
Moderately significant	Moderately significant	Extremely significant	Very significant	Extremely significant
Moderately significant	Very significant	Moderately significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Very significant	Very significant	Moderately significant
Slightly significant	Slightly significant	Very significant	Very significant	Very significant
Slightly significant	Very significant	Very significant	Very significant	Very significant
Not at all significant	Not at all significant	Slightly significant	Very significant	Very significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Slightly significant	Slightly significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Very significant
Slightly significant	Slightly significant	Moderately significant	Very significant	Very significant
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Moderately significant
Not at all significant	Not at all significant	Extremely significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Moderately significant	Moderately significant	Very significant
Slightly significant	Moderately significant	Moderately significant	Extremely significant	Extremely significant
Slightly significant	Slightly significant	Moderately significant	Extremely significant	Extremely significant
Slightly significant	Very significant	Very significant	Moderately significant	Very significant
Slightly significant	Slightly significant	Extremely significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Slightly significant	Moderately significant	Moderately significant
Slightly significant	Slightly significant	Very significant	Very significant	Extremely significant
Slightly significant	Slightly significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Very significant	Slightly significant	Moderately significant
Slightly significant	Slightly significant	Very significant	Slightly significant	Very significant
Extremely significant	Extremely significant	Very significant	Extremely significant	Extremely significant

Q10_3	Q10_4	Q11_1	Q11_2	Q11_3
You are assessing the conseq	You are assessing the conseq	You are assessing the likeliho	You are assessing the likeliho	You are assessing the likeliho
{"ImportId":"QID12_3"}	{"ImportId":"QID12_4"}	{"ImportId":"QID15_1"}	{"ImportId":"QID15_2"}	{"ImportId":"QID15_3"}
Very significant	Extremely significant	Moderately significant	Very significant	Moderately significant
Very significant	Very significant	Moderately significant	Moderately significant	Moderately significant
Extremely significant	Extremely significant	Extremely significant	Slightly significant	Moderately significant
Very significant	Extremely significant	Extremely significant	Very significant	Very significant
Slightly significant	Very significant	Moderately significant	Not at all significant	Very significant
Very significant	Very significant	Extremely significant	Extremely significant	Moderately significant
Very significant	Extremely significant	Slightly significant	Slightly significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Very significant
Slightly significant	Extremely significant	Very significant	Slightly significant	Slightly significant
Very significant	Extremely significant	Extremely significant	Very significant	Moderately significant
Very significant	Extremely significant	Very significant	Moderately significant	Moderately significant
Very significant	Extremely significant	Extremely significant	Very significant	Moderately significant
Very significant	Extremely significant	Extremely significant	Very significant	Slightly significant
Extremely significant	Extremely significant	Very significant	Moderately significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Moderately significant
Very significant	Extremely significant	Slightly significant	Slightly significant	Slightly significant
Very significant	Very significant	Not at all significant	Not at all significant	Not at all significant
Very significant	Extremely significant	Moderately significant	Slightly significant	Slightly significant
Very significant	Very significant	Very significant	Very significant	Slightly significant
Very significant	Extremely significant	Very significant	Moderately significant	Very significant
Moderately significant	Extremely significant	Very significant	Moderately significant	Moderately significant
Very significant	Extremely significant	Very significant	Very significant	Extremely significant
Moderately significant	Very significant	Very significant	Very significant	Slightly significant
Very significant	Very significant	Moderately significant	Not at all significant	Very significant
Very significant	Very significant	Very significant	Very significant	Extremely significant
Moderately significant	Extremely significant	Very significant	Slightly significant	Moderately significant
Very significant	Extremely significant	Very significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Moderately significant	Extremely significant	Moderately significant	Slightly significant	Moderately significant
Moderately significant	Extremely significant	Very significant	Extremely significant	Very significant
Very significant	Extremely significant	Very significant	Slightly significant	Slightly significant
Very significant	Extremely significant	Very significant	Slightly significant	Not at all significant
Very significant	Extremely significant	Very significant	Slightly significant	Very significant
Slightly significant	Very significant	Very significant	Not at all significant	Very significant
Moderately significant	Extremely significant	Very significant	Moderately significant	Slightly significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Very significant

Q11_4	Q11_5	Q12_1	Q12_2	Q12_3
You are assessing the likeliho	You are assessing the likeliho	You are assessing the conseq	You are assessing the conseq	You are assessing the conseq
{"ImportId":"QID15_4"}	{"ImportId":"QID15_5"}	{"ImportId":"QID17_1"}	{"ImportId":"QID17_2"}	{"ImportId":"QID17_3"}
Very significant	Extremely significant	Moderately significant	Extremely significant	Extremely significant
Moderately significant	Extremely significant	Very significant	Very significant	Very significant
Moderately significant	Very significant	Very significant	Moderately significant	Moderately significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Moderately significant	Very significant	Moderately significant	Very significant
Moderately significant	Very significant	Very significant	Very significant	Very significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Moderately significant	Very significant	Very significant	Moderately significant	Moderately significant
Extremely significant	Extremely significant	Moderately significant	Moderately significant	Very significant
Very significant	Extremely significant	Very significant	Moderately significant	Moderately significant
Very significant	Moderately significant	Slightly significant	Slightly significant	Moderately significant
Slightly significant	Slightly significant	Extremely significant	Moderately significant	Very significant
Very significant	Extremely significant	Very significant	Moderately significant	Moderately significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Slightly significant	Slightly significant
Not at all significant	Not at all significant	Not at all significant	Not at all significant	Not at all significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Slightly significant	Slightly significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Very significant
Very significant	Very significant	Extremely significant	Extremely significant	Extremely significant
Very significant	Not at all significant	Slightly significant	Slightly significant	Slightly significant
Moderately significant	Moderately significant	Moderately significant	Moderately significant	Very significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Extremely significant	Extremely significant	Extremely significant	Very significant	Very significant
Very significant	Not at all significant	Slightly significant	Slightly significant	Slightly significant
Moderately significant	Slightly significant	Slightly significant	Slightly significant	Slightly significant
Slightly significant	Moderately significant	Moderately significant	Moderately significant	Very significant
Very significant	Slightly significant	Very significant	Very significant	Very significant
Not at all significant	Moderately significant	Very significant	Very significant	Extremely significant
Very significant	Very significant	Very significant	Moderately significant	Very significant
Moderately significant	Moderately significant	Moderately significant	Slightly significant	Slightly significant
Very significant	Very significant	Moderately significant	Slightly significant	Very significant
Extremely significant	Extremely significant	Very significant	Extremely significant	Extremely significant

Q12_4	Q12_5	Q13_1	Q13_2	Q13_3
You are assessing the conseq	You are assessing the conseq	You are assessing the overall	You are assessing the overall	You are assessing the overall
{"ImportId":"QID17_4"}	{"ImportId":"QID17_5"}	{"ImportId":"QID1_1"}	{"ImportId":"QID1_2"}	{"ImportId":"QID1_3"}
Very significant	Extremely significant	Very significant	Moderately significant	Extremely significant
Very significant	Very significant	Extremely significant	Moderately significant	Very significant
Extremely significant	Extremely significant	Slightly significant	Moderately significant	Moderately significant
Very significant	Extremely significant	Slightly significant	Moderately significant	Very significant
Slightly significant	Very significant	Slightly significant	Moderately significant	Very significant
Very significant	Very significant	Very significant	Very significant	Extremely significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Very significant
Moderately significant	Extremely significant	Very significant	Moderately significant	Extremely significant
Very significant	Extremely significant	Extremely significant	Moderately significant	Extremely significant
Very significant	Extremely significant	Moderately significant	Moderately significant	Extremely significant
Moderately significant	Moderately significant	Moderately significant	Very significant	Extremely significant
Moderately significant	Extremely significant	Slightly significant	Moderately significant	Extremely significant
Very significant	Extremely significant	Moderately significant	Very significant	Very significant
Very significant	Very significant	Slightly significant	Moderately significant	Extremely significant
Slightly significant	Extremely significant	Very significant	Very significant	Very significant
Not at all significant	Not at all significant	Slightly significant	Very significant	Very significant
Very significant	Extremely significant	Moderately significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Slightly significant	Very significant	Very significant
Very significant	Very significant	Very significant	Very significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Very significant
Very significant	Very significant	Slightly significant	Very significant	Very significant
Extremely significant	Extremely significant	Very significant	Very significant	Very significant
Slightly significant	Slightly significant	Moderately significant	Slightly significant	Very significant
Very significant	Very significant	Moderately significant	Very significant	Very significant
Very significant	Extremely significant	Moderately significant	Very significant	Extremely significant
Very significant	Very significant	Moderately significant	Very significant	Extremely significant
Slightly significant	Slightly significant	Slightly significant	Moderately significant	Extremely significant
Slightly significant	Slightly significant	Moderately significant	Very significant	Extremely significant
Moderately significant	Extremely significant	Moderately significant	Extremely significant	Extremely significant
Very significant	Extremely significant	Moderately significant	Not at all significant	Very significant
Very significant	Extremely significant	Very significant	Very significant	Extremely significant
Very significant	Extremely significant	Slightly significant	Moderately significant	Very significant
Slightly significant	Slightly significant	Slightly significant	Moderately significant	Very significant
Moderately significant	Very significant	Moderately significant	Very significant	Extremely significant
Extremely significant	Extremely significant	Extremely significant	Extremely significant	Extremely significant

Q13_4	Q13_5
You are assessing the overall	You are assessing the overall
{"ImportId":"QID1_4"}	{"ImportId":"QID1_5"}
Very significant	Slightly significant
Very significant	Moderately significant
Extremely significant	Slightly significant
Very significant	Very significant
Very significant	Slightly significant
Very significant	Extremely significant
Not at all significant	Very significant
Very significant	Very significant
Slightly significant	Moderately significant
Extremely significant	Moderately significant
Very significant	Moderately significant
Very significant	Slightly significant
Very significant	Slightly significant
Extremely significant	Moderately significant
Extremely significant	Moderately significant
Very significant	Very significant
Very significant	Slightly significant
Very significant	Very significant
Very significant	Very significant
Very significant	Very significant
Very significant	Moderately significant
Moderately significant	Moderately significant
Extremely significant	Very significant
Extremely significant	Not at all significant
Very significant	Very significant
Very significant	Very significant
Extremely significant	Moderately significant
Very significant	Slightly significant
Very significant	Slightly significant
Very significant	Moderately significant
Moderately significant	Not at all significant
Extremely significant	Moderately significant
Extremely significant	Moderately significant
Very significant	Moderately significant
Very significant	Very significant
Extremely significant	Very significant