University of Southern Queensland

Faculty of Engineering and Surveying

Development and Execution of Asset Criticality Framework: A Study of Water and Wastewater Infrastructure at Toowoomba Regional Council

A dissertation submitted by

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Abstract

Toowoomba Regional Council (TRC) is proceeding to develop a documented asset management system which includes the use of criticality. Criticality is a rating assigned to an asset based on its consequence of failure. A criticality analysis identifies assets that are fundamental to performance and provides a basis for strategic decision-making. The aim of this dissertation was to provide TRC with the framework required to perform an asset criticality analysis on its water and wastewater asset base.

Criticality assessment criteria were developed in conjunction with TRC's Enterprise Risk Policy to ensure consequences were assessed against corporate interests. Severity scorecards were established to quantify the impact of the consequences and guidelines were created to ensure consistent application. A model was produced in Microsoft Excel to process data and automate criticality calculations.

The methodology and model were applied to a total of 1210 assets which varied in size, cost, location and function. The resulting asset criticality ratings were realistic and provided an accurate representation of their relative importance. In total, the criticality ratings indicated that 23.64 percent were non-critical, 73.55 percent were partially critical, 2.73 percent were critical and 0.083 percent were extremely critical.

The results indicated that the criticality framework was suitable for use by TRC and would provide a comprehensive foundation to standardise decision-making, identify critical assets and prioritise asset management activities to optimise the distribution of funds and resources.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

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Nomenclature

AWTP	Advanced Water Treatment Plant
BRE	Business Risk Exposure
CED	Common Effluent Disposal
EAM	Enterprise Asset Management
FMEA	Failure Mode and Effect Analysis
GIS	Geographic Information System
MS	Microsoft
PAC	Powdered Activated Carbon
PACL	Polyaluminium Chloride
PdM	Predictive Maintenance
PM	Preventive Maintenance
PTA	Preliminary Treatment Area
RCM	Reliability Centred Maintenance
RTF	Run-to-failure
SCADA	Supervisory Control and Data Acquisition
TRC	Toowoomba Regional Council
WIS	Water Infrastructure Services
WTP	Water Treatment Plant
WPS	Water Pump Station
WWTP	Wastewater Treatment Plant
WWPS	Wastewater Pump Station

Chapter 1 – Introduction

> *"By identifying critical assets and critical failure modes, organisations can target and refine investigative activities, maintenance plans, and capital expenditure plans at the critical areas".* (NAMS, 2011, pp. 2-95)

1.1 Introduction

The above statement suggests the need for an organisation to implement prioritisation techniques to better manage assets and associated activities. By identifying critical infrastructure, organisations can invest funds and resources into maintaining assets that pose the greatest consequence to the organisation if failure occurs (NAMS, 2011).

This is of particular relevance to organisations that manage large quantities of infrastructure designed to provide municipal services to customers. Organisations of this nature strive to deliver a reliable and acceptable standard of service and are usually governed by a variety of legislative requirements. Asset maintenance needs to be managed effectively, otherwise organisations risk being exposed to unexpected asset failure which may be of severe consequence.

A criticality analysis allows an organisation to identify assets with a high consequence of failure so they can implement appropriate maintenance activities and strategies focused on minimising risk of failure. Criticality information facilitates informed management decisions to ensure resources are allocated to the appropriate assets (Marquez, 2007).

The failure of water supply and wastewater collection infrastructure can result in a range of consequences. Water and wastewater utilities may experience significant financial, reputational, environmental, compliance or service impacts as a result of asset failure. Numerous cases have been recorded in Australia where the failure of water and wastewater infrastructure has caused significant damage to third parties and attracted considerable media attention. A recent incident occurred at the Gold Coast where a sewer main collapsed and discharged over one million litres of raw sewage into Saltwater Creek (The Advertiser, 2015). A separate incident occurred at Windsor Gardens in Adelaide where a water main failed and caused flooding to a number of domestic properties (Silva, 2013). It is unknown whether these organisations utilise a risk management system, but an asset criticality analysis may have assisted them to introduce activities to proactively manage similar assets with a high consequence of failure.

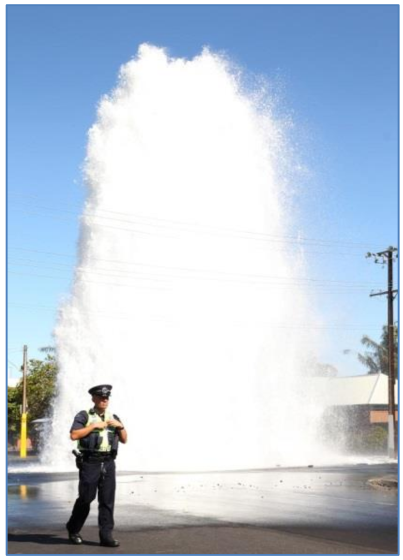

Figure 1.1: Water main burst at Windsor Gardens in Adelaide (Silva, 2013)

This dissertation aims to provide the documented research, methodologies and models required for Toowoomba Regional Council (TRC) to perform an asset criticality analysis on its water and wastewater asset base. The outcomes of this study are to be further developed by TRC and used to establish maintenance strategies that align with asset criticality. Further details about the scope of this study are detailed in section 1.3.

1.2 Background

TRC is proceeding to develop a documented asset management system which includes a criticality assessment methodology to standardise decision-making and assist with the prioritisation of asset management activities and associated resources. While this has been an objective for the Water and Waste Services Group for several years, the need for an asset management framework has been further emphasised by an emerging direction from the Commonwealth government to improve asset management across Australia. In addition, the recent release of the ISO55000 suite of standards has provided guidelines and direction for developing such a system.

1.2.1 Toowoomba Regional Council

The Toowoomba region is located in south-east Queensland approximately 125km west of Brisbane. It is situated on the western side of the Great Dividing Range and encompasses an area of 12,973km^2 with a population of approximately 160,297 people (Toowoomba Regional Council, 2014).

Toowoomba was declared a municipality in 1860 and officially became a city in 1904 (Toowoomba Regional Council, n.d.). Toowoomba is the second largest inland city in Australia and is the economic hub of the Toowoomba region and the greater Darling Downs. It is located approximately 700 metres above sea level and has a temperate climate well suited to farming and agriculture. Toowoomba has a strong and diverse economy due to the large agricultural sector and rich resource reserves available in the nearby Surat Basin (Toowoomba Regional Council, 2014).

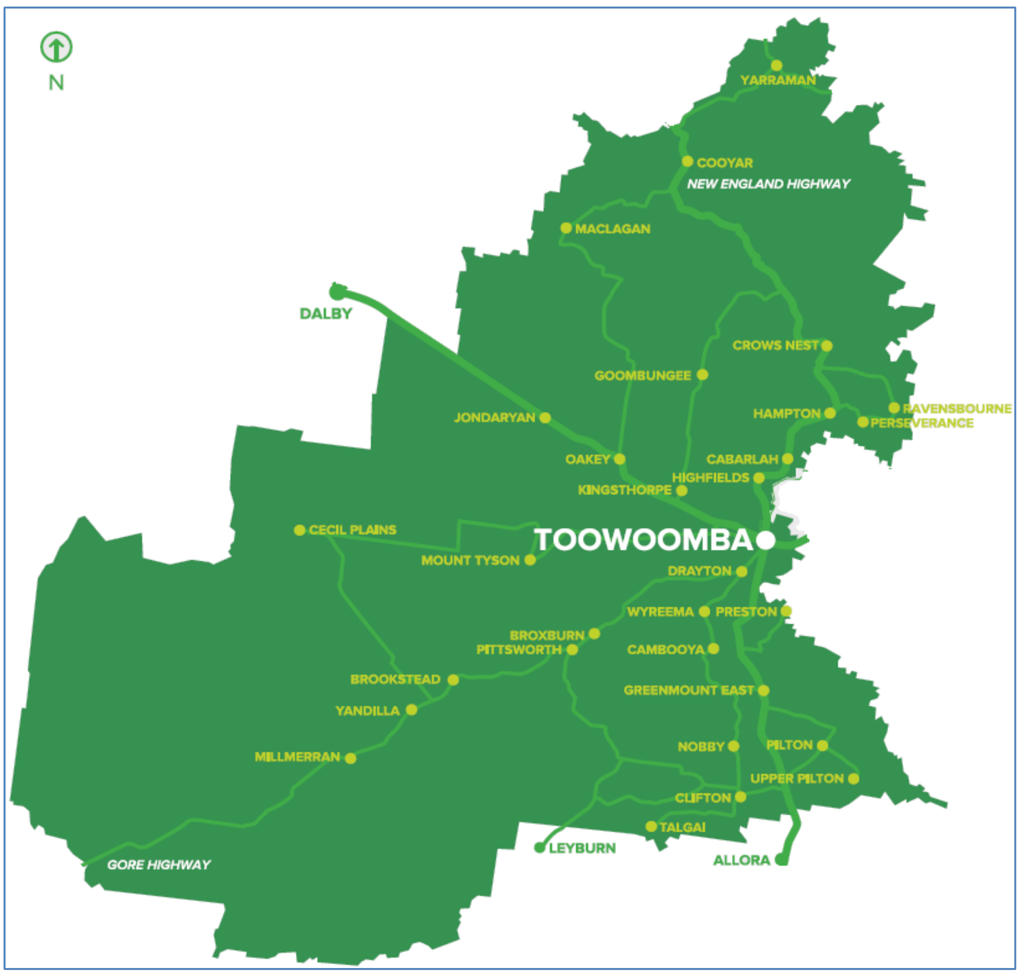

Figure 1.2: Toowoomba Regional Council Boundary Map (Toowoomba Regional Council, 2015)

TRC is the local government authority for the Toowoomba region and was formed by the amalgamation of Cambooya Shire Council, Clifton Shire Council, Crows Nest Shire Council, Jondaryan Shire Council, Millmerran Shire Council, Pittsworth Shire Council, Rosalie Shire Council and Toowoomba City Council in 2008. The amalgamation was recommended by the Local Government Review Commission Report of 2007 due to an amendment to the Local Government Act 1993 (Toowoomba Regional Council, n.d.).

1.2.2 Water Infrastructure Services Branch

TRC's organisational structure is comprised of five functional groups which deliver a range of municpal services to the Toowoomba Region (Toowoomba Regional Council, 2014):

- Finance & Business Strategy.
- Infrastructure Services.
- Environment & Community Services.
- Water & Waste Services.
- Planning & Development Services.

This dissertation focuses on assets maintained by the Water Infrastructure Services (WIS) branch which forms part of the Water & Waste Services group at TRC. WIS are responsible for the maintenance of Council's water and wastewater trunk and reticulation networks, dams, fixed plant and equipment and associated SCADA systems. WIS manages an asset portfolio with a gross value of approximately $1.7 billion which is almost evenly distributed between water and wastewater infrastructure (Toowoomba Regional Council, 2014).

Water Supply Network

WIS maintains water infrastructure within twenty different water supply schemes throughout the Toowoomba region. These schemes are Cambooya, Cecil Plains, Clifton, Crows Nest, Goombungee, Gowrie Junction, Greenmount, Haden, Highfields, Hodgson Vale, Kulpi, Millmerran, Nobby, Oakey, Pittsworth, Toowoomba Bulk, Toowoomba, Vale View, Wyreema and Yarraman. Most schemes are self-sustaining with their own raw water sources and treatment and distribution infrastructure, with the exception of Toowoomba Bulk and Kulpi which are both non-potable sources. Treated water is supplied to over 60,000 connected properties using the following infrastructure (Toowoomba Regional Council, 2014):

- 5 surface storages including dams and weirs totalling 135,719 ML.
- 7 water treatment plants capable of treating between 20 kilolitres per day to 68 mega litres per day.
- 50 water pump stations.
- 71 water reservoirs.
- 64 underground water supply systems.
- Over 1,850 kilometres of water distribution and trunk main network.

Wastewater Collection Network

WIS maintains wastewater infrastructure within thirteen different wastewater collection schemes throughout the Toowoomba region. These schemes are Cambooya Common Effluent Disposal (CED), Cecil Plains, Clifton, Crows Nest CED, Goombungee, Highfields, Millmerran, Oakey, Pittsworth, Toowoomba Expanded, Toowoomba Recycling, Wyreema and Yarraman. Most schemes are self-sustaining and have their own wastewater collection infrastructure, treatment facility and method of discharge. TRC collects and treats wastewater from over 115,000 connected population using the following infrastructure.

- 1 advanced water treatment plant.
- 7 wastewater treatment plants.
- 87 wastewater pump stations.
- Over 1,050 km wastewater mains.

1.2.3 Asset Criticality and Maintenance Management

Asset criticality is a rating assigned to an asset based on its consequence of failure. Asset criticality is generally assessed against criteria aligned to business objectives and risk policies. The purpose of an asset criticality analysis is to identify infrastructure that is critical to operation and to determine the appropriate maintenance activities required to reduce the overall Business Risk Exposure (BRE). In addition, criticality analysis has the potential to assist businesses in the following areas (Trilogics Technologies, Inc., 2005):

- Development of asset management programs, policies and emergency procedures.
- Identification of suitable preventative maintenance strategies such as Reliability Centred Maintenance and Predictive Maintenance.
- Identification of assets that require additional training to operate in order to prevent failures caused by human error.
- Prioritisation of asset maintenance and renewals.

Asset maintenance in WIS is weighted toward reactive activities and maintenance schedules are typically based on manufacturer recommendations. The prioritisation of asset maintenance and renewals are performed at the discretion of skilled technicians, with the exception of underground infrastructure which has a well-established condition assessment program used to generate long term renewals. Although this approach has proven satisfactory for numerous years, WIS has recognised the need to implement proven methodologies and introduce best management practices to optimise maintenance and make informed decisions.

An asset criticality analysis is the first step towards understanding the consequence of asset failure and the associated risk to WIS and TRC. In the early stages, an asset criticality analysis will identify crucial assets that require immediate development and implementation of maintenance strategies and performance monitoring plans. In the long term, asset criticality ratings will be combined with likelihood data to obtain overall risk ratings used to forecast renewals and associated budget requirements.

1.3 Research Objectives and Brief Methodology

The overarching aim of this research is to provide TRC with the methodology and tools required to perform an asset criticality analysis on its entire water and wastewater asset base. The main research objectives are outlined below:

- Creation and documentation of customised criticality framework and methodologies for water and wastewater infrastructure at TRC.
- Development of a partially automated criticality Microsoft Excel model designed to rank water and wastewater assets by criticality.
- Determine the criticality of all assets within the scope of the study using the partially automated criticality model and analyse the results.

The following methodology will be used to attain these objectives:

- Perform an extensive literature review on asset maintenance management and asset criticality.
- Identify and understand the major asset groups and asset types at TRC.
- Develop assessment criteria for each asset group in line with TRC risk policies.
- Prepare consequence of failures, failure effects, severity scores and criteria weightings for each asset group.
- Identify assets involved in the case study and perform site visits to collect and validate asset data.
- Perform the criticality analysis and examine the results to determine successes, issues and differences between expected and actual outputs.
- Adjust or calibrate to the criticality model based on results. Perform a secondary criticality analysis and use the results to identify critical infrastructure at TRC.
- Present the findings to an asset management group at TRC for assessment and review.

1.4 Dissertation Structure

This dissertation has been organised into several chapters which are briefly outlined below.

Chapter 1 – Introduction

A brief introduction to the dissertation and includes background information relating to TRC, water and wastewater infrastructure and asset criticality.

Chapter 2 – Literature Review

Literature reviews performed on asset maintenance and asset criticality which form the basis of this dissertation.

Chapter 3 – Criticality Analysis Methodology

The methodology used to create the asset criticality analysis framework and includes details relating to asset structures, failure modes and effects, consequence criteria, severity criteria, criteria weights, criticality ratings and criticality calculators.

Chapter 4 – Overview of Study Sites

A brief overview of the infrastructure analysed as part of this dissertation.

Chapter 5 – Application of Criticality Analysis

Explanation of the process used to perform the criticality analysis on the selected infrastructure.

Chapter 6 – Analysis of Results

Analysis and discussion of the results obtained from the criticality analysis.

Chapter 7 – Conclusions

Summary of the main findings and provides recommendations for improvement and further study.

Chapter 8 – Bibliography

A list of references used throughout the dissertation.

Chapter 2 – Literature Review

2.1 Introduction

This chapter provides a systematic review of existing literature to establish the requirement for criticality analysis within an organisation. In addition, this chapter will provide context around asset criticality by reviewing asset maintenance management and asset criticality analysis techniques.

2.2 Asset Maintenance Management

Asset maintenance is the process of performing any action during the life cycle of an asset to ensure it remains capable of performing the required function. The aim of asset maintenance is to reduce the rate of deterioration and failures to ensure that required levels of service are continually met (NAMS, 2011).

Rojas & Davis (2015) suggest that asset maintenance management is a continuous process improvement strategy for improving the availability, safety, reliability and longevity of physical assets. Similarly, Lee (2003) defines asset maintenance management as any management activity that determines maintenance objectives, priorities, strategies and responsibilities, and implements them by means such as maintenance planning, maintenance control and maintenance supervision.

This dissertation focuses on maintenance planning which is any action undertaken to prepare a maintenance plan such as asset identification, prioritisation and performance evaluation (Marquez, 2007). The aim of a maintenance plan is to transform organisational priorities into maintenance priorities by identifying critical operational objectives.

A criticality analysis can be used to determine the appropriate maintenance management methods to for a particular asset. Criticality analyses are discussed in detail in section 2.3 and maintenance management methods are discussed below.

2.2.1 Run-to-Failure Approach

Run-to-failure (RTF) management is a technique through which equipment or infrastructure is allowed to fail before any maintenance, repair or replacement action is undertaken. No effort is made to anticipate or prevent failure modes, so asset failure is simply allowed to occur before any action is undertaken (Moubray, 1997). RTF management is generally considered the most expensive form of maintenance due to significant down times associated with reactive work. Substantial costs may be incurred from increased repair times and labour costs as a result of slow reaction times, fault diagnostics, reactive task planning requirements, procurement processes and supplier delivery schedules (Mobley, 2002). However, Maintenance Assistance Incorporated (2015) suggests that a RTF approach can be the most cost effective method when employed in the appropriate scenario, such as:

- When the cost of regular maintenance exceeds the cost of repair after asset failure.
- When the consequence of failure or criticality is low.
- When a significant spares inventory is available.
- When regular maintenance would cause more disruption than simply repairing an asset when it fails, such as pipework that provides a continuous potable water supply to consumers.
- Where there is a high level of equipment or process redundancy.

In addition, Maintenance Assistance Incorporated (2015) suggests a RTF approach should be avoided in the following scenarios:

- When the consequence of failure or criticality is high.
- Where total maintenance costs would be reduced with a proactive approach.

2.2.2 Preventive Maintenance

Preventive maintenance (PM) aims to reduce the likelihood of unexpected asset failure by performing maintenance activities at a predetermined frequency. The frequency may be based on time intervals, meter intervals or other occurrences such as service hours or number of starts (Palmer, 2012). Rather than scheduling maintenance based on an observed issue, PM activities are performed based on the expectation that regular maintenance will reduce the chance of issues arising. Unlike the RTF method, PM uses a planned approach which reduces the costs associated with failure response times, fault diagnostics, reactive task planning, procurement processes and supplier delivery schedules. Planned maintenance has the advantage of being able to pre-organise all equipment, resources and costs. Furthermore, equipment can be shut down to coincide with off-peak production times to minimise service disruption (Maintenance Assistance Inc., 2015). The disadvantage of PM is the possibility of performing unnecessary repairs as there is a significant chance that equipment would not need to be rebuilt or refurbished within the prescribed maintenance frequency (Mobley, 2002). Maintenance Assistance Incorporated (2015) suggests PM is best employed when equipment has a critical operational function or has failure modes that can be prevented with regular maintenance. In addition, Maintenance Assistance Incorporated (2015) suggests PM should be avoided when equipment does not serve a critical function or has random failures that are unrelated to maintenance, such as electrical circuit boards.

2.2.3 Predictive Maintenance

Predictive maintenance (PdM) is a condition based PM program which uses techniques such as vibration monitoring, oil analysis and thermography to detect symptoms of serious equipment problems (Mobley, 2002). The aim of PdM is to forecast asset failure so PM activities can be performed just before failure occurs. PdM ensures the maintenance frequency is as low as possible to prevent failure without incurring the costs associated with over-maintenance. Although PdM is capable of optimising maintenance times to reduce costs, there is generally a high capital price required to purchase specialised monitoring equipment. In addition, a high skill level is usually required to accurately collect and interpret condition monitoring data. For these reasons, PdM should be employed when equipment has a critical operational function or has failure modes that can be economically predicted with regular monitoring (Maintenance Assistance Inc., 2015).

2.3 Asset Criticality Analysis

Asset criticality analysis is a technique used to rank assets based on the consequence of failure in conjunction with business objectives. The definition of a critical asset will vary between organisations but can loosely be defined as equipment whose failure has the highest consequence or potential impact on the goals of a business (Smith & Mobley, 2007).

Criticality analysis has great flexibility as it allows an organisation to assess the consequence of failure against criteria derived from their own core business values. By comparing all assets against the same set of criteria, a relative ranking can be established which enables a diverse range of assets to be compared on equal terms. The results of a criticality analysis are used to identify assets that require strict management which has the potential to assist businesses in the following areas (Trilogics Technologies, Inc., 2005):

- Development of asset management programs and policies.
- Identification of suitable preventative maintenance strategies such as Reliability Centred Maintenance and Predictive Maintenance.
- Prioritisation of asset maintenance and renewals.
- Identification of assets that require additional training to operate in order to prevent failures caused by human error.

The methodology to determine the criticality of an asset is reasonably static and is only subject to minor adaptations to suit varying business objectives or asset types. A typical approach to performing a detailed asset criticality analysis is outlined in Figure 2.1.

Figure 2.1: Example of a high-level approach to performing an asset criticality analysis (Atkinson, 1998)

However, there are numerous methods that enhance criticality analysis for alternative decision making. Marquez (2007) suggests these methods include the use of qualitative techniques, risk-based techniques and decision making techniques, all of which will be discussed further in the chapter.

The importance of an asset criticality analysis should not be underestimated. There are a number of case studies and examples where the failure of an asset has caused significant disruption to services. Hastings (2010) discussed a scenario that occurred at the Varanus Island gas terminal in Western Australia where a production unit failed and cut off one third of the state's gas supply. Similarly, a second scenario was observed where the gas supply to Melbourne was cut off for several weeks due to an equipment failure at the Longford gas plant. As a result, other sources of gas supply were expanded to reduce risk by introducing redundancy in the system (Hastings, 2010). It was unknown whether these organisations had a risk management system, but they may have been able to identify critical assets and prioritise maintenance and improvement plans if they had performed a criticality analysis prior to these incidents.

2.3.1 Consequence of Failure and Severity

Consequence of failure is a common factor in all methods of asset criticality analysis. Consequence is defined as the outcome of an event which affects objectives (Standards Australia, 2009). In the context of asset criticality analysis, the consequence of failure is the result or effect of an event, where the event happens to be the failure of an asset. Whereas, severity is defined as the significance or intensity of the consequence (Ayyub, 2003). In the context of asset criticality analysis, the severity is the amount of qualitative or quantitative damage that may be inflicted by the failure of an asset, usually represented on a numeric scale.

Consequence of failure and severity criteria are generally assessed against the mission, values or objectives of a business and can be adapted to suit any level of required detail. For example, Pschierer-Barnfather et al. (2011) suggested potential consequence categories and associated units of measure for an electrical network as shown in Table 2.1.

Table 2.1: Example of consequence criteria and potential units of measure (Pschierer-Barnfather, et al., 2011)

Consequence Criteria	**Units of Measure**
Network Performance	• Loss of system capacity (in MWh) • Number of SAIDI minutes
Safety	• Number of fatalities • Number of major injuries • Number of minor injuries
Financial	• Cost of repairs including collateral damage and site clean up • Cost of replacement
Environmental	• Volume of oil spilled • Volume of SF6 lost • Number of fires with significant smoke / pollution • Volume of waste created • Scale of disturbance (traffic / noise)
Additional Criteria including Reputation, Regulatory and Legal	• Exposure to bad media • Breach of licenses

The severity of asset failure is typically measured on a qualitative or quantitative scale ranging from low impact to high impact in terms of the consequence criteria units of measure. In the scenario outlined by Pschierer-Barnfather et al. (2011), a high severity score for the environmental criteria might be more than 1000 litres of oil spilled and a low severity score may be 0-10 litres of oil spilled. As mentioned previously, the consequence critieria and severity scores will vary between organisations due to different business objectives.

2.3.2 Qualitative Approach to Criticality Analysis

A qualitative approach to criticality relies on people's experience, opinions and observations to obtain information about critical assets. This type of information is typically extracted through interviews, questionnaires and focus groups targeted at asset operators and technicians. It avoids the need to retrieve processes and determine quantitative data such as failure rates and incident severity data (Marquez, 2007).

A qualitative approach is simpler and faster than a quantitative approach to implement, making it an appealing method for businesses with a large asset base and minimal resources. It provides a foundation open to future enhancement as it can be quantified at a later date as resources become available. In addition, a qualitative criticality analysis can be applied at any phase of the asset lifecycle and is particularly useful at the design phase where criticality can be pre-determined. However, the qualitative approach has notable limitations. For instance, the quality of results is heavily dependent on the people performing the analysis and can easily be swayed by personal bias making it hard to achieve consistent results (Anderson, 2010). However, the risks associated with qualitative analysis could be overcome by establishing detailed methodology, guidelines and criteria that are not subject to ambiguity or misinterpretation. This would provide an element of control to ensure results are consistent and useful for decision making.

2.3.3 Quantitative Approach to Criticality Analysis

A quantitative approach to criticality involves the analysis of asset failure frequency and incident severity data expressed in measurable quantities (Marquez, 2007). A criticality analysis can be quantified by calculating asset failure rates or expressing failure severity as a determinate figure such as monetary cost. This approach is rigorous, complex and time consuming, and is typically applied by mature organisations with generous resourcing and adequate historical asset failure data (Atkinson, 1998). Most organisations perform a qualitative criticality analysis to establish a basic criticality ranking and quantify the analysis with figures as time and resources permit. A quantitative element can be applied to any criticality analysis but is particularly prominent in risk-based methods as discussed in section 2.3.5. The major advantage to using a quantitative approach to criticality analysis is that results are explicit, consistent and credible. However, the reliability of a quantitative analysis depends on a combination of the quantity and quality of data used in calculations. It is important to establish methodologies for data collection to ensure data consistency and integrity to achieve reliable results.

2.3.4 Analytic Hierarchy Process Approach to Criticality Analysis

The Analytic Hierarchy Process (AHP) was a technique developed by T.L. Saaty to provide a simplified approach to complex, multi-criteria decision making. The purpose of the AHP is to deconstruct a problem into a hierarchy of sub-problems which can be more easily comprehended and evaluated (Bhushan & Rai, 2004). Decision makers can show the relationship of the goal, objectives, sub-objectives and alternatives in a hierarchy and perform comparative judgements to derive priorities of elements with respect to their parents (Marquez, 2007). Bhushan & Rai (2004) explain the AHP can be applied to a variety of decision making scenarios as outlined below:

- Choice – selection of one alternative from a set of alternatives.
- Prioritisation/evaluation – determining the relative merit of a set of alternatives.
- Resource allocation – finding the best combination of alternatives subject to a variety of constraints.
- Benchmarking – of processes or systems with other, known processes or systems.
- Quality management.

As mentioned above, the AHP is capable of evaluating decisions relating to prioritisation and evaluation which can be applied to the methodology to determine asset criticality. The following steps demonstrate one possible approach.

1. Define decision criteria in the form of a hierarchy of objectives as shown in Figure 2.2.

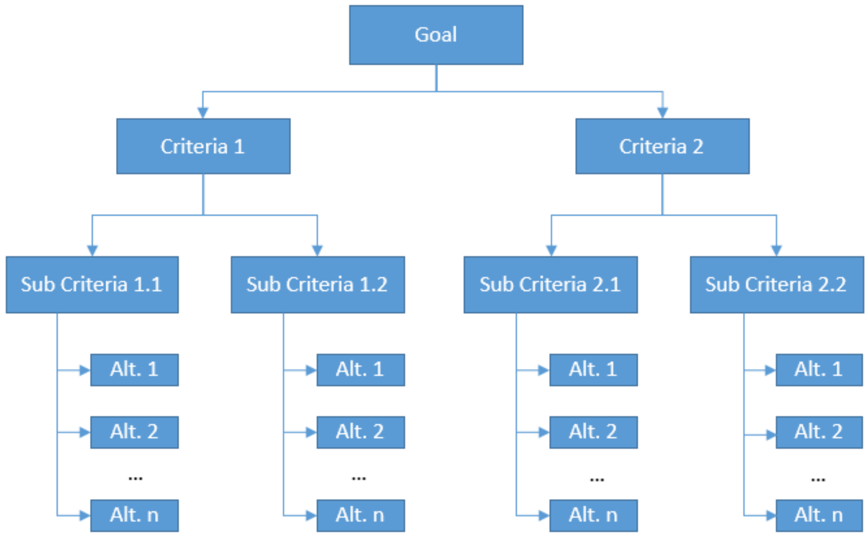

Figure 2.2: Example of decision hierarchy (Marquez, 2007)

In a criticality analysis for a service orientated or asset based organisation, the goal would be to prioritise assets according to their criticality. The criteria could potentially be based on business objectives or consequence criteria as explained in section 2.3.1 and may include information such as network performance, safety or financial categories. The alternatives could potentially be a list of assets such as a transformer, pump or motor. This is represented in Figure 2.3.

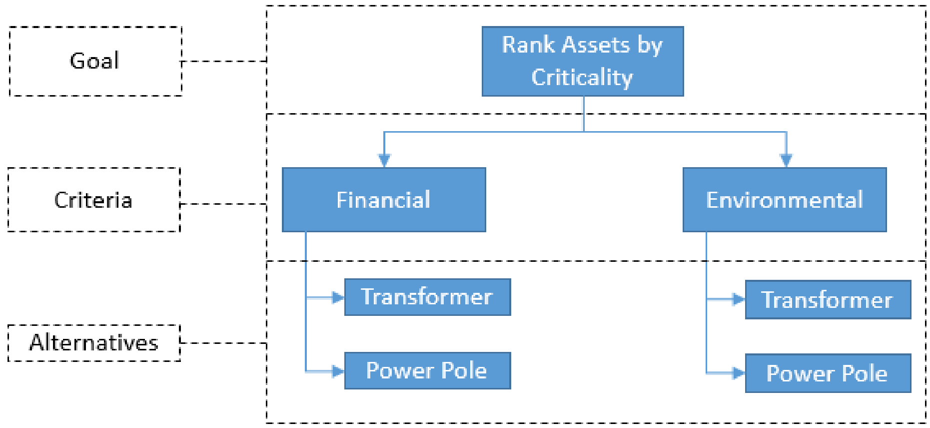

Figure 2.3: Example of potential goals, criteria and alternatives in a criticality analysis

The goal, criteria and alternatives must be identified and adequately defined to enhance transparency and allow informed decision making.

2. Define the scale for each criteria and evaluate alternatives (Marquez, 2007). The alternatives must be evaluated against the severity scale identified for each particular criteria. Using an electrical distribution network for example, a transformer might be given a high severity score for the environmental criteria as its failure has the potential to spill more than 1000 litres of oil. Whereas, a power pole would be given a low severity score as it does not have any environmental impact if it fails. A similar evaluation must be conducted for the same assets against the remaining criteria. In order to determine the relative value of the alternatives, the severity score for each individual asset must be represented as a ratio of the total score for each criteria. This is represented in equation 2.1 below:

$$Relative\ Value = \frac{C_i}{\sum_i C_i} \tag{2.1}$$

3. Quantify judgements on pair alternative criteria (Marquez, 2007). A judgement matrix created using pairwise comparisons of the criteria. Pairwise comparisons allow an analyst to focus on only two factors at one time which simplifies the decision making process (Bevilacqua & Braglia, 2000). A judgement scale is used to perform the comparison which allows an analyst to compare criteria by relative preference.

Table 2.2: Judgements ratio scale (Marquez, 2007)

Judgements	**Score**
Equal	1
	2
Weak	3
	4
Strong	5
	6
Very Strong	7
	8
Absolute	9

In terms of a criticality analysis, an example use of the judgement scale in pairwise comparisons would be to compare the two or more criteria with respect to each other. For example, financial criterion may be considered to be equally important as environmental criterion so it would receive a pairwise judgement score of 1. This analysis would be performed against all criteria and the result would form a $n \times n$ judgment matrix.

4. Determine criteria weighting and its consistency (Marquez, 2007). After the judgement matrix has been formed, criteria weights must be established by determining the normalized eigenvector of the matrix. In addition, a consistency rating must be calculated to examine the adequacy of the results as shown below:

$$I_R = \frac{CI}{RI} \tag{2.2}$$

where I_R = consistency rating (0.10 or less is considered acceptable);

RI = random average value of CI for n-by-n matrix;

$CI = \frac{\lambda_{max} - n}{n-1}$;

and λ_{max} = maximum eigenvalue;

n = number of factors.

5. Determine the final criticality hierarchy. This is done by multiplying the relative value for each alternative by the criterion weight, repeated for all criteria. The sum of these values for each alternative becomes the final criticality ranking, with the highest number becoming the most critical asset.

The AHP approach to criticality is great for complex decision making where multiple criteria and assets are involved. However, Bhushan & Rai (2004) indicate there have been major controversies over the life of the AHP method such as rank reversal. Rank reversal is where a criteria or alternative is removed or introduced, potentially causing the existing pairwise comparisons to change which may result in the shift of ranks (Bhushan & Rai, 2004). Rank reversal is possible in the AHP approach to criticality but depends on the level at which pairwise comparisons are made. In the approach discussed in steps 1 to 5 above, rank reversal would only affect the criteria if a new criterion was added. Rank reversal would not affect the alternatives as they are assessed against severity scores and do not use pairwise comparisons. Ultimately, the benefits of the AHP approach to asset criticality appear to outweigh the disadvantages.

2.3.5 Risk-based Approach to Criticality Analysis

Risk and risk management is an extremely broad subject that is prominent in many organisations. Risk is often expressed as a combination of the consequences of an event and the associated likelihood of occurrence (Standards Australia, 2009). The management of risk is the process of acknowledging its existence and implementing plans to eliminate, mitigate or reduce it (Hastings, 2010). The same approach to risk can be applied to the operation, maintenance or management of assets. Risk can be derived by combining the consequence of asset failure and the likelihood of occurrence. It is important to note that the consequence of failure element of asset risk is usually determined separately using a criticality analysis. This means risk can be determined by combining results from a criticality analysis with the likelihood of asset failure. By adding likelihood, results from a risk-based criticality analysis can be used to prioritise assets and align maintenance actions to business targets at any time (Marquez, 2007).

Like all risk-based analyses, a risk-based approach to criticality analysis can be quantitative or qualitative. Basically, risk-based criticality analysis can be quantified using actual consequence data or asset failure data. Quantitative data provides a more accurate view of consequence and likelihood as it is based on actual figures which cannot be influenced by bias or opinion. Figure 2.4 demonstrates a quantitative approach where likelihood is calculated numerically as probability and the consequence is calculated as a monetary value.

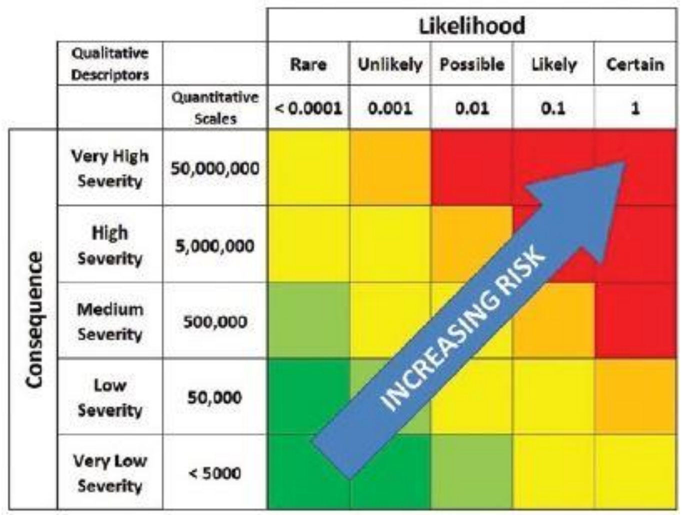

Figure 2.4: Quantitative risk-based approach to criticality (Webster, 2011)

As discussed previously, a risk-based approach is different to a normal criticality analysis due to the addition of likelihood. The results from a normal criticality analysis are used to rank assets in accordance with their consequence of failure which influences the selection and implementation of appropriate maintenance strategies. The criticality of an asset will not change with maintenance, condition or failure frequencies. Whereas, the results of a risk-based criticality analysis are used to prioritise assets that pose an immediate risk to the business. These results will change with maintenance, condition or failure frequency because the likelihood of failure criteria is altered. The benefit of this approach is that results provide an immediate snapshot of overall business risk which can assist to prioritise maintenance work orders and target costs to areas of immediate priority. Furthermore, this approach can be used to provide a relative context to a failure based on the individual circumstance of each asset (Pschierer-Barnfather, et al., 2011).

2.3.6 Areas of Controversy

After performing an extensive literature review, it is evident that controversy exists around the definition of an asset criticality analysis. The most consistent definition of an asset criticality analysis revolves around the assessment of asset failure consequences and severity as suggested by NAMS (2011), Pschierer-Barnfather et al. (2011) and Chandima Ratnayake (2014). However, other sources such as Jaderi et al. (2014), Sondalini (2012) and Seifeddine (2003) indicate that asset criticality involves the addition of risk-based elements such as failure frequency. Based on the quantity and quality of literature, the former definition is the most widely accepted and is promoted by sources ranging from international standards to journal articles. These sources indicate that risk-based analyses are an additional enhancement to a normal criticality analysis which focusses on consequence and severity of asset failure. The lack of clarity is interesting and it appears the ambiguity is potentially fuelled by the following reasons:

- Lack of consistent definition, methodology and standards.
- Utilisation by numerous organisations who adapt the technique to suit business objectives which eventually leads to redistribution and further editing.
- Lack of awareness that criticality can be applied as a standalone assessment without the use of reliability or risk techniques.

2.4 Chapter Summary

Chapter 2 systematically reviewed literature and obtained background information relating to maintenance management and asset criticality.

A review of maintenance management literature suggests that RTF is the fastest method to implement as it does not require significant planning. However, RTF has the potential to be the most expensive form of maintenance when used ineffectively and should generally be employed when the consequence of failure is low or a high level of process redundancy is available. On the other hand, PM uses a planned approach and can be time consuming to implement compared to RTF. PM has the advantage of being able to pre-organise equipment and resources to reduce the overall cost associated with reactive task planning. PM frequencies can be optimised through the use of PdM which uses an analytical approach to forecast asset failure. PdM has the potential to reduce the costs associated with over-maintenance, but it can be expensive to implement due the high capital costs required to collect appropriate data.

A review of criticality analysis literature suggests there are limitations to each method of criticality analysis. For example, a qualitative approach is subjective to the bias, opinion or exaggeration of the analyst which can lead to inaccurate or inconsistent results. Whereas, a quantitative approach has a high degree of accuracy but is data intensive and potentially time consuming to perform. The approach selected is ultimately governed by the maturity of the organisation and their available data and resources.

Chapter 3 – Criticality Analysis Methodology

3.1 Introduction

An asset criticality analysis cannot be undertaken without first developing the framework and methodology required to assess water and wastewater infrastructure. Criticality assessment criteria were established to consistently measure the severity of asset failure in line with corporate consequence criteria. A number of actions were performed before the criticality analysis could be undertaken, including:

- Identification of critical asset groups and sub-groups specific to WIS.
- Identification of asset failure modes and typical failure effects for water and wastewater infrastructure.
- Development of consequence criteria in line with TRC's Enterprise Risk Management Framework Policy.
- Development of severity scores to measure the impact of asset failure.
- Development of weightings to emphasise the importance of specific criteria and their influence on asset criticality.
- Creation of a semi-automated calculator based on the assessment criteria, severity scores and weightings to process large volumes of asset data and generate a criticality rating.

3.2 Asset Categorisation

Asset categorisation is where assets are grouped based on similarities including attributes or functions. WIS categorises assets into classifications, groups, sub-groups and types for various asset management purposes.

3.2.1 Asset Classifications and Groups

WIS have separated water and wastewater into separate classifications due to the distinct difference between water supply networks and wastewater collection networks. Asset groups were created by grouping assets with similar characteristics or functions within a network. A representation of WIS asset classifications and groups is shown in Figure 3.1.

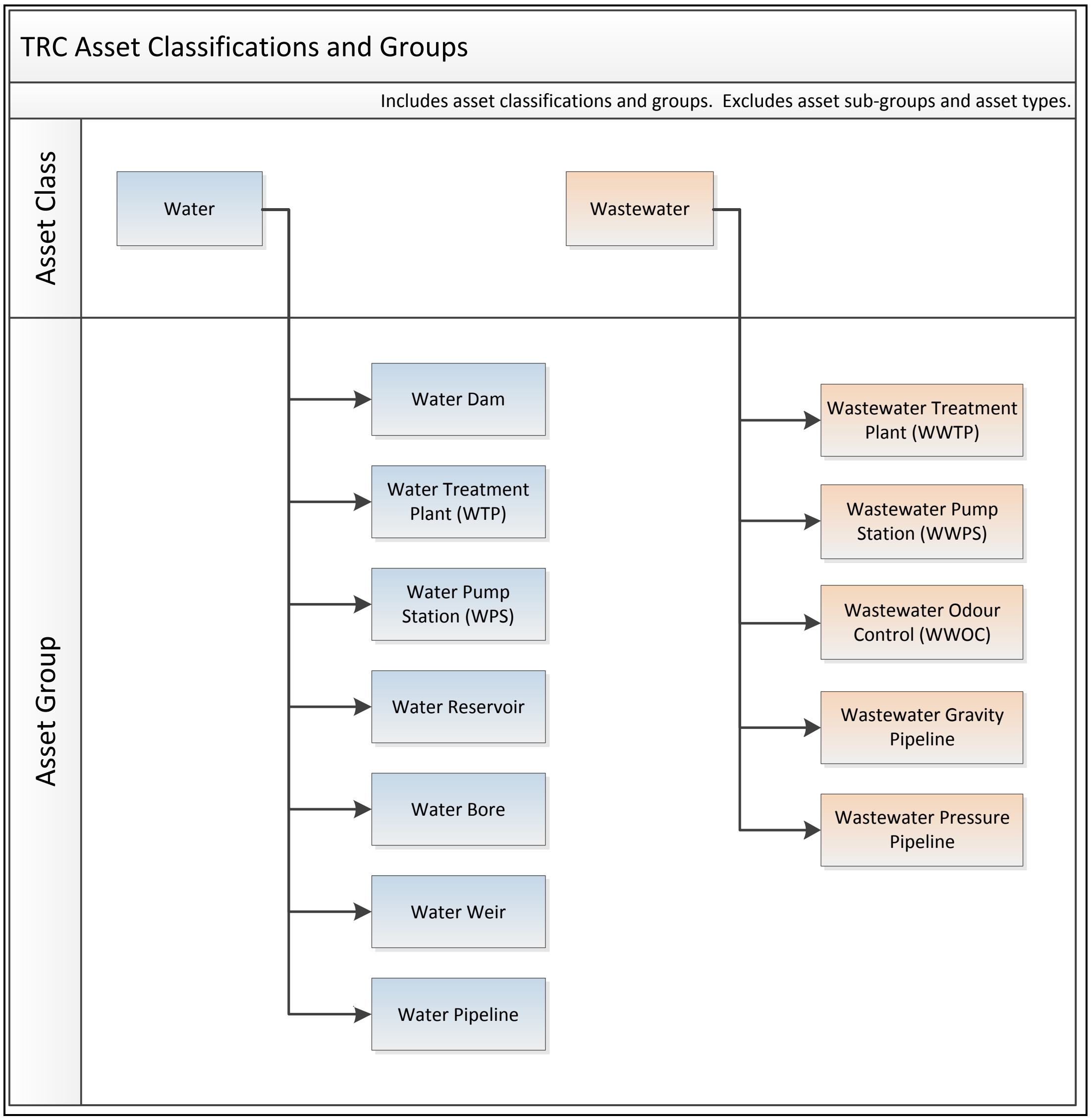

Figure 3.1: Representation of WIS asset classifications and groups

Dams and weirs were excluded from this dissertation as they are already governed by strict regulations and legislation. Wastewater Odour Control facilities were excluded from this analysis as WIS does not currently maintain any standalone odour control facilities.

In addition, it is important to note that asset groups are also broken into “active” and “passive” assets. Active assets include above ground infrastructure such as dams, treatment plants, pump stations, reservoirs, bores and weirs. Passive assets include underground infrastructure such as pipelines and associated fittings and manholes.

3.2.2 Asset Sub-Groups and Types

Asset sub-groups and asset types were developed due to the requirement to collect detailed technical data about assets. Sub-groups and types were established to group similar assets at a more refined level for maintenance, condition assessments, useful life calculations and reporting purposes. Due to time constraints, this dissertation will focus on analysing a selected portion of asset types as indicated in Figure 3.2 below.

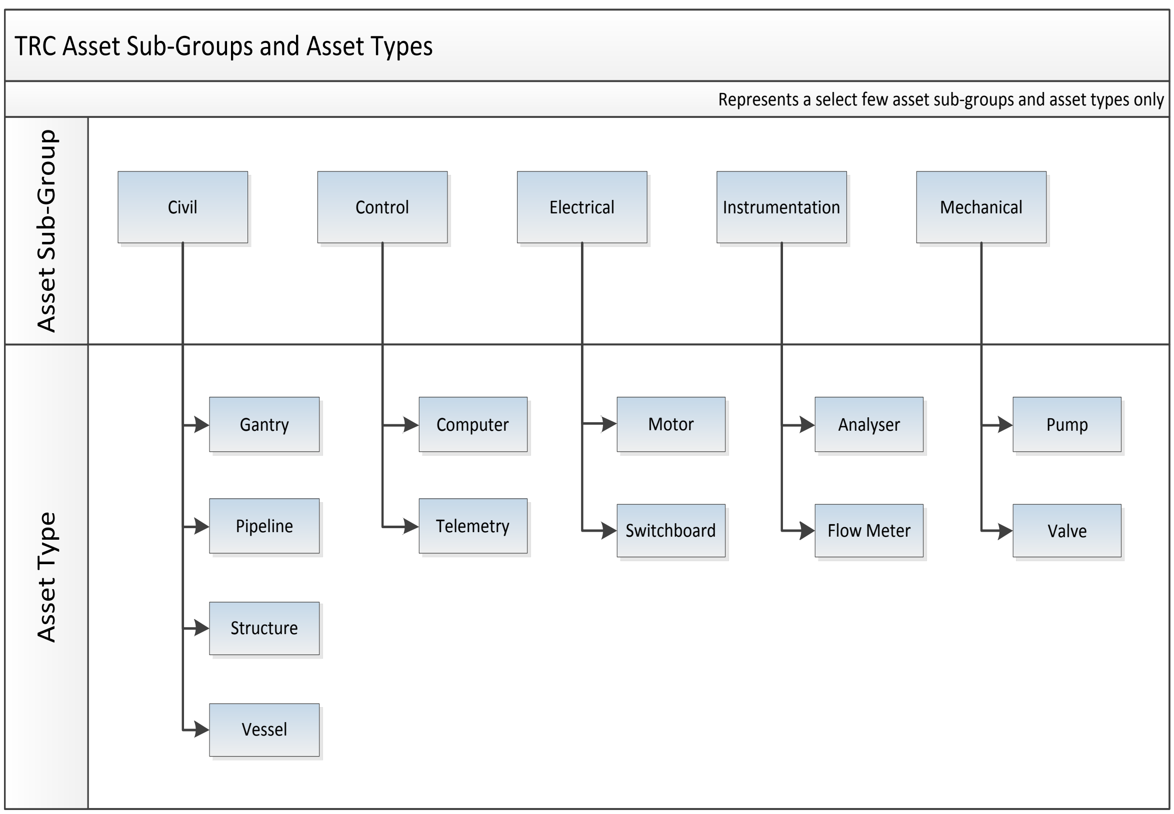

Figure 3.2: Representation of TRC asset sub-groups and asset types analysed in this dissertation

3.3 Failure Mode and Effect Analysis

Failure Mode and Effect Analysis (FMEA) is recognised as an essential tool used in Reliability Centred Maintenance and should be undertaken before criticality assessment criteria is constructed. FMEA is used to identify asset failure modes, failure causes, failure frequencies and effects that may occur as a result (Marquez, 2007).

A very basic adaptation to a FMEA was purposely undertaken to reduce the impact on TRC resources. Although the analysis was not as thorough as a traditional FMEA, it provided enough detail to produce a list of basic failure modes for water and wastewater network infrastructure. The failure effects were then identified and used to influence consequence categories and factors as discussed in section 3.4.2 and 3.4.3.

It should be noted that the resulting effects were not impacted by the level at which the FMEA was undertaken. For example, a pipe can experience specific failure modes including longitudinal cracking, circumferential cracking and wall perforation. Each failure mode would result in overflow, loss of supply and injuries. However, the same effects would be experienced if the failure mode was at a higher level such as structural failure.

Similarly, a pump can experience imbalance, misalignment, looseness, rub, bearing defects and structural failure. Depending on the situation, each failure mode could potentially result in overflow or leakage, loss of supply, biological contamination or injuries. Again, the same effects would be experienced if the failure mode was at a higher level such as pump equipment failure.

3.3.1 Water Failure Modes and Effects

The results of the basic FMEA undertaken on water assets are displayed in Table 3.1 on the following page.

Table 3.1: Water asset group high level failure modes and effects

Asset Group	Possible Failure Modes	Possible Failure Effects
WTP	• Mechanical equipment failure • Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure	• Overflows • Loss of supply • Biological contamination • Injuries or illness • Chemical contamination
WPS	• Pump equipment failure • Motor equipment failure • Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure	• Overflows • Loss of supply • Biological contamination • Injuries or illness • Chemical contamination
Water Reservoir	• Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure	• Overflows • Loss of supply • Biological contamination • Injuries or illness • Chemical contamination
Water Bore	• Pump equipment failure • Motor equipment failure • Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure	• Overflows • Loss of supply • Biological contamination • Infiltration • Injuries or illness • Chemical contamination
Water Pipeline	• Corrosion • Structural failure • Valve failures • Under-capacity	• Overflows • Loss of supply • Biological contamination • Injuries or illness • Chemical contamination

As shown in Table 3.1, the common failure effects for all water asset groups were treated water overflows, loss of supply, biological contamination, chemical contamination and injuries or illness. Water Bore was the only asset group which differed having the additional effect of aquifer infiltration. The consequence of the failure effects were assessed and incorporated into the development of consequence categories and factors in section 3.4.2.

3.3.2 Wastewater Failure Modes and Effects

The results of the FMEA undertaken on wastewater asset groups are displayed in Table 3.2.

Table 3.2: Wastewater asset group high level failure modes and effects

Asset Group	Possible Failure Modes	Possible Failure Effects
WWTP	• Mechanical equipment failure • Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure	• Sanitary sewer overflow • Injuries or illness • Environmental contamination
WWPS	• Pump equipment failure • Motor equipment failure • Electrical equipment failure (including power loss) • Control system equipment failure • Instrumentation failure • Civil or structural failure • Under-capacity	• Sanitary sewer overflow • Injuries or illness • Environmental contamination
Wastewater Pipelines	• Corrosion • Structural failure (including cracks, breaks, deformation and fractures) • Blockages • Washouts • Under-capacity • Infiltration	• Sanitary sewer overflow • Injuries or illness • Environmental contamination

As shown in Table 3.2, the common failure effects for all wastewater asset groups were sanitary sewer overflows, injuries or illness and environmental contamination. The consequence of the failure effects were assessed and contributed to the development of consequence categories and factors in section 3.4.3.

3.4 Consequence Criteria

The development of consequence criteria was essential before an asset criticality analysis could be undertaken. Consequence criteria provided a consistent foundation for assets to be compared so a relative criticality ranking could be generated. The following actions had to occur to develop the criteria:

- Review of TRC Enterprise Risk Management policies with a focus on consequence of failure criteria.

- Breakdown of high level enterprise consequence categories into manageable components including failure consequence categories and consequence factors.

- Consideration of how consequence factors could be measured to assist the development of severity criteria in section 3.6.

3.4.1 Enterprise Consequence Categories

There needed to be alignment between enterprise risk criteria and asset criticality criteria to ensure consequences were assessed in accordance with the interests of the organisation. This approach was consistent with Standards Australia (2014) which states that "the approach used for managing risk in asset management is aligned with the organisation's approach for managing risk". TRC's Enterprise Risk Management and Framework Policy (Policy 2.18) documents the high-level consequence categories deemed critical to business objectives. Table 3.3 described the enterprise consequence categories and examined whether they are suitable for use in a criticality analysis.

Table 3.3: Suitability assessment of enterprise consequence categories

Enterprise Consequence Categories	**Enterprise Consequence Category Description**	**Suitability for Asset Criticality Analysis**	
Financial	Considers the impact on TRC's overall budget.	✓	The financial impacts of asset failure can be measured on a smaller scale, so it was considered in the criticality analysis.
People	Considers the impact on TRC's workforce and the consequential effects on service delivery.	✗	Enterprise criteria relates to loss of TRC workforce which cannot be considered when assessing asset criticality. Therefore, this criterion was excluded from the analysis.
Reputation	Considers the impact on TRC's reputation due to media attention and external investigations.	✓	The impacts of asset failure on TRC's reputation can be measured, therefore it was considered in the criticality analysis.
Environmental	Considers the impact on the natural environment.	✓	The impacts of asset failure on the environment can be measured, so it was considered in the criticality analysis.
Corporate Strategy	Considers the impact on TRC's ability to achieve objectives outlined in the corporate plan.	✗	The benefits of an asset criticality analysis contribute to the overall corporate plan. The impact on the corporate plan cannot be assessed at an asset failure level, so it was excluded from the analysis.
Service Delivery	Considers the impact on TRC's ability to meet customer expectations.	✓	The impacts of asset failure on service delivery can be measured, so it was considered in the criticality analysis.
Compliance	Considers the impact on TRC due to non-compliance.	✓	The impacts of asset failure on compliance can be measured, so it was considered in the criticality analysis.

As shown in Table 3.3, the People and Corporate Strategy criteria were excluded from the criticality analysis. The failure of an asset has no major effect on either criteria and their exclusion would have no impact the final results. Alternatively, these consequences could be equally applied to all assets therefore having no relative impact on the assessment.

3.4.2 Water Consequence Factors

An asset criticality assessment evaluates assets against detailed criteria in order to produce results with a high level of granularity. The enterprise consequence categories displayed in Table 3.3 were very broad and had to be dissected into smaller components. Each component was aligned to the enterprise consequence categories to ensure failure consequences were assessed in accordance with corporate interests. The failure consequence categories were established by considering the impacts of failure effects identified in section 3.3.1 and are shown below.

Table 3.4: Water failure consequence categories aligned with enterprise consequence categories

Enterprise Consequence Categories	**Failure Consequence Categories**	**Considerations**
Financial	Repair Costs	Consider costs to reinstate the asset which may include direct replacement costs, accessibility issues and traffic management requirements.
	Third Party Losses	Consider third party damage incurred due to asset failure which may be influenced by asset location, proximity to third party infrastructure and quantity of product discharged.
Reputation	Media	Consider media coverage which may be influenced by asset location and quantity of product discharged.
	Public Health & Safety	Consider effects on public health and safety which may be influenced by asset location and quantity of product discharged.
Environmental	Environmental Damage	Consider potential damage to the environment which may be influenced by the quantity of product discharged and the proximity to sensitive environmental areas.
Service Delivery	Service Delivery	Consider impacts to service delivery due to asset failure which may be influenced by the number of people affected, the type of people affected and the resilience of the water supply network.
Compliance	Compliance	Consider potential compliance breaches as a result of asset failure which may be influenced by quantity of product discharged, proximity to sensitive environmental areas and the quality of product and services provided to customers.

Based on the considerations discussed in Table 3.4, it was possible to further dissect the failure consequence categories into consequence factors. This was performed to provide additional granularity to results by analysing consequences in more detail.

Table 3.5: Water consequence factors aligned with failure consequence categories

Failure Consequence Categories	**Consequence Factors**	**Explanation**
Repair Costs	Asset Cost	The asset cost influences the total repair or replacement cost.
	Difficulty of Repair	Represents the length of time required to repair or replace the asset which influences the total repair or replacement cost.
Third Party Losses	Location	Location affects whether asset failure will cause damage to private property.
	Volume Discharged	The volume discharged influences the extent of third party damage.
Media	Media Exposure	The amount of media exposure obtained as a result of asset failure. Media exposure is influenced by a number of factors including location, volume discharged, customer type and number of customers affected.
Public Health & Safety	Potential for Injury	The potential for members of the public to become injured as a result of asset failure.
Environmental Damage	Volume Discharged	The volume discharged influences the severity of environmental damage.
	Proximity to Sensitive Area	Asset failure has the potential to damage the environment, particularly when located near sensitive areas including waterways and landslide zones.
Service Delivery	Equivalent Population Affected	Indication of the number of people potentially affected by asset failure if service was lost.
	Customer Type	The type of customers affected by asset failure including residential areas, community areas, industrial zones, dialysis patients, hospitals, and so on.
	Failure Tolerance	Ability of the network to provide a continuous water supply to customers without the use of the failed asset.
Compliance	Statutory Requirements	Potential licence breaches, investigations or non-compliance as a result of asset failure.

3.4.3 Wastewater Consequence Factors

As discussed in section 3.4.2, an asset criticality assessment must evaluate assets against detailed criteria in order to produce results with a high level of granularity. The failure consequence categories developed for wastewater network groups were aligned to the enterprise consequence categories as shown in Table 3.6.

Table 3.6: Wastewater failure consequence categories aligned with enterprise consequence categories

Enterprise Consequence Categories	Failure Consequence Categories	Considerations
Financial	Repair Costs	Consider costs to reinstate the asset which may include direct replacement costs, accessibility issues and traffic management requirements.
	Third Party Losses	Consider third party damage incurred due to asset failure which may be influenced by asset location, proximity to third party infrastructure and quantity of product discharged.
Reputation	Media Exposure	Consider media coverage which may be influenced by asset location and quantity of product discharged.
	Public Health & Safety	Consider effects on public health and safety which may be influenced by asset location and quantity of product discharged.
Environmental	Environmental Damage	Consider potential damage to the environment which may be influenced by the quantity of product discharged and the proximity to sensitive environmental areas.
Service Delivery	Service Delivery	Consider impacts to service delivery due to asset failure which may be influenced by the number of people affected, the type of people affected and the capacity for product storage.
Compliance	Compliance	Consider potential compliance breaches as a result of asset failure which may be influenced by quantity of product discharged and the proximity to sensitive environmental areas.

Based on the considerations discussed in Table 3.6, it was possible to further dissect the failure consequence categories into consequence factors. This was performed to provide additional granularity to results by analysing consequences in more detail.

Table 3.7: Wastewater consequence factors aligned with failure consequence categories

Failure Consequence Categories	Consequence Factors	Explanation
Repair Costs	Asset Cost	The asset cost influences the total repair or replacement cost.
	Difficulty of Repair	Represents the length of time required to repair or replace the asset which influences the total repair or replacement cost.
Third Party Losses	Location	Location affects whether asset failure will cause damage to private property.
	Volume Discharged	The volume discharged influences the extent of third party damage.
Media Exposure	Location	Location affects the potential exposure to the public. For example, a pipe failure in the CBD will have more exposure than a rural area which increases the consequence of media attention.
	Volume Discharged	The volume discharged can make the failure appear more severe which can attract negative media attention.

Failure Consequence Categories	Consequence Factors	Explanation
Public Health & Safety	Potential for Injury	The potential for members of the public to become sick or injured as a result of asset failure.
Environmental Damage	Volume discharged	The volume discharged influences the severity of environmental damage.
	Proximity to Sensitive Area	Asset failure has the potential to damage the environment, particularly when located near sensitive areas including waterways and landslide zones.
Service Delivery	Equivalent Population Affected	The equivalent population affected represents the impact on wastewater collection services.
	Customer Type	The type of customers affected by asset failure including residential areas, community areas, industrial zones, hospitals, and so on.
	Failure Tolerance	Ability of the network to prevent impact due to asset failure.
Compliance	Statutory Requirements	Potential licence breaches, investigations or non-compliance as a result of asset failure.

3.5 Available Data Sources

The availability and quality of data dictated what information was included in the severity criteria and associated guidelines. TRC maintain a variety of databases which enabled data to be examined from the following sources:

- TechnologyOne Enterprise Asset Management (EAM) module.
- Esri ArcGIS Geographic Information System (GIS).
- Citect SCADA Supervisory Control and Data Acquisition (SCADA) system.
- WaterGEMS water distribution modelling and management software.
- Knowledge from experienced engineers, technicians and operators.

Each source had advantages and disadvantages in data quality, availability and impact on resources to analyse. A brief description of each data source is contained in subsequent sections.

3.5.1 TechnologyOne

TechnologyOne is the primary financial, works management and asset management system for TRC. The EAM module contains information and history pertaining to operational works, capital works and assets. A large amount of asset data is captured including attributes, work histories and financial information. For the purpose of a criticality analysis, TechnologyOne was mainly used to obtain financial asset information, attribute data and failure data.

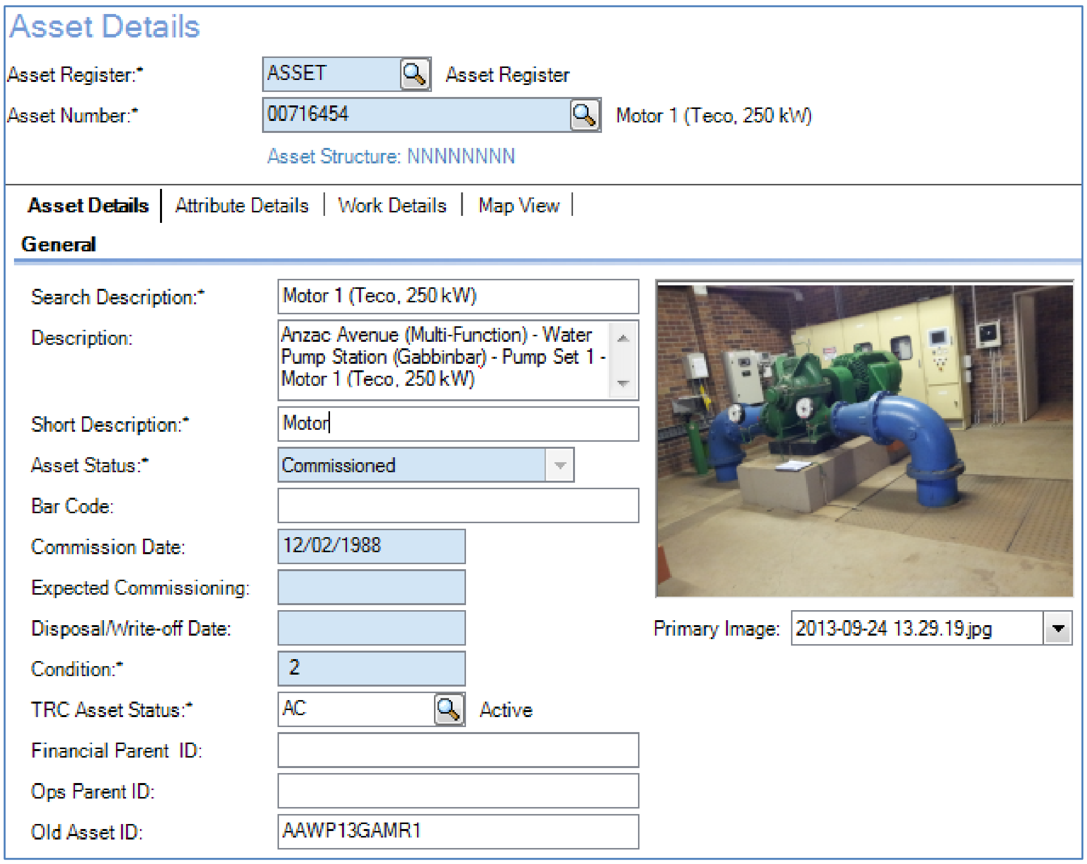

Figure 3.3: Example of TechnologyOne asset screen display

3.5.2 Esri ArcGIS

ArcGIS is a powerful tool used by TRC to record information, execute spatial analyses, create maps and locate assets. ArcGIS has the ability to perform a multitude of other functions, but its ability to perform spatial queries on assets was the main reason for its use in a criticality analysis.

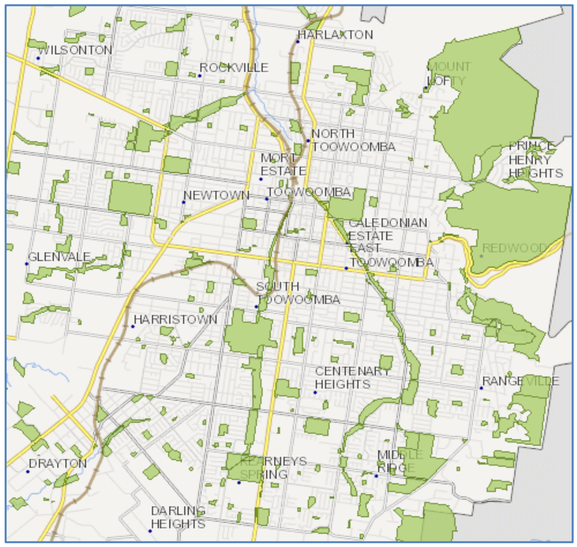

Figure 3.4: Example screenshot of TRC ArcGIS mapping software

3.5.3 Citect SCADA

Citect SCADA is a control system used by TRC to interact with various water and wastewater equipment. SCADA interprets and processes raw data gathered from field Input/Output devices and presents it on an interactive dashboard installed on desktop computers. The dashboard allows operators to remotely control equipment and monitor its performance. For the purpose of a criticality analysis, SCADA was used to obtain historical flow data on various assets. In addition, information from SCADA was fed into hydraulic models for analysis.

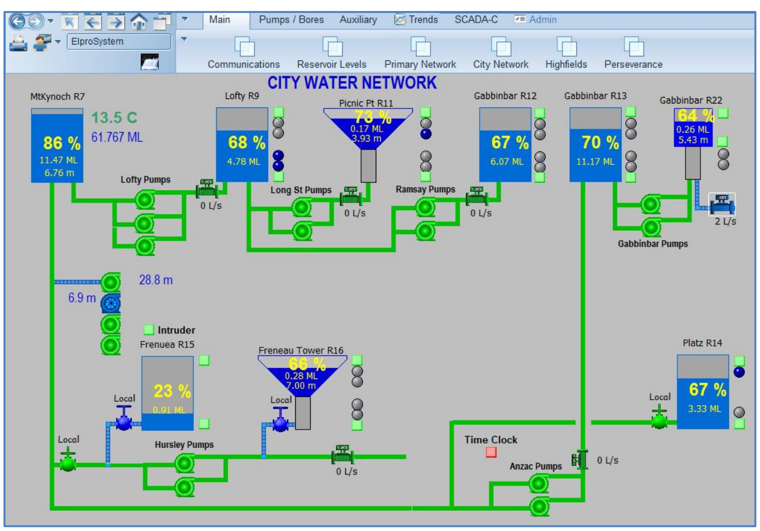

Figure 3.5: Example screenshot of water supply network SCADA interface

3.5.4 WaterGEMS

WaterGEMS is hydraulic modelling software used by TRC to plan, design and simulate the operation of water supply networks. WaterGEMS is capable of modelling system performance under varying conditions by altering demands, changing flows and shutting down network components such as pumps and valves. For the criticality analysis, information was obtained from WaterGEMS wherever possible as it contained accurate quantifiable data. WaterGEMS was mainly used to simulate effects on service delivery due to the impact of pipe breakages.

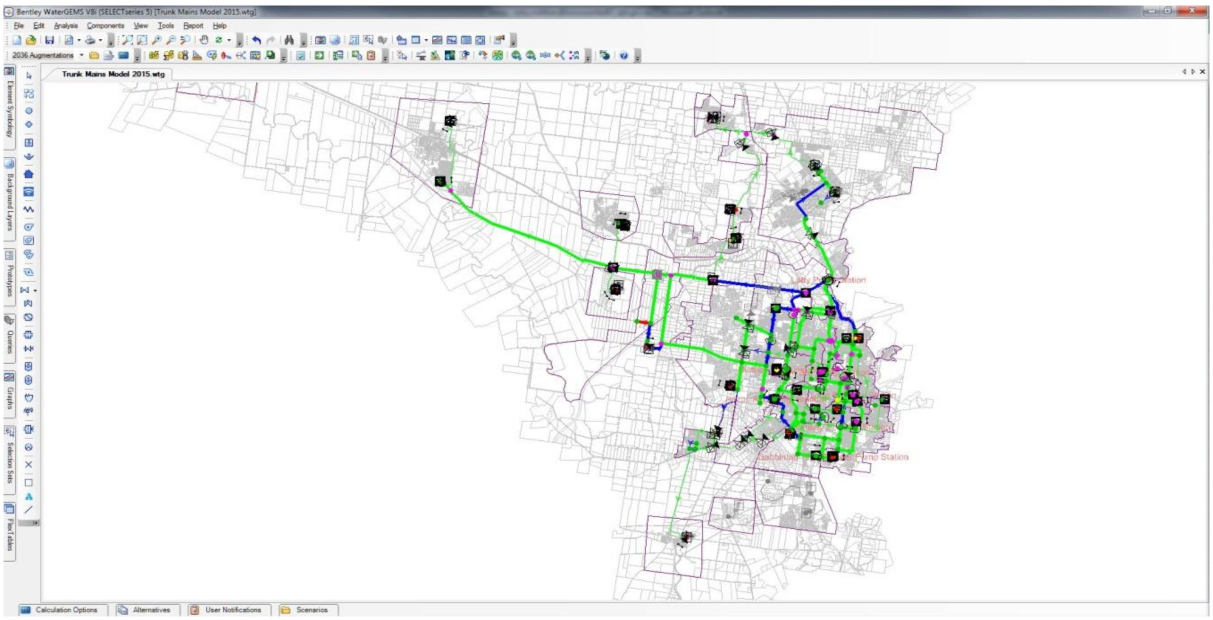

Figure 3.6: Example screenshot of WaterGEMS software interface

3.5.5 TRC Knowledge and Experience

Staff experience is one of the most important sources of information for a criticality analysis. Water and wastewater infrastructure has been operated by skilled technical, maintenance and operational staff for numerous years and their knowledge is invaluable. However, a majority of the knowledge has not been documented, so interviews had to be conducted to obtain relevant information.

3.6 Severity Criteria

Severity criteria must be established to measure the intensity of consequences experienced as a result of asset failure. In order to develop the severity criteria, the following actions had to occur:

- Assessment of data quality and availability to identify how the consequence factors could be measured and whether a qualitative or quantitative analysis was required.

- Development of a scale to record the severity of asset failure for each consequence factor.

- Development of guidelines to explain what each part of the scale represents to assist users to apply the severity criteria in a consistent manner.

3.6.1 Severity Scale

Ayyub (2003) suggested a numeric scale be used to measure the amount of qualitative or quantitative damage that could be inflicted by the failure of an asset. A five-point scale was selected for all consequence factors in order to align with the TRC Enterprise Risk Policy. The numeric TRC Enterprise Risk severity scale is explained in Table 3.8.

Table 3.8: TRC Enterprise Risk Policy severity scale

Enterprise Severity Score	Severity Score Description
1	Insignificant
2	Minor
3	Moderate
4	Major
5	Catastrophic

The severity scores and description did not provide enough information to produce highly detailed results. Severity criteria and guidelines had to be established and are discussed in section 3.6.23.6.2 Severity Scores and Guidelines.

3.6.2 Severity Scores and Guidelines

A semi-quantitative approach was used to develop the severity criteria and guidelines for improved accuracy and granularity. This method was used due to the availability of quantitative data from WaterGEMS, SCADA and GIS.

The severity scores and associated criteria were developed through consultation with a team of WIS engineers, managers and technical officers. The team developed the criteria by considering what impact would be deemed as insignificant, minor, moderate, major or catastrophic for each consequence factor.

The consequence factors were reviewed in isolation which allowed the team to focus on scores that truly warranted a catastrophic rating for each factor. This approach was necessary to ensure that severity scores were developed to suit each consequence factor without being influenced by other criteria. Weightings were then developed to ensure important criteria or more severe criteria received a higher score, as discussed in section 3.7. The severity criteria and guidelines for water assets are located in Table 3.9 on the following page.

Table 3.9: Water severity criteria and guidelines

Consequence Factors	Score	Severity Criteria	Guidelines for Passive	Guidelines for Active
		Financial – Repair Costs		
Asset Cost	1 2 3 4 5	Less than $5,000 $5,000 to $25,000 $25,000 to $75,000 $75,000 to $150,000 More than $150,000	Use pipe segment lengths and schedule of rates to estimate asset cost. Maximum replacement length is 250m.	Use asset sizes, failure modes, historical failures and TRC knowledge to estimate the maximum asset cost.
Difficulty of Repair	1 2 3 4 5	Less than 1 day 1 to 3 days 3 to 7 days 7 to 14 days More than 14 days	Consider location, accessibility and pipe diameters to estimate repair difficulty.	Consider location, accessibility and asset sizes to estimate repair difficulty.
		Financial – Third Party Losses		
Location	1 2 3 4 5	NI, R, EC, LD, SP, SC, OS RR, DC, T, EI, LC, CF OS, SR, LII, LDR, MU MII, LDMR PC, MC, HII	Refer to zone classifications in Table 3.11.	Refer to zone classifications in Table 3.11.
Volume Discharged	1 2 3 4 5	Less than 20 kL 20 to 50 kL 50 to 250 kL 250 to 1,000 kL More than 1,000 kL	Where possible, use a hydraulic model to simulate a pipe break open to atmosphere and consider response times, e.g. 1 hour.	Where possible, use a hydraulic model to simulate a pipe break open to atmosphere and consider response times.
		Reputation – Media		
Media Exposure	1 2 3 4 5	Insignificant Coverage Local Media Coverage Broad Coverage National Coverage International Coverage	Consider location, volume discharged and effects on service delivery.	Consider location, volume discharged and effects on service delivery.
		Reputation – Public Health & Safety		
Potential for Injury/Illness	1 2 3 4 5	No Injury or Near Miss First Aid Treatment Medical Treatment Hospitalisation Death or Disability	Consider location, pipe diameter, and potential volumes discharged.	Consider location, potential volumes discharged and asset type.
		Environmental – Environmental Damage		
Volume Discharged	1 2 3 4 5	Less than 250 kL 250 to 1000 kL 1000 to 2000 kL 2000 to 5,000 kL More than 5,000 kL	Where possible, use a hydraulic model to simulate a pipe break open to atmosphere and consider repair duration.	Mainly applies to passive infrastructure. However, pipes and tanks within active water sites can be treated in the same way.

Consequence Factors	Score	Severity Criteria	Guidelines for Passive	Guidelines for Active
Proximity to Sensitive Area	1 2 3 4 5	Insignificant Minor Moderate Major Within sensitive zone	Where possible, use GIS to identify proximity to waterways and landslip zones.	Where possible, use GIS to identify proximity to waterways and landslip zones.
Service Delivery – Service Delivery				
Equivalent Population (EP) Affected	1 2 3 4 5	Less than 100 people 100 to 1,000 people 1,000 to 5,000 people 5,000 to 10,000 people More than 10,000 people	Where possible, use a hydraulic model to simulate water supply shortfall. Convert to EP affected by dividing by average demand of 200 litres/person/day.	Where possible, use a hydraulic model or SCADA to obtain flow data. Convert to EP affected by dividing by average demand of 200 litres/person/day.
Customer Type	1 2 3 4 5	Residential Community Use Mixed Use Industrial Commercial	Type of customers affected using demand patterns as a reference. Perform manual assessment of hospitals and dialysis patients.	Type of customers affected using demand patterns as a reference. Perform manual assessment of hospitals and dialysis patients.
Failure Tolerance	1 2 3 4 5	More than 28 days 7 to 28 days 3 to 7 days 1 to 3 days Less than 1 day	Most reticulation and distribution pipes will have less than 1 day failure tolerance. Transfer mains differ. Hydraulic model automatically considers alternative supply.	How long does it take for asset failure to cause service failure or plant shut down? Consider alternative supplies, storage sources and previous failure events.
Compliance – Compliance				
Statutory Requirements	1 2 3 4 5	Insignificant Minor Moderate Major Catastrophic	Consider the severity of environmental damage and lack of water supply to customers.	Consider the severity of environmental damage and lack of water supply to customers.

The severity criteria and guidelines for water assets are located in Table 3.10 on the following page.

Table 3.10: Wastewater severity criteria and guidelines

Consequence Factors	**Score**	**Severity Criteria**	**Guidelines for Gravity Pipes and Pressure Pipes**	**Guidelines for WWTP and WWPS**
Financial – Repair Costs				
Asset Cost	1 2 3 4 5	Less than $5,000 $5,000 to $25,000 $25,000 to $75,000 $75,000 to $150,000 More than $150,000	Use pipe segment lengths and schedule of rates to estimate asset cost. Maximum replacement length is 250m.	Use asset sizes, failure modes, historical failures and TRC knowledge to estimate the maximum asset cost.
Difficulty of Repair	1 2 3 4 5	Less than 1 day 1 to 3 days 3 to 7 days 7 to 14 days More than 14 days	Consider location, accessibility, pipe diameters and pipe depths to estimate repair difficulty.	Consider location, accessibility and asset sizes to estimate repair difficulty.
Financial – Third Party Losses				
Location	1 2 3 4 5	NI, R, EC, LD, SP, SC, OS RR, DC, T, EI, LC, CF OS, SR, LII, LDR, MU MII, LDMR PC, MC, HII	Refer to zone classifications in Table 3.11.	Refer to zone classifications in Table 3.11.
Volume Discharged	1 2 3 4 5	Less than 5 kL 5 to 20 kL 20 to 50 kL 50 to 100 kL More than 100 kL	Consider the flow and typical response times to estimate a volume discharged.	Consider the flow, typical response times and indirect causes of discharge such as switchboard failure causing overflow.
Reputation – Media Exposure				
Location	1 2 3 4 5	NI, R, EC, LD, SP, SC, OS RR, DC, T, EI, LC, CF OS, SR, LII, LDR, MU MII, LDMR PC, MC, HII	Refer to zone classifications in Table 3.11.	Refer to zone classifications in Table 3.11.
Volume Discharged	1 2 3 4 5	Less than 5 kL 5 to 20 kL 20 to 50 kL 50 to 100 kL More than 100 kL	Consider the flow and typical response times to estimate a volume discharged.	Consider the flow, typical response times and indirect causes of discharge such as switchboard failure causing overflow.
Reputation – Public Health & Safety				
Potential for Injury/Illness	1 2 3 4 5	No Injury or Near Miss First Aid Treatment Medical Treatment Hospitalisation Death or Disability	Consider location, pipe diameter, and potential volumes discharged.	Consider location, potential volumes discharged and asset type.
Environmental – Environmental Damage				

Consequence Factors	Score	Severity Criteria	Guidelines for Gravity Pipes and Pressure Pipes	Guidelines for WWTP and WWPS
Volume Discharged	1 2 3 4 5	Less than 5 kL 5 to 20 kL 20 to 50 kL 50 to 100 kL More than 100 kL	Consider the flow and typical response times to estimate a volume discharged.	Consider the flow, typical response times and indirect causes of discharge such as switchboard failure causing overflow.
Proximity to Sensitive Area	1 2 3 4 5	Insignificant Minor Moderate Major Within sensitive zone	Where possible, use GIS to identify proximity to waterways.	Where possible, use GIS to identify proximity to waterways.
Service Delivery – Service Delivery				
Equivalent Population (EP) Affected	1 2 3 4 5	Less than 100 people 100 to 1,000 people 1,000 to 5,000 people 5,000 to 10,000 people More than 10,000 people	Where possible, use a WaterGEMS model to determine the equivalent population affected. EP affected is based on a production rate of 150 litres/person/day.	Where possible, use a WaterGEMS model to determine the equivalent population affected. EP affected is based on a production rate of 150 litres/person/day.
Customer Type	1 2 3 4 5	Residential Community Use Mixed Use Industrial Commercial	The type of customers producing wastewater.	The type of customers producing wastewater.
Failure Tolerance	1 2 3 4 5	More than 28 days 7 to 28 days 3 to 7 days 1 to 3 days Less than 1 day	Most pipes will have less than 1 day failure tolerance due to their failure modes.	Consider overflow storages and previous failure events.
Compliance – Compliance				
Statutory Requirements	1 2 3 4 5	Insignificant Minor Moderate Major Catastrophic	Consider the severity of environmental damage and effects on public health and safety.	Consider the severity of environmental damage and effects on public health and safety.

The zone classifications abbreviations are described in Table 3.11 below.

Table 3.11: Zone classification descriptions

Zone Identifier	Zone Description	Zone Identifier	Zone Description
NI	Nil Impact Zone (TRC Compound)	**T**	Township
R	Rural	**CF**	Community Facilities
EC	Emerging Community	**SR**	Sport & Recreation
LD	Limited Development	**LII**	Low Impact Industry
SP	Special Purpose	**LDR**	Low Density Residential
SC	Specialised Centre	**MU**	Mixed Use
OS	Open Space	**MII**	Medium Impact Industry
RR	Rural Residential	**LDMR**	Low-Medium Density Residential
DC	District Centre	**PC**	Principal Centre
EI	Extractive Industry	**MC**	Major Centre
LC	Local Centre	**HII**	High Impact Industry

3.7 Criteria Weightings

Criteria weightings were developed to reflect the relative importance of the consequence factors as identified by WIS. Weightings were developed using a pairwise comparison approach through consultation with a team of engineers, managers and technical officers.

Pairwise comparisons were performed on enterprise consequence categories and consequence factors and an overall weighting for each consequence factor was derived. The two-step approach is explained below:

1. A pairwise comparison was performed using the enterprise consequence categories as alternatives. The weightings obtained from this pairwise comparison showed how important each enterprise consequence category was to WIS. For example, environmental received an 8.90% weighting.

2. A pairwise comparison was performed for each enterprise consequence category using the consequence factors as alternatives. The weightings obtained from each pairwise comparison showed how much each consequence factor contributed to each consequence category. For example, volume discharged and proximity to sensitive area both received a weight of 50%, meaning both criteria equally contributed to the environmental consequence category.

The two-step approach was undertaken to reduce the size of the pairwise comparison. It became too overwhelming to compare all consequence factors in one pairwise matrix. Instead, a weighting was derived for each enterprise consequence category which was then multiplied by the contribution of its respective consequence factors as demonstrated in equation 3.1.

$$Weight_{CF_x} = Weight_{ECC} \times Contribution_{CF_x} \tag{3.1}$$

where CF = Consequence factor;

ECC = Relevant enterprise consequence category; and

$x = 1 \dots n$ for associated consequence factors.

For example, volume discharged received an overall consequence factor rating of 4.45% by multiplying 50% and 8.90%. This resulted in an overall rating for each consequence factor as demonstrated in subsequent figures.

3.7.1 Water Weighting Results

Consequence factor weightings were derived for water assets using the method outlined in section 3.7. Using the pairwise comparison approach, the financial and service delivery enterprise consequence categories obtained the highest total weightings at 29.76%. Reputation and compliance were the next highest with a total of 15.80%. Environmental was deemed the least important and had the lowest weight at 8.90%. The contribution of each consequence factor was then multiplied by its relevant enterprise consequence category to obtain individual consequence factor weightings. The results are summarised in Figure 3.7.

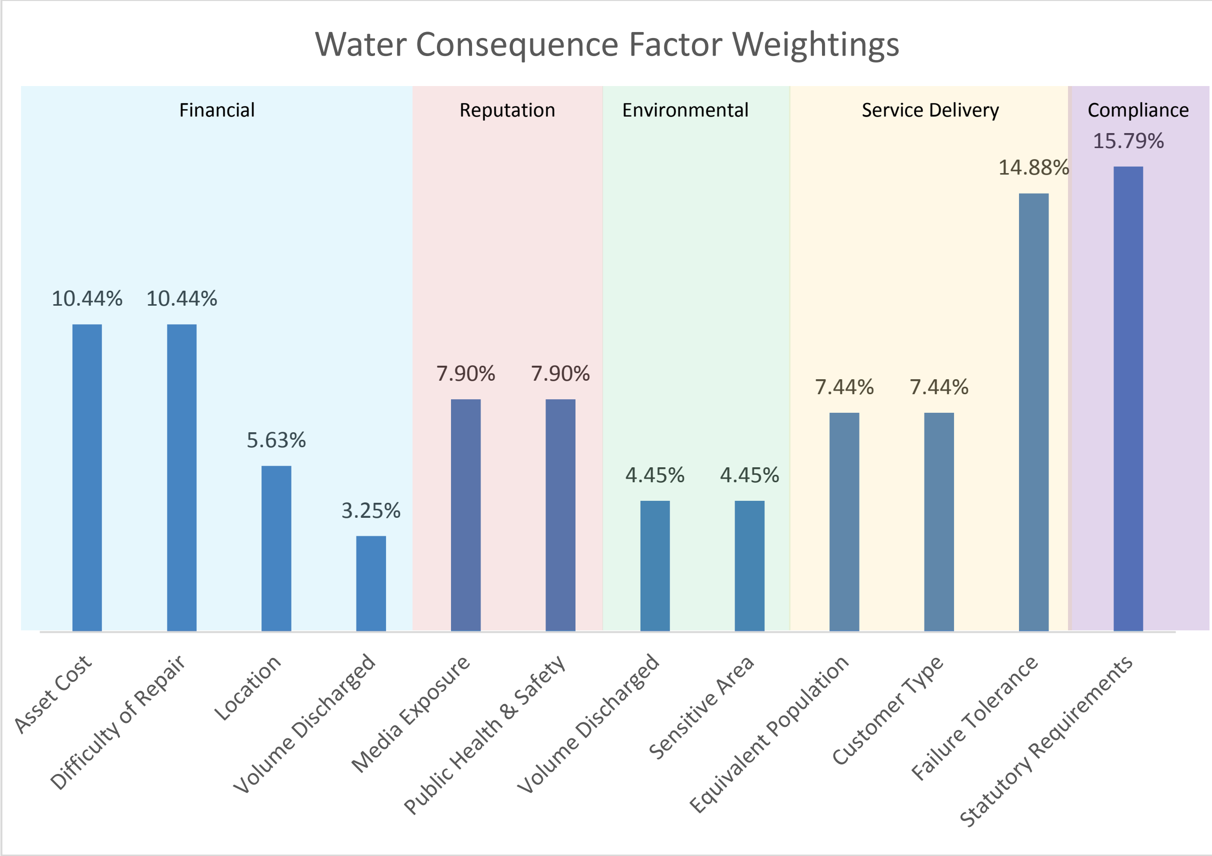

Figure 3.7: Water consequence factor weightings

3.7.2 Wastewater Weighting Results

Consequence factor weightings were derived for water assets using the method outlined in section 3.7. Using the pairwise comparison approach, the financial, environmental and service delivery enterprise consequence categories obtained the highest total weightings at 25.0%. Reputation and compliance were deemed the least important and obtained the lowest weightings at 12.5%. The contribution of each consequence factor was then multiplied by its relevant enterprise consequence category to obtain individual consequence factor weightings, and the results are summarised in Figure 3.8.

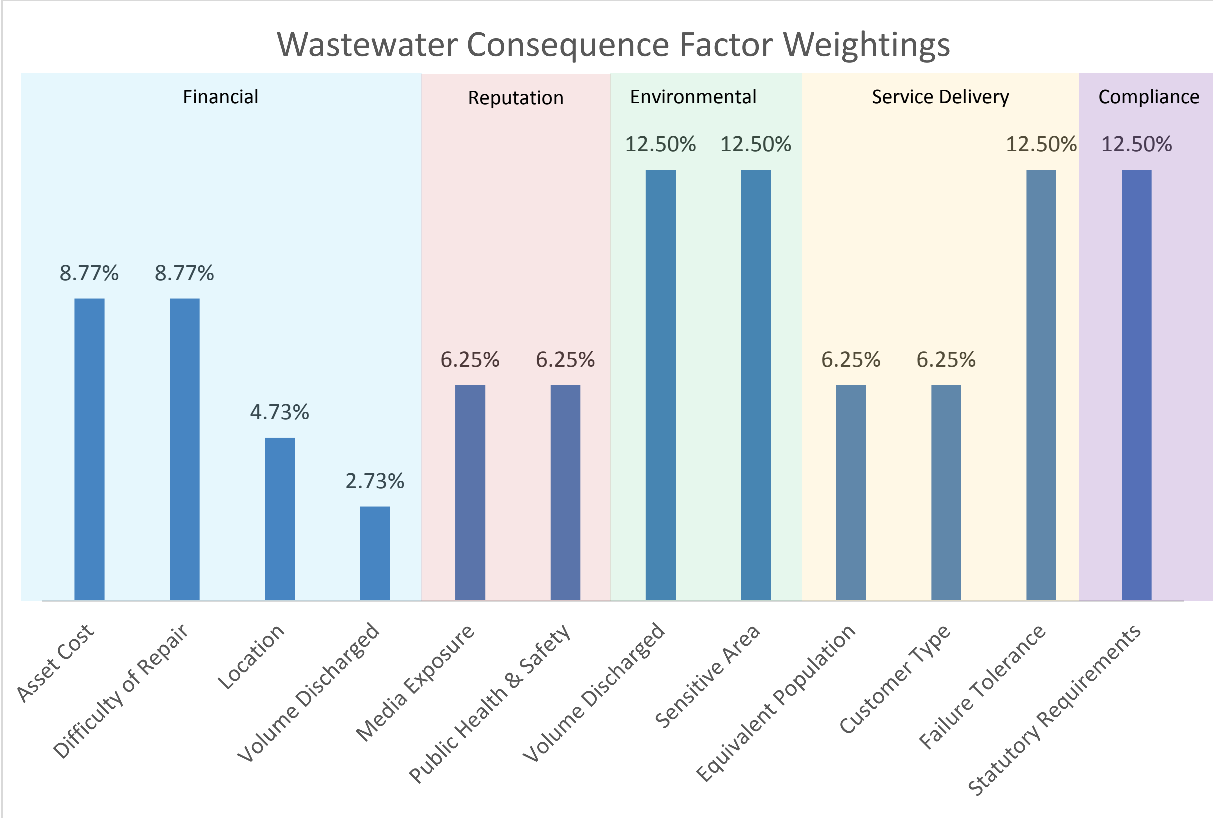

Figure 3.8: Wastewater consequence factor weightings

3.8 Derivation of Overall Criticality Rating

The overall criticality rating was derived by considering the consequence factor severity scores and associated weights. The scoring and weighting system produced a minimum and maximum possible score of 1 and 5 respectively and a specific asset management and maintenance approach was applied to the asset based on the score it received. These asset management and maintenance techniques are displayed in Table 3.12 on the following page.

Table 3.12: Summary of criticality ratings and associated management techniques

Overall Criticality Rating	Suggested Maintenance and Monitoring Technique	Comments
1 to 2	RTF or basic condition assessments.	Non-critical assets with minor consequences. Business is willing to accept failure.
2 to 3	PM and basic condition assessments.	Partially critical assets with moderate consequences. Basic techniques must be employed to keep asset operational and reduce BRE.
3 to 4	PM, reliability centred maintenance and detailed condition assessments.	Critical assets with major consequences. Rigorous techniques are suggested if resources permit to keep asset operational to reduce BRE.
4 to 5	PdM, reliability centred maintenance, performance monitoring and detailed condition assessments.	Extremely critical assets with catastrophic consequences. Rigorous techniques must be employed to keep asset operational and monitor its performance to reduce BRE.

The overall criticality rating was derived by totalling the weighted severity score of each consequence factor as described in equation 3.2.

$$CR = \sum_{x=1}^{n} SS_{CF_x} \times Weight_{CF_x} \qquad (3.2)$$

where $CR =$ Criticality rating of asset;

$SS =$ Severity score;

$CF =$ Consequence factor;

and 1…n is the consequence factors numbered from first to last.

3.9 Criticality Assessment Calculators

The main purpose of the criticality assessment calculators was to automate as many calculations as possible to generate an overall asset criticality rating. Microsoft (MS) Excel was the preferred software package due to its simplistic design, ability to be customised and its universal recognition throughout organisations. TechnologyOne was considered for use as it is the primary asset database for TRC. However, there were no test environments available to make system changes. Regardless, the processes and formulas established in MS

Excel could easily be incorporated into TechnologyOne in future if required. Refer to Appendix B for example screenshots.

3.9.1 Water Calculator

Two separate spread sheets were created for water assets. One spread sheet was designed to automatically process large quantities of raw pipe data to generate severity scores and the second spread sheet was designed to perform the criticality calculations for all water assets.

Water Pipe Analysis Calculator

Segment	Label	Start Node	Stop Node	Pipe Length (m)	Diameter	Material	Volume Shortfall (	EP Affected	Flow Availabl	Unit Rate	Basic Asset Cost	Zone	Asset Group
Criticality Segment - 9	P-408	J-12	26	0	225	AC	146391	731.955	62.61	358	0	Community Use	Water Pipeline
Criticality Segment - 9	P-331	J-12	24	1	225	AC	146391	731.955	62.61	358	358	Community Use	Water Pipeline
Criticality Segment - 9	P-286	23	J-38	0	225	AC	146391	731.955	65	358	0	Industrial	Water Pipeline
Criticality Segment - 9	P-256	J-38	J-12	278	225	AC	146391	731.955	64.28	358	89500	Industrial	Water Pipeline
Criticality Segment - 20	P-299	J-14	53	1	225	AC	146391	731.955	405.66	358	358	Mixed Use	Water Pipeline
Criticality Segment - 20	5	Reservoir1	J-14	4	225	AC	146391	731.955	405.66	358	1432	Mixed Use	Water Pipeline
Criticality Segment - 40	P-304	J-114	22	7	225	AC	146391	731.955	65.71	358	2506	Mixed Use	Water Pipeline
Criticality Segment - 40	P-299	53	J-113	3	225	AC	146391	731.955	405.66	358	1074	Mixed Use	Water Pipeline
Criticality Segment - 40	P-336	Booster Pum	J-114	1	225	AC	146391	731.955	65.71	358	358	Mixed Use	Water Pipeline
Criticality Segment - 40	P-335	J-113	Booster Pum	1	225	AC	146391	731.955	284.77	358	358	Mixed Use	Water Pipeline
Criticality Segment - 41	P-286	J-107	23	111	225	AC	146391	731.955	65	358	39738	Industrial	Water Pipeline
Criticality Segment - 41	P-304	22	J-107	96	225	AC	146391	731.955	65.71	358	34368	Mixed Use	Water Pipeline
Criticality Segment - 19	P-141	J-8	62	2	200	AC	144341	721.705	61.27	322	644	Residential	Water Pipeline
Criticality Segment - 19	42	J-8	60	2	200	PVC	144341	721.705	61.27	322	644	Mixed Use	Water Pipeline
Criticality Segment - 19	21	J-16	27	0	100	PVC-U	144341	721.705	62.53	210	0	Mixed Use	Water Pipeline
Criticality Segment - 19	P-408	26	J-11	6	225	AC	144341	721.705	62.61	358	2148	Community Use	Water Pipeline
Criticality Segment - 19	P-332	25	J-11	1	225	AC	144341	721.705	62.58	358	358	Mixed Use	Water Pipeline
Criticality Segment - 19	P-160	J-16	J-83	2	225	AC	144341	721.705	62.53	358	716	Mixed Use	Water Pipeline

Figure 3.9: Partial screenshot of Water Pipe Analysis Calculator

The purpose of the Water Pipe Analysis Calculator was to automatically generate severity scores from WaterGEMS hydraulic models and GIS data. However, not all information could be sourced from WaterGEMS and GIS, so the Water Pipe Analysis Calculator was used to automatically process as much information as possible. The major functions of the Water Pipe Analysis Calculator are listed below.

- Receive raw data from WaterGEMS and GIS.
- Automatically convert raw flow data into meaningful information such as equivalent population affected and asset cost based on rules outlined in section 3.6.2.
- Automatically assign a severity rating according to pipe segments using rules outlined in section 3.6.2.

The Water Pipe Analysis Calculator was able to be copied and reproduced for all WaterGEMS models with only slight manipulation of excel formulas. A summary of tabs contained within the Water Pipe Analysis Calculator are displayed in Table 3.13.

Table 3.13: Description of tabs within the Water Pipe Analysis Calculator

Tab Name	Tab Description
Model Results	Contains a majority of raw data generated from the WaterGEMS hydraulic model. Includes information such as system demanded volume, system supplied volume and system demand shortfall.
Pipe Details	Contains asset attribute data from WaterGEMS and GIS such as pipe diameter, pipe length, pipe material and start and stop nodes. Basic calculations have also been included to lookup flow values and asset location from the 'Demand' and 'Available Flow' tabs.
Demand	Contains raw data from WaterGEMS relating to demand, location and zones.
Available Flow	Contains raw data from WaterGEMS relating to flow calculations in the event of a pipe break.
Schedule of Rates	Contains costing information for pipes based on diameter and material which is used to calculate basic asset costs.
Pipe Severity Scores	Contains formulas used to lookup information from all tabs and automatically calculate severity scores based on the established criteria.
Severity Criteria	Contains the severity criteria established throughout the dissertation and rearranges it in an order that can be automatically interpreted by the 'Pipe Severity Scores' tab.

Water Criticality Analysis Calculator

Asset No.	Financial Score	Reputation Score	Environmental Score	Service Delivery Score	Compliance Score
00717326	0.51	0.63	0.09	0.74	0.63
00717413	1.26	0.39	0.36	1.19	0.63
00006070	0.51	0.24	0.09	0.89	0.47
00006112	0.92	0.16	0.09	1.19	0.32
00717463	0.61	0.16	0.09	0.30	0.16
00001253	0.51	0.16	0.09	0.45	0.16
00717564	0.51	0.16	0.09	0.89	0.32
00006203	0.61	0.16	0.09	0.45	0.16

Figure 3.10: Partial screenshot of Water Criticality Analysis Calculator

The purpose of the Water Criticality Analysis Calculator was to obtain a criticality rating for all water assets using severity scores input by the user. The resulting criticality ratings were then combined into one master sheet where statistical analysis was undertaken. The major functions of the Water Criticality Analysis Calculator are listed below.

- Perform pairwise comparisons and automatically calculate weightings as discussed in section 3.7. These weightings could be manually overwritten if required.
- Receive pipe severity data from the Water Pipe Analysis Calculator and automatically generate criticality ratings.
- Input severity data for active assets and automatically generate criticality ratings.
- Automatically perform statistical analysis on combined criticality ratings and summarise on a dashboard.

All formulas and calculations derived throughout Chapter 3 were included in the Water Criticality Analysis Calculator. A summary of tabs contained within the Water Criticality Analysis Calculator are displayed in Table 3.14.

Table 3.14: Description of tabs within the Water Criticality Analysis Calculator

Tab Name	**Category and Description**
Navigation	Main navigational page that directs users to different areas of the spread sheet using hyperlinks.
Dashboard	Visual presentation of data from various tabs including 'Combined Criticality Data' and 'Criteria Weighting Summary'. Uses hyperlinks to direct users to relevant areas within the tab.
Pipe Criticality Calculator	Automatically generates an overall criticality rating for pipes based on severity scores derived from the Water Pipe Analysis Calculator.
Water Active Assets	Automatically generates an overall criticality rating for water active assets based on input severity scores.
Severity Guidelines	Contains the severity criteria established throughout the dissertation for the user to reference if required.
Criteria Weighting Summary	Provides an overview of the criteria weightings used in the calculator. Also provides an option for the user to manually override a weighting if unsatisfied by the results of the pairwise comparisons.
Pairwise Comparisons	Contains all information relating to the pairwise comparisons, including the judgement matrix, calculations, normalised calculations and resulting weights.
Lists	Contains 'behind the scenes' data to populate drop down lists.
Counts	Contains 'behind the scenes' data used to generate graphs and figures displayed on the 'Dashboard' tab.

3.9.2 Wastewater Calculator

The wastewater calculator was almost identical to the water calculator described in section 3.9.1 where two separate spread sheets were created. The Wastewater Pipe Analysis Calculator was designed to automatically process large quantities of raw pipe data to generate severity scores. The Wastewater Criticality Analysis Calculator was designed to perform the criticality calculations for all wastewater assets. Due to the similarities, refer to the water calculators described in section 3.9.1 to obtain an understanding about the development and operation of the wastewater calculators. Specific information and screenshots relating to the wastewater calculators are located in Appendix B.

3.10 Chapter Summary

Chapter 3 developed the framework required to perform a criticality analysis on water and wastewater infrastructure at TRC. A summary of the main actions undertaken is described below:

- Typical failure modes and effects were identified and used to influence the development of criticality criteria.
- Detailed consequence factors were created and aligned to the corporate risk policy to ensure consequences were assessed in accordance with the interests of the organisation.
- Severity scores and guidelines were produced to quantify the intensity of the consequence factors.
- The consequence factors were weighted using a pairwise comparison approach that accounted for the opinions of WIS managers, engineers and maintenance planners.
- A method was established to derive an overall criticality rating based on the combination of severity scores and criteria weights.
- MS Excel calculators were developed to process data and automatically generate criticality ratings based on severity scores input by the user.

Chapter 4 – Overview of Study Sites

4.1 Introduction

The main aim of this dissertation was to develop a semi-automated asset criticality calculator capable of performing an analysis on TRC's entire water and wastewater asset base. However, time and resources did not permit an analysis of that magnitude so two sites were selected from each major asset group, and a random sample of assets were selected from each site. The range of sites and assets were selected to provide a comprehensive dataset suitable to thoroughly test the performance of the calculator, selected criteria and severity scales. The results from the calculator should support the operators' opinions and if not, the calculator should provide enough information to justify the difference.

4.2 Water Study Sites

The following sites were selected for analysis as they provide an appropriate representation of water infrastructure around the Toowoomba region. These sites vary in size, cost, location and other criteria that will be evaluated in the criticality assessment.

Table 4.1: List of water study sites and the respective number of assets analysed

Asset Group	**Case Study Site or Zone**	**No. Sub-Group Assets Analysed Within Site or Zone**
WTP	Mt Kynoch WTP	8
	Perseverance WTP	7
WPS	Anzac Avenue WPS	8
	Blue Mountain Heights WPS	5
Water Reservoir	Horners Reservoir	5
	Top Camp Reservoir	3
Water Bore	Hamblin Bore	4
	Mackenzie Bore	5
Water Pipeline	Toowoomba Oakey Pipeline	52 segments
	Blue Mountain Heights Pressure Zone	227 segments

4.2.1 Mt Kynoch Water Treatment Plant

Mt Kynoch WTP is a conventional treatment plant that removes suspended particles, metal ions and micro-organisms from the water and disinfects it ready for human consumption. Mt Kynoch WTP treats water obtained from Cooby, Perseverance and Cressbrook dams and distributes it to a majority of Toowoomba and the surrounding area. Although water from Mt Kynoch WTP is the primary source of potable water for the Toowoomba region, it is also supplemented by numerous bores scattered around the city (Toowoomba Regional Council, 2014).

Figure 4.1: Aerial photo of the Mt Kynoch Water Treatment Plant site and infrastructure

Mt Kynoch WTP is capable of treating up to 68 ML of water each day using processes discussed below (Toowoomba Regional Council, 2014).

1. <u>Pre-Treatment</u>

   Pre-treatment occurs at the Mt Kynoch intake where raw water from multiple sources is dosed with 8 mg/L Powdered Activated Carbon (PAC) to remove organic contaminants. Organic material is adsorbed onto the surface of the PAC remains trapped until the PAC is removed through the treatment process. In addition to PAC dosing, lime may be introduced to the inlet to alter the pH and alkalinity of raw water when necessary. Blended water from the dams is fairly neutral and generally maintains a pH value between 7.2 and 7.6, however it can range between 6.5 and 8.5 on occasion.

2. <u>Coagulation</u>

   Polyaluminium Chloride (PACL) is a cationic coagulant that is added to the raw water inlet tank at the start of the treatment process. The coagulant works by altering the charge on the surface of suspended microscopic particles. This reduces the repulsion between particles and allows them to coagulate to form 'flocs' that become large enough to be removed in the settling tank.

3. <u>Flocculation</u>

   After dosing the raw water with PACL, it flows into five flocculator tanks where it is slowly mixed. This ensures that the floc can become as large as possible by allowing more time for the suspended solids to clump together.

4. <u>Sedimentation</u>

   The aim of the settling tank is to remove as many clumps of dirt and organic matter as possible from the water before it enters the filters. Water is passed up through sloped tubes which give floc an opportunity to settle from the water and stick to the sides of the tubes. Sludge generated from the process is periodically flushed and sent to the waste lagoon. The settling process is important to remove a majority of organic matter which ensures the longevity of the filter media.

5. <u>Contact Filtration</u>

   Contact filtration occurs when turbidity is low and water quality is good. If water quality is high, raw water bypasses the flocculation and sedimentation phase and is sent directly to the filters.

6. <u>Media Filtration</u>

   From the sedimentation phase, the water is pre-chlorinated with 2.5 mg/L of chlorine to oxidize iron and manganese so it can be removed by the filters. However, before reaching the filters the water is dosed with 0.03 mg/L of anionic polymer that serves to provide a slippery coating to the filter media to prevent the surface being blocked by floc. In addition, the anionic polymer acts as a coagulant to bind small groups of floc together. The water is then passed through eight media filters consisting of coal, sand and three layers of different sized rocks. The purpose of filtering the water is to remove excess particles that were not removed during the sedimentation process. Over time, the filters reduce in efficiency as they begin to block up. To counteract this, the filters are backwashed when the head loss reaches 30 percent.

7. Disinfection

   Once the water has passed through the filters it is sent to the chlorine gallery where it is dosed with fluoride and 2.2 mg/L chlorine before being sent to the clear water tank and on-site reservoirs. Contact time for the chlorine disinfection process is achieved in the reservoirs and is necessary to kill any micro-organisms that may have passed through the earlier stages of the plant. The primary disinfecting agent used in the treatment process is gaseous chlorine.

Of the 841 assets recorded at Mt Kynoch WTP, the following eight assets described in Table 4.2 were randomly selected for analysis:

Table 4.2: Assets within Mt Kynoch WTP selected to participate in the criticality analysis

Asset No.	Asset Description
00717413	Mount Kynoch WTP - Pre-treatment - Inlet Tank - Structure - **Inlet Tank Structure**
00717326	Mount Kynoch WTP - Disinfection - Chlorination - Disinfection - **Chlorination Drum 1**
00006112	Mount Kynoch WTP - Electricals & Controls - General - **Clear Water Main Pump Room Switchboard**
00006070	Mount Kynoch WTP - Electricals & Controls - Citect Computer Control System - **Computer Operation Control**
00717564	Mount Kynoch WTP - Chemical Dosing - Magnasol Dosing - **Dosing Pump 1**
00006203	Mount Kynoch WTP - Filtration - Filter 1 - Valves & Fittings - **Filter Inlet Actuated Penstock**
00001253	Mount Kynoch WTP - Filtration - Service Water - **Service Water Flow Meter**
00717463	Mount Kynoch WTP - Flocculation - Flocculator 1 - **Flocculator Motor**

4.2.2 Perseverance Water Treatment Plant

Perseverance WTP was constructed for the sole purpose of treating and supplying water to Lake Perseverance Active Recreation Centre. Perseverance WTP is a small facility which receives inflow from Cressbrook Dam. Raw water is pre-treated with sodium hypochlorite and PACL which is injected directly into the inlet line. The partially treated water is then passed through two in-line filter vessels before being stored in a small concrete tank. The water may be disinfected with additional sodium hypochlorite post-filtration, depending on the chlorine residual in the tank. Treated water is then boosted from the tank to the activity centre where it is received by consumers.

Figure 4.2: Photo of infrastructure at Perseverance WTP

Of the 58 assets recorded at Perseverance WTP, the following seven assets described in Table 4.3 were randomly selected for analysis:

Table 4.3: Assets within Perseverance WTP selected to participate in the criticality analysis

Asset No.	Asset Description
00718371	Perseverance WTP - Filtration - Filter - **Vessel 1**
00718392	Perseverance WTP - Inflow - **Pipes & Fittings**
00718377	Perseverance WTP - Electricals & Controls - **SCADA / Telemetry**
00718381	Perseverance WTP - Electricals & Controls - **Switchboard**
00718391	Perseverance WTP - Inflow - **Flow Meter**
00718365	Perseverance WTP - Booster Pumping - Pump Set 1 - **Pump 1**
00718350	Perseverance WTP - Filtration - Backwash - **Manual Butterfly Valve (Filter)**

4.2.3 Anzac Avenue Water Pump Station

Anzac Avenue WPS is situated on the Western Trunk Main and is designed to boost potable water received from Mt Kynoch to the Gabbinbar reservoir. Due to the length of trunk main from Mt Kynoch, water is re-chlorinated at Anzac Avenue before it is pumped to Gabbinbar reservoirs.

Figure 4.3: Photo of Anzac Avenue WPS site (left) and one of two booster pump sets (right)

Of the 87 assets recorded at Anzac Avenue WPS, the following eight assets described in Table 4.4 were randomly selected for analysis:

Table 4.4: Assets within Anzac Avenue WPS selected to participate in the criticality analysis

Asset No.	Asset Description
00716445	Anzac Avenue WPS - Discharge Main - **Common Discharge Pipes & Fittings**
00716456	Anzac Avenue WPS - Buildings - **Gantry (W.L.L. 2000 kg)**
00716458	Anzac Avenue WPS - **Remote Telemetry Unit (Elpro)**
00716483	Anzac Avenue WPS - Electrical & Controls - **Switchboard**
00716454	Anzac Avenue WPS - Pump Set 1 - **Motor 1 (Teco, 250 kW)**
00716466	Anzac Avenue WPS - Disinfection - **Chlorine Analyser (Grundfos Alldos)**
00716457	Anzac Avenue WPS - Pump Set 1 - **Pump 1 (Borg Warner,250x300x500)**
00716427	Anzac Avenue WPS - Pump Set 1 - **Discharge Non Return Valve**

4.2.4 Blue Mountain Heights Water Pump Station

Blue Mountain Heights WPS is designed to supply water to the Blue Mountain Heights reticulation system and is positioned within the Mt Kynoch WTP boundary.

Figure 4.4: Photo of Blue Mountain Heights WPS site (left) and the booster pump set configuration (right)

The pump station pressurizes the system on demand and uses three booster pumps configured in series to increase pressure. A fourth booster pump is configured in standby position in case of duty failure.

Of the 40 assets recorded at Blue Mountain Heights WPS, the following five assets described in Table 4.5 were randomly selected for analysis:

Table 4.5: Assets within Blue Mountain Heights WPS selected to participate in the criticality analysis

Asset No.	Asset Description
00717118	Mount Kynoch WTP - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - **General Pipes & Fittings**
00717104	Mount Kynoch WTP - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Electrical & Controls - **Switchboard**
00717092	Mount Kynoch WTP - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Instrumentation - **Chlorine Analyser**
00717116	Mount Kynoch WTP - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Pump Sets - **Pressure Pump 1**
00717099	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Valves & Fittings - **Reflux Valve**

4.2.5 Horners Reservoir

Horners Reservoir is supplied with drinking water predominantly sourced from the Eastern Valley Bore Station. The potable water is gravity fed from Horners Reservoir to the Horners Pressure Zone where it is received by customers through the reticulation network.

Figure 4.5: Photo of Horners Reservoir site (left) and the inside of the reservoir structure when drained (right)

Water can be supplied to Horners Reservoir from alternative sources including Queens Park Bore Station, Alderley Street Bore Station, Stephen Street Bore Station or the Eastern Trunk Main via a valve on the corner of Herries Street and Mary Street.

Of the 12 assets recorded at Horners Reservoir, the following five assets described in Table 4.6 were randomly selected for analysis:

Table 4.6: Assets within Horners Reservoir selected to participate in the criticality analysis

Asset No.	**Asset Description**
00713889	Horners Reservoir R19 - **Reservoir Structure**
00713892	Horners Reservoir R19 - **Pipes & Fittings**
00713893	Horners Reservoir R19 - **Telemetry Unit**
00713899	Horners Reservoir R19 - Instrumentation - **Pressure Gauge**
00713894	Horners Reservoir R19 - Valves & Fittings - **Inlet Gate Valve**

4.2.6 Top Camp Reservoir

Top Camp Reservoir is supplied with drinking water predominantly sourced from the Hamblin Bore Station. It is equipped with a chlorine re-dosing facility designed to re-chlorinate water before entering the reticulation system.

Figure 4.6: Photo of the Top Camp Reservoir site and structure

Top Camp Reservoir has one megalitre of storage capacity and gravity feeds to most properties. Customers residing in close proximity to the reservoir have a dedicated pressure system to pressurize mains. Top Camp reservoir can supply potable water to the Hodgson Vale East and West reticulation systems, Top Camp reticulation system and the Lockyer Valley Council area.

Of the four assets recorded at Top Camp Reservoir, the following three assets described in Table 4.7 were randomly selected for analysis:

Table 4.7: Assets within Top Camp Reservoir selected to participate in the criticality analysis

Asset No.	Asset Description
00171756	Claudia Ct Reservoir 1 - **Pipes & Fittings**
00012694	Claudia Ct Reservoir 1 - **Structure**
00012695	Claudia Ct Reservoir 1 - **Telemetry**

4.2.7 Hamblin Bore

Hamblin Bore supplies water to the Top Camp Reservoir and directly feeds consumers in the Mount Rascal reticulation zone. Hamblin Bore is drilled to a depth of 212 metres and is part of the Main Range Volcanics aquifer.

Figure 4.7: Photo of Hamblin Bore site and building

Of the five assets recorded at Hamblin Bore, the following four assets described in Table 4.8 were randomly selected for analysis:

Table 4.8: Assets within Hamblin Bore selected to participate in the criticality analysis

Asset No.	Asset Description
00171735	Hamblin Bore 5 - Pipes & Fittings - **Bore Casing**
00171737	Hamblin Bore 5 - Pipes & Fittings - **Delivery Column**
00171739	Hamblin Bore 5 - Pipes & Fittings - **Flow Meter (Bore)**
00171736	Hamblin Bore 5 - Pump Set 1 - **Submersible Pump and Motor**

4.2.8 Mackenzie Bore

Mackenzie Bore is one of three production bores that supply Eastern Valley Bore Station. Raw water from Mackenzie Bore is pumped to Eastern Valley via a submersible pump. The water is blended with the other raw water sources and disinfected with Sodium Hypochlorite before it is pumped to Horners and Gabbinbar reservoirs.

Figure 4.8: Photo of Mackenzie Bore site and infrastructure

Of the 17 assets recorded at Mackenzie Bore, the following five assets described in Table 4.9 were randomly selected for analysis:

Table 4.9: Assets within Mackenzie Bore selected to participate in the criticality analysis

Asset No.	**Asset Description**
00719443	Mackenzie Street Bore - Pipes & Fittings **(Delivery Column)**
00718564	Mackenzie Street Bore - Electrical & Controls - **Telemetry Unit**
00718562	Mackenzie Street Bore - Electrical & Controls - **Switchboard**
00718594	Mackenzie Street Bore - Instrumentation - **Flow Meter**
00718697	Mackenzie Street Bore - Pump Set 1 - **Submersible Pump**

4.2.9 Toowoomba Oakey Pipeline

The Toowoomba Oakey Pipeline is a large water trunk main recently constructed to convey drinking water from Mt Kynoch WTP via the Western Trunk Main to reservoirs in Gowrie Junction, Gowrie Mountain, Meringandan, Kingsthorpe and Oakey. Figure 4.9 highlights the 52 pipe segments selected for analysis along the Toowoomba Oakey Pipeline.

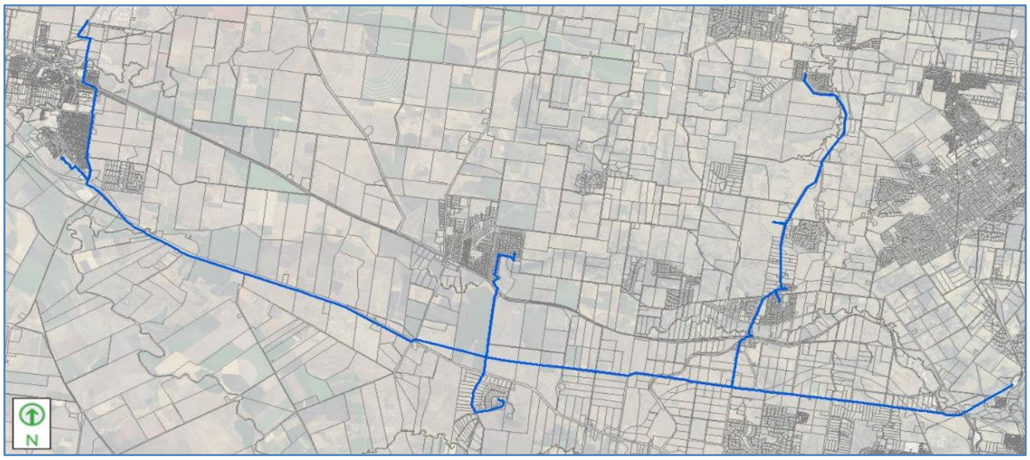

Figure 4.9: Basic representation of the Toowoomba Oakey Pipeline extracted from GIS

4.2.10 Blue Mountain Heights Pipeline Network

The Blue Mountain Heights pipeline system consists of trunk and reticulation mains that convey water from the Blue Mountain Heights WPS to consumers. Figure 4.10 highlights the 227 pipe segments selected for analysis within the Blue Mountain Heights pressure zone.

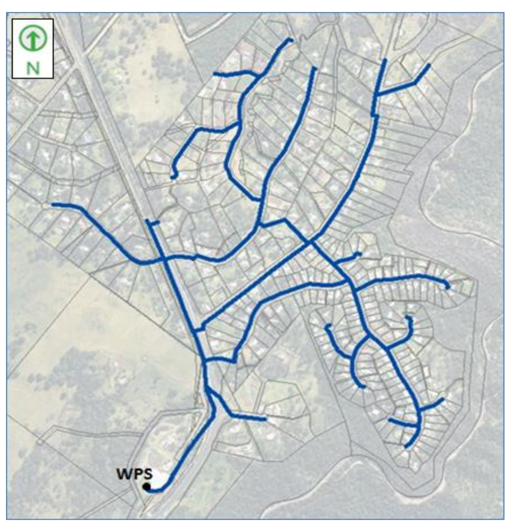

Figure 4.10: Basic representation of the Blue Mountain Heights pipeline network extracted from GIS

4.3 Wastewater Study Sites

The following sites were selected for analysis as they provide a decent representation of wastewater infrastructure around the Toowoomba region. These sites vary in size, cost, location and other criteria that will be evaluated in the criticality assessment.

Table 4.10: List of wastewater study sites and the respective number of assets analysed

Asset Group	Case Study Site or Zone	No. Sub-Group Assets Analysed Within Site or Zone
WWTP	Wetalla Water Reclamation Facility	8
	Yarraman WWTP	7
WWPS	Gowrie Junction WWPS	8
	Boundary Street WWPS (TOPS11)	7
Wastewater Pipelines	Boundary Street WWPS (TOPS11) Pipelines	49 gravity segments 3 pressure segments
	Gowrie Junction WWPS Rising Main	6 pressure segments
	Highfields Wastewater Pipelines	758 gravity segments 40 pressure segments

4.3.1 Wetalla Water Reclamation Facility

Toowoomba's first WWTP was opened in 1926 and continued to expand in order to cater for a rapidly growing population. By 1980, Council had established a large sewerage system that catered for approximately 80,000 residents. However, Toowoomba continued to expand which lead to an increase of effluent being discharged into Gowrie Creek. The environmental flow was unable to cope with high levels of nitrogen and phosphorus and blooms of Cyanobacteria began to increase downstream from the treatment plant. A new treatment plant was required that could treat the effluent to a safe level that could then be discharged to the environment. This resulted in the construction of Wetalla Water Reclamation Facility (WRF) which is a Biological Nutrient Removal plant and is the primary sewage treatment facility for Toowoomba and surrounding areas (Toowoomba Regional Council, 2014).

Figure 4.11: Photo of Wetalla Water Reclamation Facility site and infrastructure

Wetalla Water Reclamation Facility (WRF) uses high-tech mechanical, biological and chemical processes to treat wastewater to a level that is acceptable to discharge back into the environment. Wetalla is capable of treating an average dry weather flow of up to 30 ML/day using processes discussed below.

1. Preliminary Treatment Area

   Wastewater arrives at the treatment facility through a large gravity main and is initially received at the Preliminary Treatment Area (PTA). The PTA is made up of two channels which aim to remove coarse and heavy solid material and then split the flow equally between the two reactor tanks.

2. Biological Treatment

   From the PTA the wastewater flows to the reactor tanks, where a variety of different processes are undertaken to remove nutrients, carbon and nitrogen from the sewage. This is achieved by moving the wastewater through a number of different zones within the reactor tanks. When the wastewater has proceeded through all of the zones, the mixed liquor flows to the clarifiers.

3. Clarification

   The mixed liquor received by the clarifiers has very high settling characteristics. The clarifiers have very little movement, creating an environment suitable for the solids to effectively settle, allowing separation of the water and solids to occur.

4. Disinfection

   The separated water from the clarifiers is disinfected with chlorine before it is eventually discharged into Gowrie Creek.

5. Return Activated Sludge Pumping System

   The Return Activated Sludge pumping system transfers settled sludge from the clarifiers back into the reactor tanks. This ensures suspended solid levels in the mixed liquor remain at the required concentrations.

6. Aerobic Digestion

   The aerobic digesters use intermittent aeration to release volatiles from the sludge. This occurs in a series of controlled environments and allows nitrification and denitrification to continue, while still keeping the phosphorus in the biomass.

7. Sludge Handling System

   The sludge handling system aims to dewater sludge by pressing it through a belt filter. The pressed biological sludge is then received by the solar hall where it is sufficiently dried to become suitable for reuse.

8. Effluent Reuse

   Raw water from the Wetalla WRF is pumped through a 5 micron strainer to balance tanks, from where it feeds the microfiltration units. Permeate from the microfiltration units' flows to the chlorine contact tank where disinfection with sodium hypochlorite occurs. The disinfected water then flows to the New Acland Coal balance tank and should be of a high enough quality to meet the required reclaimed water standards.

The effluent reuse process is undertaken at the Advanced Water Treatment Plant (AWTP) on site. The AWTP will be excluded from the criticality analysis as it forms part of TRC's water reuse scheme and is not part of its wastewater scheme.

Of the 1734 assets recorded at Wetalla WRF, the following eight assets described in Table 4.11 were randomly selected for analysis:

Table 4.11: Assets within Wetalla WRF selected to participate in the criticality analysis

Asset No.	Asset Description
00715412	Wetalla WRF - Preliminary Treatment (PTA) - General - **Preliminary Treatment Structure**
00715414	Wetalla WRF - Biological Treatment - Anaerobic/Anoxic Digestion Bioreactor 1 - **Pipework (RAS Pump Stations To Tanks 1, 7 & 8)**
00715055	Wetalla WRF - Electricals & Controls - Biosolids & Solar Dryer MCC - **Solar Rake PLC 1 (Tiller Controls)**
00715018	Wetalla WRF - Electricals & Controls - Disinfection MCC - **Switchboard**
00714804	Wetalla WRF - Digested Sludge Dewatering - Digested WAS Pump Station 2 - **Motor 1 (7.5 kW)**
00715448	Wetalla WRF - Preliminary Treatment (PTA) - Flow Splitting - **Flow Splitter To Bioreactor 1 Flow Meter**
00714603	Wetalla WRF - Aerobic Digestion - Aerobic Digester Blowers - **Blower 1**
00714811	Wetalla WRF - High Flow Bypass - **Penstock 1**

4.3.2 Yarraman Wastewater Treatment Plant

Yarraman WWTP was commissioned in 1974 and augmented in 1982 to cater for growth. Raw sewage is gravity fed from customers to a WWPS where it is pumped to an inlet chamber at the treatment plant. Raw sewage is screened at the inlet before flow is equally split between two primary sedimentation tanks which aim to reduce suspended solids. Sludge is pumped from the primary settling tanks to digesters before being dried in six drying beds. Flow from the primary sedimentation tanks is then passed through a roughing filter before undergoing secondary sedimentation in two tanks. Flow is then directed between two biological filters before undergoing tertiary sedimentation in two tanks. The separated water from the tertiary sedimentation tanks is disinfected with chlorine before it is sent to an effluent lagoon ready for irrigation.

Figure 4.12: Aerial photo of the Yarraman Wastewater Treatment Plant site and infrastructure

Of the 342 assets recorded at Yarraman WWTP, the following seven assets described in Table 4.12 were randomly selected for analysis:

Table 4.12: Assets within Yarraman WWTP selected to participate in the criticality analysis

Asset No.	Asset Description
00012257	Yarraman STP - **Inlet Chamber 1**
00012295	Yarraman STP - Effluent Pump Station - **Gantry**
00173500	Yarraman STP - Electricals & Controls - **Remote Telemetry Unit**
00012366	Yarraman STP - Electricals & Controls - **Main Switchboard and Controls**
00173473	Yarraman STP - Effluent Disposal - Effluent Irrigation Pump Station - **Flow Meter**
00012265	Yarraman STP - Primary Sedimentation - Tank 1 - **Drive Assembly Gearbox**
00173444	Yarraman STP - Disinfection and Discharge - Sodium Hypochlorite Dosing - **Dosing Pump**

4.3.3 Gowrie Junction Wastewater Pump Station

Gowrie Junction WWPS is one of seven sites constructed as part of the Toowoomba Wastewater Infrastructure Project (TWIP). It receives sewage from a gravity catchment area and from Kingsthorpe WWPS. Gowrie Junction WWPS pumps sewage to a discharge manhole where it is gravity fed to Kooringa Valley WWPS.

Figure 4.13: Photo of Gowrie Junction WWPS site and infrastructure

Of the 50 assets recorded at Gowrie Junction WWPS, the following eight assets described in Table 4.13 were randomly selected for analysis:

Table 4.13: Assets within Gowrie Junction WWPS selected to participate in the criticality analysis

Asset No.	Asset Description
00716834	Gowrie St SPS 66 - Wet Well - **Wet Well Structure**
00716804	Gowrie St SPS 66 - Chemical Dosing - **Storage Tank**
00716828	Gowrie St SPS 66 - Electricals & Controls - **Telemetry**
00716839	Gowrie St SPS 66 - Electricals & Controls - **Switchboard**
00716805	Gowrie St SPS 66 - Chemical Dosing - **Control Panel**
00716838	Gowrie St SPS 66 - **Flow Meter (DN375)**
00716840	Gowrie St SPS 66 - Pump Set 1 - **Pump 1**
00716801	Gowrie St SPS 66 - Chemical Dosing - **Pump 1**

4.3.4 Boundary Street Wastewater Pump Station (TOPS11)

Boundary Street WWPS (TOPS11) receives sewage from a gravity catchment area predominantly fed by industrial sites and does not receive inflow from other pump stations. TOPS11 pumps sewage to TOPS10 which is another WWPS on Boundary Street.

Figure 4.14: Photo of Boundary Street WWPS (TOPS11) site and infrastructure

As shown in Figure 4.14, TOPS11 is situated very close to a waterway which should be considered in future analyses. Of the 19 assets recorded at TOPS11, the following seven assets described in Table 4.14 were randomly selected for analysis:

Table 4.14: Assets within Boundary Street WWPS (TOPS11) selected to participate in the criticality analysis

Asset No.	Asset Description
00001515	Boundary St SPS 11 - Structure - **Wet Well Structure**
00013745	Boundary St SPS 11 - Structure - **Overflow Storage**
00006804	Boundary St SPS 11 - Electricals & Controls - **Telemetry**
00719032	Boundary St SPS 11 - Electricals & Controls - **Switchboard (24 kW)**
00006753	Boundary St SPS 11 - Instrumentation - **Flow Meter**
00719030	Boundary St SPS 11 - **Pump & Motor 1 (Forrer 12 kW)**
00006748	Boundary St SPS 11 - Valves & Fittings - **Valve Reflux**

4.3.5 Boundary Street Wastewater Pump Station (TOPS11) Pipeline Network

The Boundary Street WWPS pipeline network is a series of gravity and pressure mains designed to collect and transport wastewater from customers in the TOPS11 catchment. Figure 4.15 highlights the 52 pipe segments selected for analysis within the TOPS11 pipeline network.

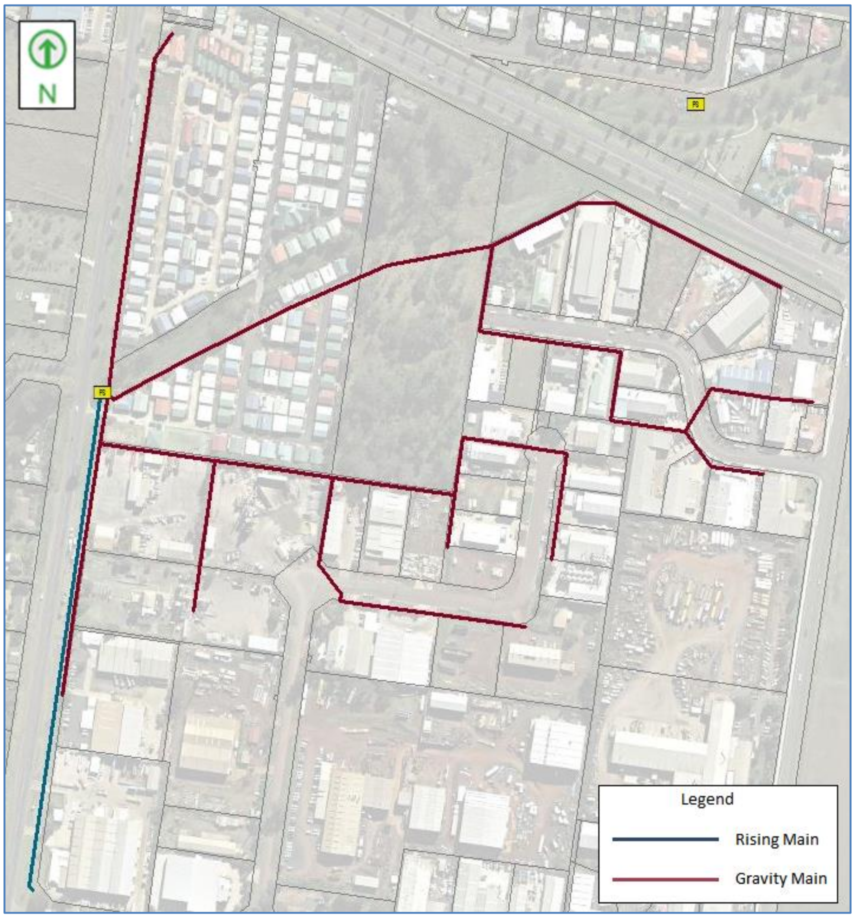

Figure 4.15: Basic representation of the TOPS11 pipeline network extracted from GIS

4.3.6 Gowrie Junction Wastewater Pump Station Rising Main

The Gowrie Junction WWPS rising main is designed to pump wastewater to a large discharge manhole where it is gravity fed to another WWPS. Refer to section 4.3.3 for additional information about the source of the rising main. Figure 4.16 highlights the 6 rising main segments selected for analysis.

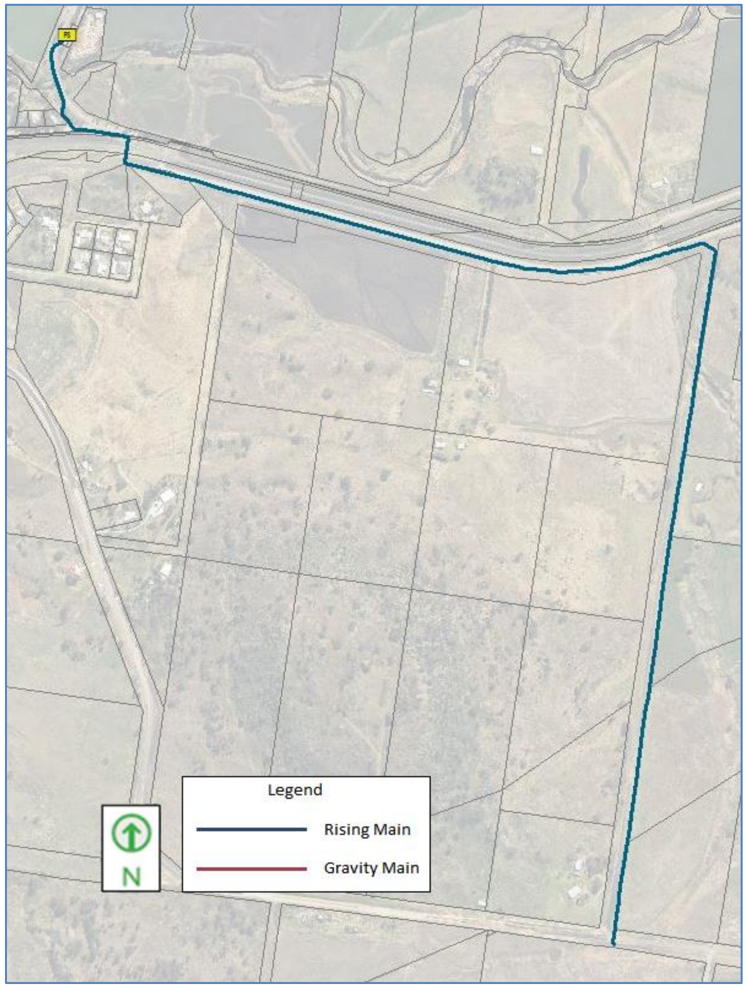

Figure 4.16: Basic representation of the Gowrie Junction WWPS rising main extracted from GIS

4.3.7 Highfields Wastewater Pipeline Network

The Highfields wastewater pipeline network is a series of gravity and pressure mains designed to collect wastewater from customers in Highfields and transport it to Wetalla WRF for treatment and disposal. Figure 4.17 highlights the 798 pipe segments selected for analysis within the Highfields wastewater collection network.

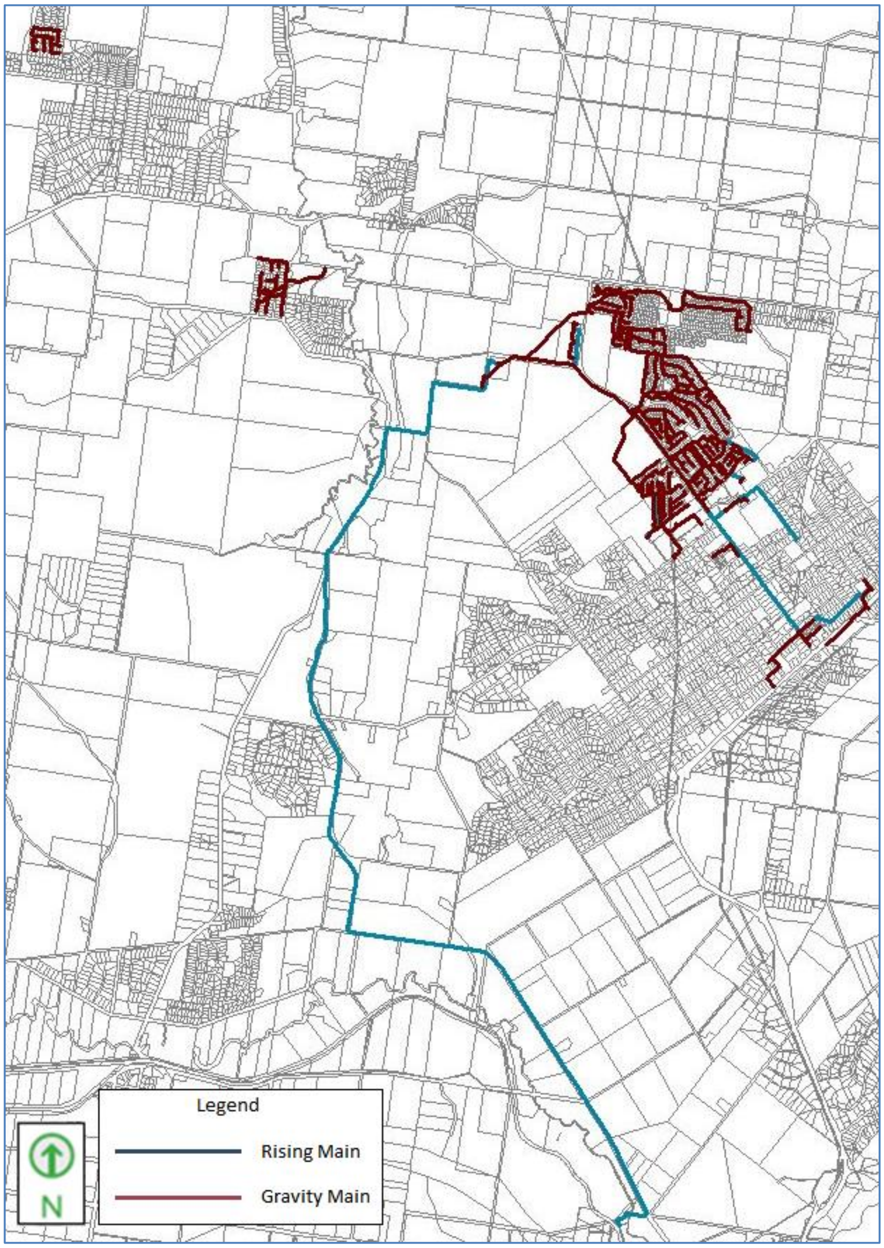

Figure 4.17: Basic representation of the Highfields wastewater pipeline network extracted from GIS

4.4 Chapter Summary

Chapter 4 provided an overview of the study sites and assets selected for analysis which varied in size, cost, location and function. The range of assets provided a comprehensive dataset suitable to thoroughly test the performance of the calculator, selected criteria and severity scales. Refer to individual sections to obtain detailed information pertaining to each site.

Chapter 5 – Application of Criticality Analysis

5.1 Introduction

The next phase was to apply the criticality framework developed in Chapter 3 to the sites and zones outlined in Chapter 4 to derive a criticality rating. A brief summary of the process used to undertake a criticality analysis for water and wastewater active and passive assets is described in subsequent sections. A basic flow diagram was created to depict the criticality assessment process used in this project and is shown in Figure 5.1.

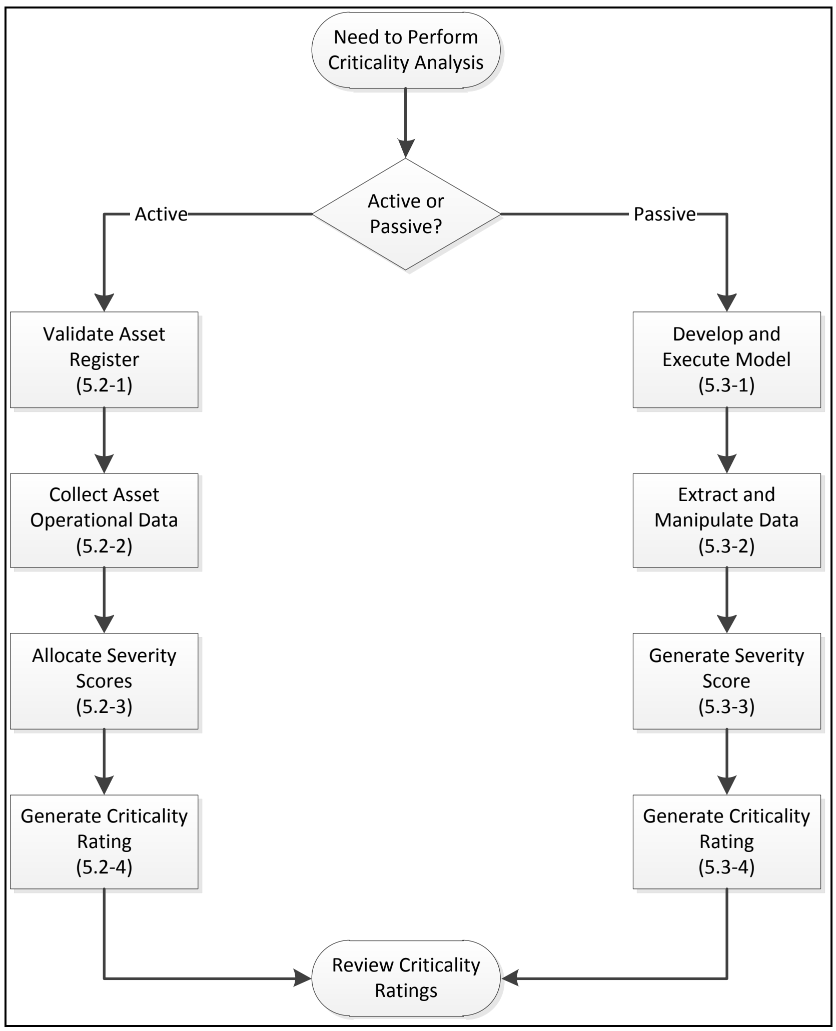

Figure 5.1: Water criticality analysis process diagram

Each step in Figure 5.1 was marked with a reference number which refers to headings within this chapter. This was performed to further explain the steps depicted in Figure 5.1.

5.2 Process for Active Assets

The process used to obtain criticality ratings for active assets is described below.

1. Validation of Asset Register

   All active sites discussed in Chapter 4 were visited to verify the accuracy of the WIS asset register and process diagrams before performing the criticality analysis. Asset data was extracted from TechnologyOne and each asset was validated on site. Similarly, existing process diagrams were obtained from TRC and validated by walking through the operational processes on site. This step was only performed to ensure the data presented in this dissertation was completely accurate. However, it could be excluded where data confidence is high.

2. Data Collection

   All relevant operational data was collected for each site from SCADA, ArcGIS, TechnologyOne and TRC operators. The type of data collected was driven by the severity guidelines outlined in section 3.6 and included information such as:

   - Financial asset data from TechnologyOne.
   - Repair difficulty, media exposure, potential for injury, failure tolerance, statutory requirements information from TRC operators.
   - Volume discharged and equivalent population affected from SCADA.
   - Locational data from GIS.
   - Customer type information from GIS and TRC operators.

3. Allocation of Severity Scores

   Severity scores were assigned to each consequence factor in accordance with the severity criteria discussed in section 3.6. Severity scores were input directly into the criticality analysis calculators discussed in section 3.9.

4. <u>Generation of Criticality Ratings</u>

Criticality ratings were generated using the criticality analysis calculators discussed in section 3.9. The basic asset data and severity scores collected in the previous step were uploaded to the Water Criticality Analysis Calculator or Wastewater Criticality Analysis Calculator which had pre-configured formulas to derive the criticality ratings.

Active asset details and severity scores were entered into the Active Assets tab to generate a criticality rating, as shown in Figure 5.2, Figure 5.3 and Figure 5.4.

Asset No.	Asset Description	Asset Group	Asset Sub-Group
00713888	Horners Reservoir R19 - Parent	Water Reservoir	Parent
00713889	Horners Reservoir R19 - Structure	Water Reservoir	Civil
00713892	Horners Reservoir R19 - Pipes & Fittings	Water Reservoir	Civil
00713893	Horners Reservoir R19 - Telemetry Unit	Water Reservoir	Control
00713899	Horners Reservoir R19 - Instrumentation - Pressure Gauge	Water Reservoir	Instrumentation
00713894	Horners Reservoir R19 - Valves & Fittings - Inlet Gate Valve	Water Reservoir	Mechanical
00012411	Claudia Ct Reservoir 1 - Parent	Water Reservoir	Parent
00171756	Claudia Ct Reservoir 1 - Pipes & Fittings	Water Reservoir	Civil
00012694	Claudia Ct Reservoir 1 - Structure	Water Reservoir	Civil
00012695	Claudia Ct Reservoir 1 - Telemetry	Water Reservoir	Control
00171734	Hamblin Bore 5 - Parent	Water Bore	Parent
00171735	Hamblin Bore 5 - Pipes & Fittings - Bore Casing	Water Bore	Civil
00171737	Hamblin Bore 5 - Pipes & Fittings - Delivery Column	Water Bore	Civil
00171739	Hamblin Bore 5 - Pipes & Fittings - Flow Meter (Bore)	Water Bore	Instrumentation
00171736	Hamblin Bore 5 - Pump Set 1 - Submersible Pump and Motor	Water Bore	Mechanical

Figure 5.2: Water Criticality Analysis Calculator – example of water active asset details

Asset Cost	Difficulty of Repair	Volume Dischargec	Location	Media Exposure	Potential for Injury (Public)	Proximity to Sensitive Area	Population Affected	Customer Type	Failure Tolerance	Statutory Requirements
4	4	4	3	3	3	1	5	3	3	3
5	4	5	3	4	2	1	5	3	5	3
2	1	4	3	2	1	1	5	3	5	3
1	1	1	1	1	1	1	1	1	4	1
1	1	1	1	1	1	1	1	1	1	1
1	1	4	3	2	1	1	5	3	5	3
4	4	4	2	2	2	2	2	3	2	2
2	1	2	2	2	1	2	2	3	5	2
5	4	4	2	2	2	2	2	3	5	2
1	1	1	1	1	1	1	1	3	4	1
3	2	3	2	2	1	5	2	3	2	2
3	5	1	2	2	1	5	2	3	2	4
2	2	1	2	2	1	2	2	3	2	2
2	2	1	2	1	1	1	1	1	1	1
2	3	1	2	2	1	1	2	3	2	2

Figure 5.3: Water Criticality Analysis Calculator – example of water active asset severity scores

Financial Score	Reputation Score	Environmental Score	Service Delivery Score	Compliance Score	CRITICALITY RATING	DATA CONFIDENCE
1.13	0.47	0.22	1.04	0.47	3.35	Med
1.27	0.47	0.27	1.34	0.47	3.82	Med
0.61	0.24	0.22	1.34	0.47	2.88	Med
0.30	0.16	0.09	0.74	0.16	1.45	Med
0.30	0.16	0.09	0.30	0.16	1.00	Med
0.51	0.24	0.22	1.34	0.47	2.78	Med
1.08	0.32	0.27	0.67	0.32	2.65	Med
0.49	0.24	0.18	1.12	0.32	2.34	Med
1.18	0.32	0.27	1.12	0.32	3.20	Med
0.30	0.16	0.09	0.89	0.16	1.60	Med
0.73	0.24	0.36	0.67	0.32	2.31	Med
0.98	0.24	0.27	0.67	0.63	2.79	Med
0.56	0.24	0.13	0.67	0.32	1.92	Med
0.56	0.16	0.09	0.30	0.16	1.27	Med
0.67	0.24	0.09	0.67	0.32	1.98	Med

Figure 5.4: Water Criticality Analysis Calculator – example of water active asset criticality ratings

Additional screenshots of the entire calculator are located in Appendix B.

5.3 Process for Passive Assets

The process used to obtain criticality ratings for passive assets is described below.

1. <u>Model Development and Execution</u>

   All passive infrastructure discussed in Chapter 4 had pre-configured models in WaterGEMS which were developed and executed by the Network Planning branch at TRC.

2. <u>Data Extraction and Manipulation</u>

   Raw data from the model was extracted from WaterGEMS and converted to a MS Excel compatible file. The data was transferred to the Water Pipe Analysis Calculator or Wastewater Pipe Analysis Calculator where it was moved into the correct columns in the document. The formulas within the document were then adjusted to suit the new data range.

Segment	Are all demands met?	Is Balanced?	Maximum Allowable Demand Shortfall (%)	System Demanded Volume (L)	System Supplied Volume (L)
Criticality Segme	FALSE	TRUE	0	146,391.00	0
Criticality Segme	FALSE	TRUE	0	146,391.00	0
Criticality Segme	FALSE	TRUE	0	146,391.00	0
Criticality Segme	FALSE	TRUE	0	146,391.00	0
Criticality Segme	FALSE	TRUE	0	146,391.00	2,050.00
Criticality Segme	FALSE	TRUE	0	146,391.00	88,244.20
Criticality Segme	FALSE	TRUE	0	146,391.00	104,207.90
Criticality Segme	FALSE	TRUE	0	146,391.00	105,593.80

Model Results / Pipe Details / Demand / Available Flow / Schedule of Rates / Pipe Severity Scores / Severity Criteria

Figure 5.5: Water Pipe Analysis Calculator – example of water passive data manipulation

3. <u>Severity Score Development</u>

   Severity scores for passive assets were automatically generated in the Water Pipe Analysis Calculator or Wastewater Pipe Analysis Calculator based on the severity guidelines discussed in section 3.6. Refer to Figure 5.3 for an example of what the automatic severity scores look like in the Water Pipe Analysis Calculator.

4. <u>Criticality Ratings</u>

   Criticality ratings were generated using the Water Criticality Analysis Calculator or Wastewater Criticality Analysis Calculator created in section 3.9. The basic asset data and severity scores generated in the previous step were transferred to the criticality analysis calculators which had pre-configured formulas to derive the criticality ratings. Refer to Figure 5.4 for an example of the criticality ratings generated using the Water Criticality Analysis Calculator.

5.4 Chapter Summary

Chapter 5 outlined the main processes involved to perform the criticality analysis using the methodology and tools developed in Chapter 3. The main elements were to collect and process raw data, obtain severity scores and automatically generate criticality ratings.

Chapter 6 – Analysis of Results

6.1 Introduction

Severity data was collected for each study site and a criticality rating was generated using the processes discussed in Chapter 5. This chapter presents and analyses the results to determine the performance of the established criteria and confirm whether the developed methodology was capable of obtaining feasible results.

6.2 Water Criticality Ratings

A criticality analysis was performed on a random selection of assets within each water study site. A total of 324 assets were analysed and the results are discussed in the following sections. A full list of the water criticality analysis results are located in Appendix C.

6.2.1 Mt Kynoch Water Treatment Plant

The results of the criticality analysis performed on eight random assets at Mt Kynoch WTP are displayed in Figure 6.1 on the following page.

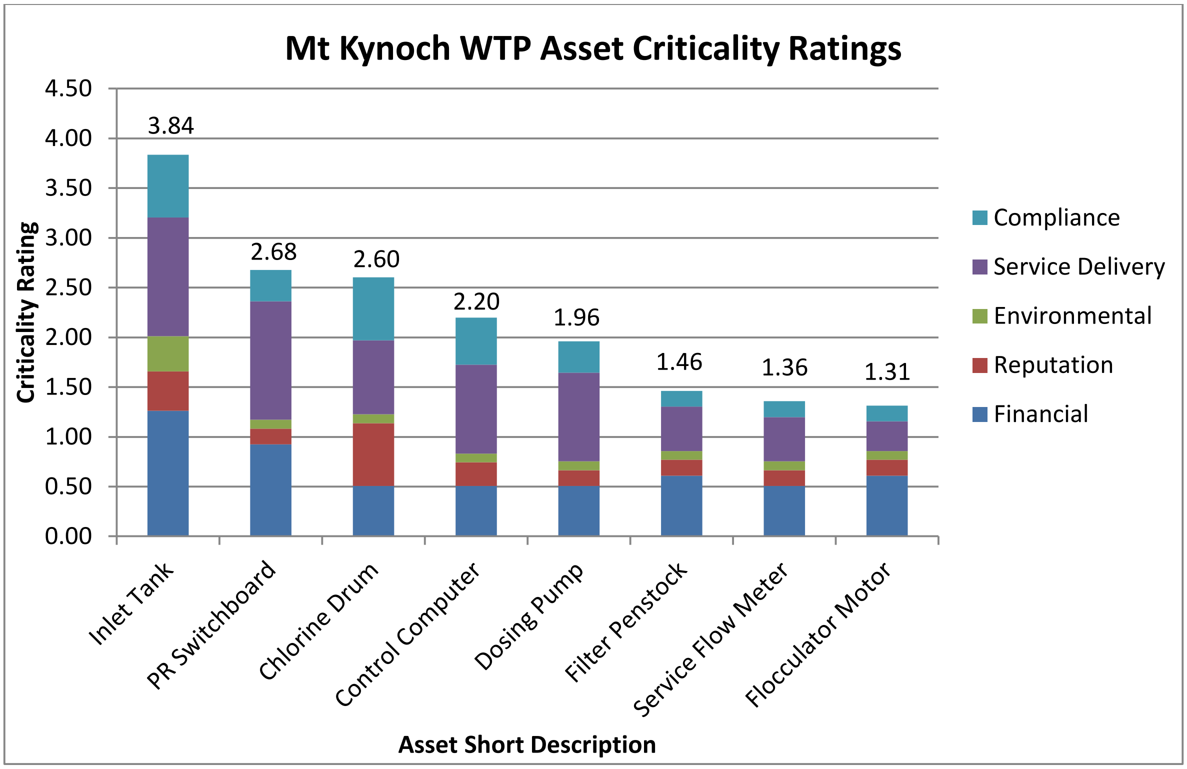

Figure 6.1: Criticality ratings and consequence score distribution for assets within Mt Kynoch WTP site

The inlet tank received the highest criticality rating of 3.84 which is feasible as the inlet tank is an expensive concrete structure that receives all inflow to the plant. The inlet tank was comprised of predominantly financial and service delivery consequences, which received individual scores of 1.26/1.49 and 1.19/1.49 respectively. These scores are realistic, because if the inlet tank were to structurally fail, the plant would be shut down until it was repaired. This would have a significant effect on the budget, and service delivery as the storage reserves deplete.

At the other end of the spectrum, the flocculator motor received the lowest criticality rating of 1.31. Again, this seems feasible as the flocculator motor is one of five motors in five tanks. If the one motor was to fail, mixing in this tank would not occur and flocculation would not be as efficient in that one particular tank only. Four other flocculator motors and tanks would remain online, so there would be minimal impact on service delivery due to redundancy in the system. This is reflected in the consequence scores, where the highest value obtained was 0.61/1.49 in the financial category as a direct result of the motor price and repair difficulty.

6.2.2 Perseverance Water Treatment Plant

The results of the criticality analysis performed on seven random assets at Perseverance WTP are displayed in Figure 6.2 below.

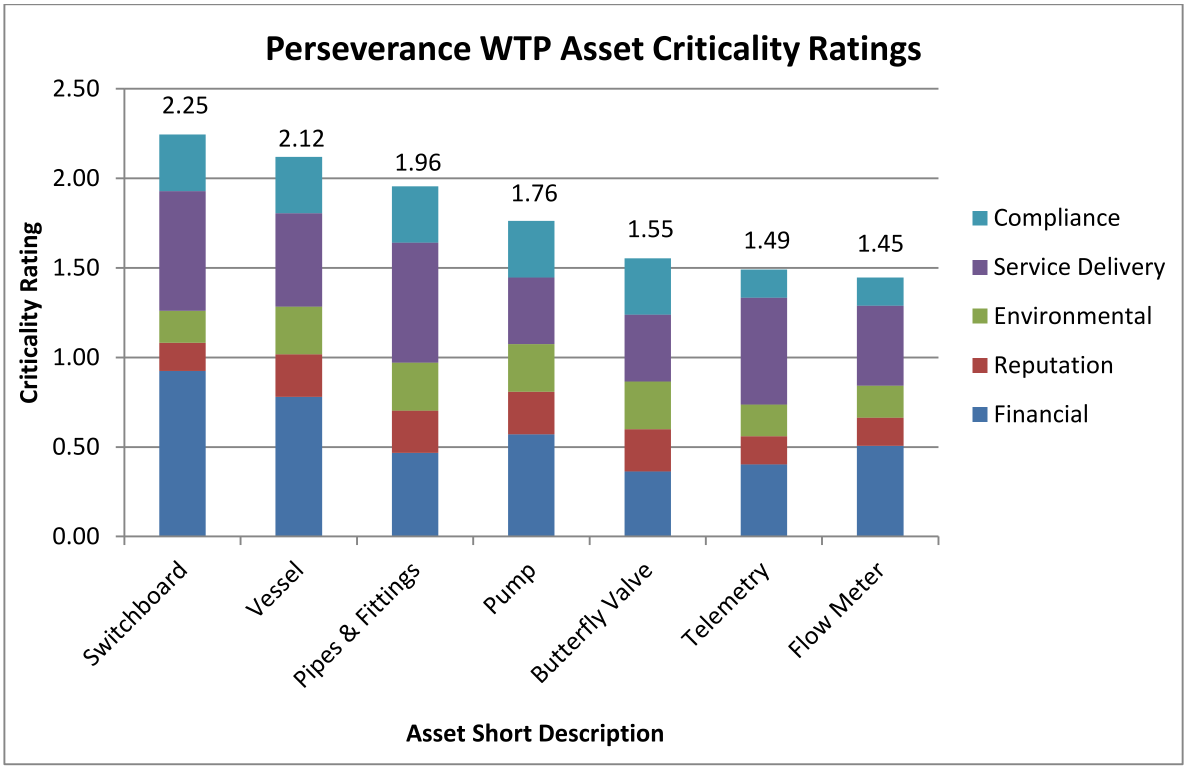

Figure 6.2: Criticality ratings and consequence score distribution for assets within Perseverance WTP site

The switchboard received the highest criticality rating of 2.25 which is feasible as the switchboard is an expensive component responsible for powering and controlling a majority of the equipment. Switchboard failure was comprised of predominantly financial and service delivery consequences, which received individual category scores of 0.92/1.49 and 0.67/1.49 respectively.

At the other end of the scale, the inflow flow meter received the lowest criticality rating of 1.45. As the name suggests, the sole purpose of the inflow flow meter is to measure raw water inflow to the treatment plant. The main consequence of failure would be related to the asset cost and the repair difficulty which was reflected by the highest consequence score of 0.51/1.49 in the financial category.

6.2.3 Anzac Avenue Water Pump Station

The results of the criticality analysis performed on eight random assets at Anzac Avenue WPS are displayed in Figure 6.3 below.

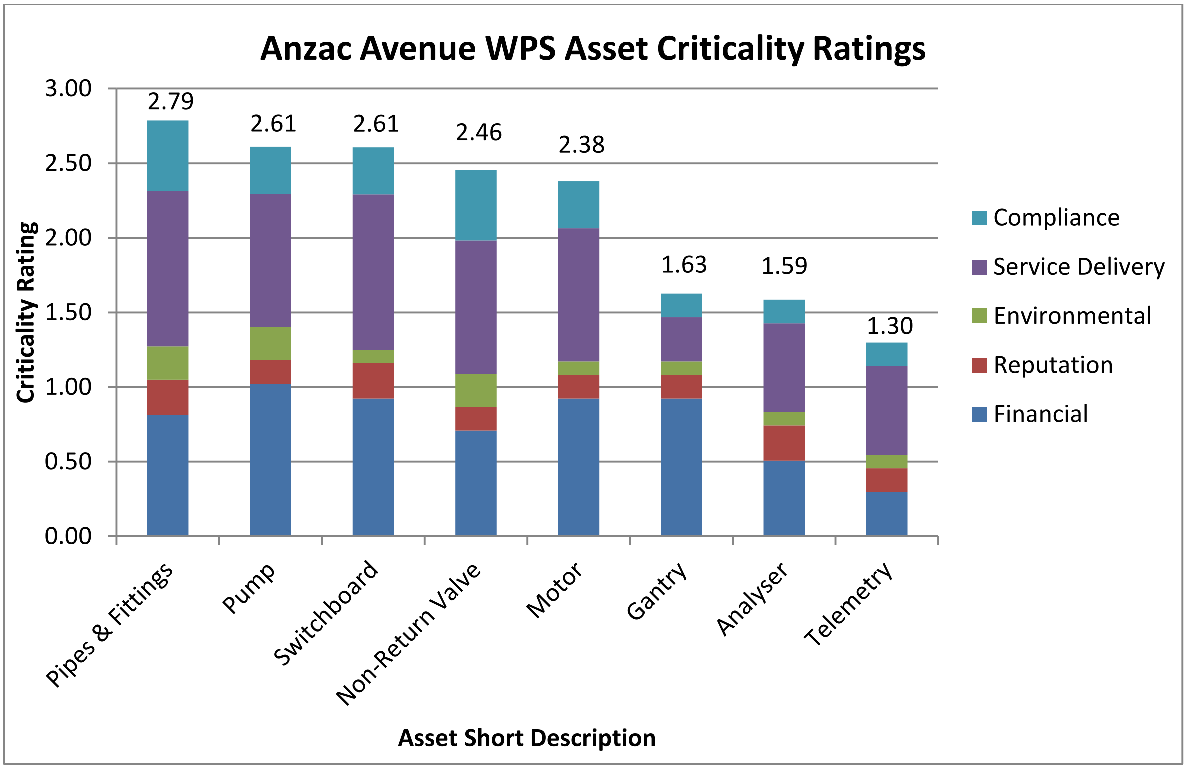

Figure 6.3: Criticality ratings and consequence score distribution for assets within Anzac Avenue WPS site

The common discharge pipes and fittings received the highest criticality rating of 2.79 which is feasible as it is the single point of discharge from the pumps. If the common pipes were to fail, the pump station would need to be shut down until repaired. Anzac Avenue WPS is the major potable water contributor to the Gabbinbar reservoir which supplies the Gabbinbar reticulation zone. If the common discharge pipes failed, it is likely that service to over 35,000 people would be severely impacted within one to two weeks. The severity of failure is reflected by the highest consequence score of 1.04/1.49 in the service delivery category.

Conversely, the telemetry received the lowest criticality rating of 1.30 which is a realistic value. The telemetry forms part of the communication system and is generally cheap and easy to fix, as suggested by low financial consequence score of 0.3/1.49.

6.2.4 Blue Mountain Heights Water Pump Station

The results of the criticality analysis performed on five random assets at Blue Mountain Heights WPS are displayed in Figure 6.4 below.

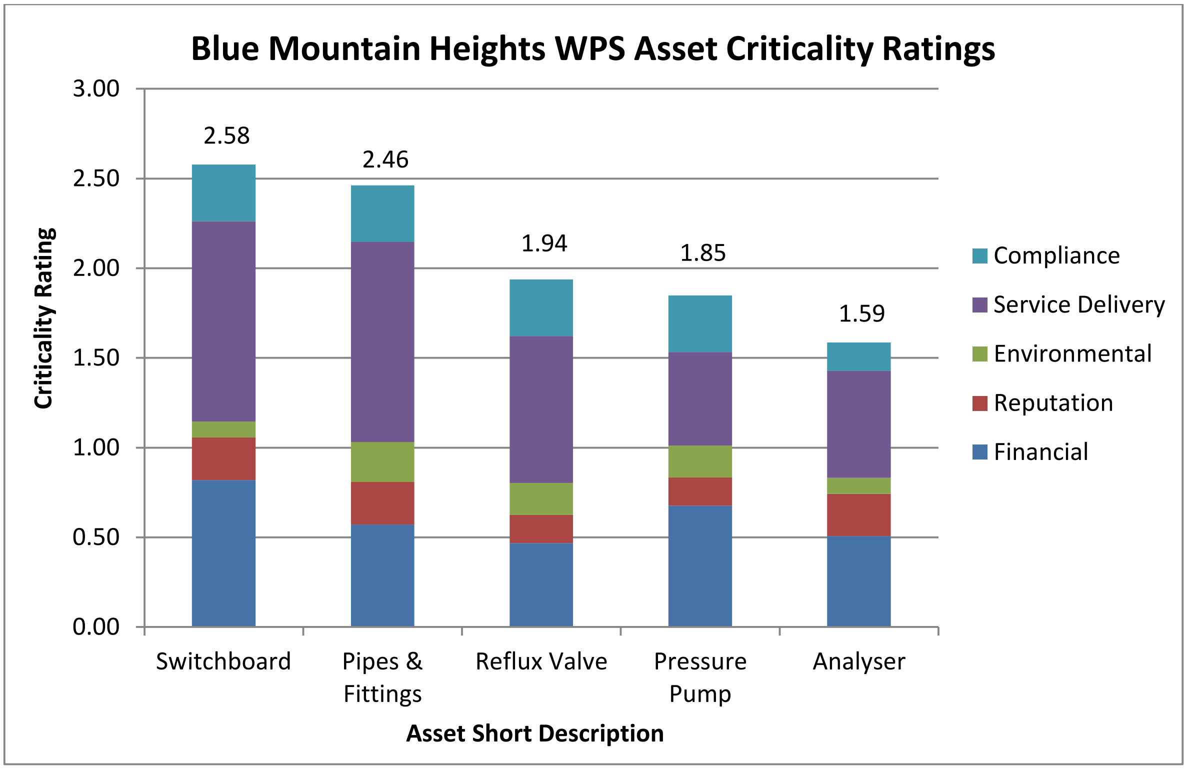

Figure 6.4: Criticality ratings and consequence score distribution for assets within Blue Mountain Heights WPS site

The switchboard received the highest criticality rating of 2.58 which is feasible as the switchboard is an expensive component responsible for powering and controlling a majority of the equipment. Switchboard failure was comprised of predominantly financial and service delivery consequences, which received individual category scores of 0.82/1.49 and 1.12/1.49 respectively. The high service delivery score was attributed to the fact that the Blue Mountain Heights Pressure Zone is serviced by the pump station which boosts pressure on demand. There is no alternative water storage available to supply customers in the event of failure.

At the other end of the spectrum, the analyser received the lowest criticality rating of 1.59. The analyser is designed to monitor chlorine residual in the system to ensure there is adequate disinfection to maintain a potable water supply. Analyser failure was comprised of predominantly financial and service delivery consequences, which received individual category scores of 0.51/1.49 and 0.60/1.49 respectively. The value of 0.60 for service delivery is questionable, as analyser failure would only affect service delivery if the plant was shut down due to unknown residuals causing safety issues. In reality, manual testing would likely be performed in order to keep the plant operational. Until manual testing procedures are formally established, the service delivery consequence score remains feasible.

6.2.5 Horners Reservoir

The results of the criticality analysis performed on five random assets at Horners Reservoir are displayed in Figure 6.5 below.

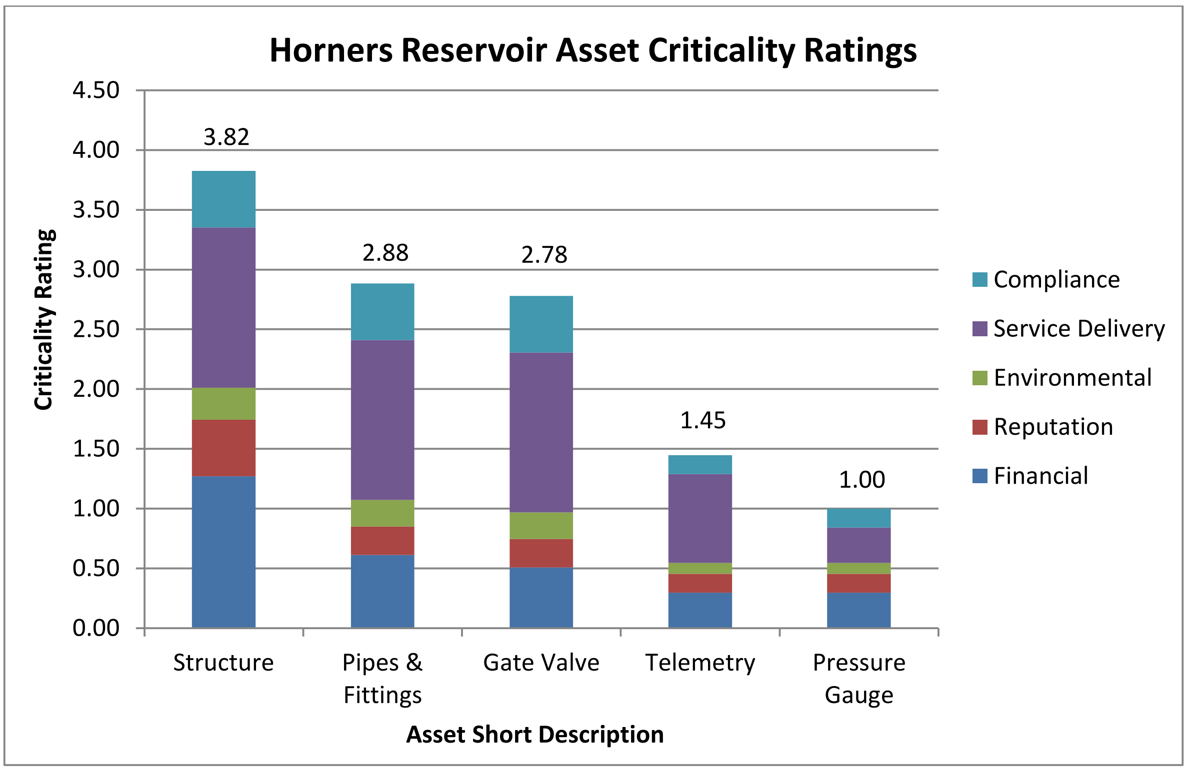

Figure 6.5: Criticality ratings and consequence score distribution for assets within Horners Reservoir site

The reservoir structure received the highest criticality rating of 3.82 which is feasible as the reservoir is expensive, supplies water to over 15,000 people, and is located near houses in a residential area. If the structure were to fail, there would be significant impacts on the budget and service delivery, as reflected by financial and service delivery consequence scores of 1.27/1.49 and 1.34/1.49 respectively.

Conversely, the pressure gauge received the lowest possible criticality rating of 1.0. The manual pressure gauge is a cheap device and has no significant consequence of failure to TRC.

6.2.6 Top Camp Reservoir

The results of the criticality analysis performed on three random assets at Top Camp Reservoir are displayed in Figure 6.6 below.

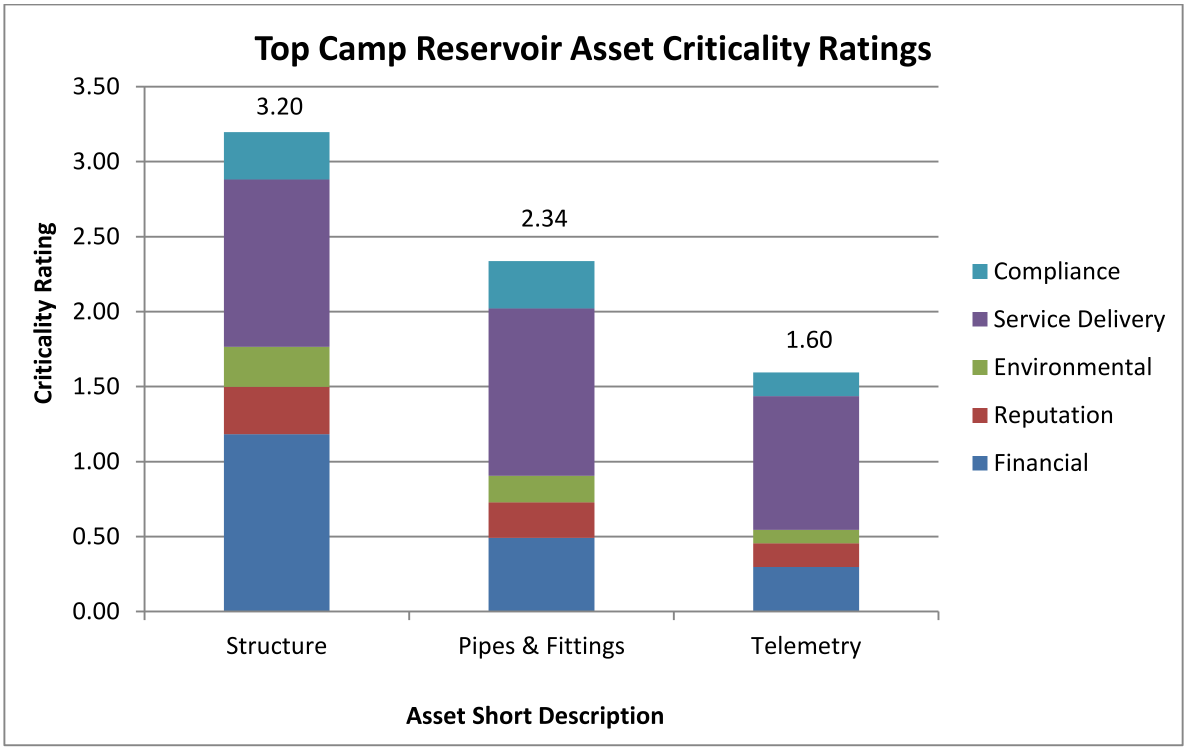

Figure 6.6: Criticality ratings and consequence score distribution for assets within Top Camp Reservoir site

The reservoir structure received the highest criticality rating of 3.2 which is feasible as the reservoir is expensive and supplies water to approximately 700 people. If the structure were to fail, there would be significant impacts on the budget and service delivery, as reflected by financial and service delivery consequence scores of 1.18/1.49 and 1.12/1.49 respectively.

At the other end of the scale, the telemetry received the lowest criticality rating of 1.6 which is a realistic value. The telemetry forms part of the communication system and is generally cheap and easy to fix, as suggested by a low financial consequence score of 0.3/1.49.

6.2.7 Hamblin Bore

The results of the criticality analysis performed on four random assets at Hamblin Bore are displayed in Figure 6.7 below.

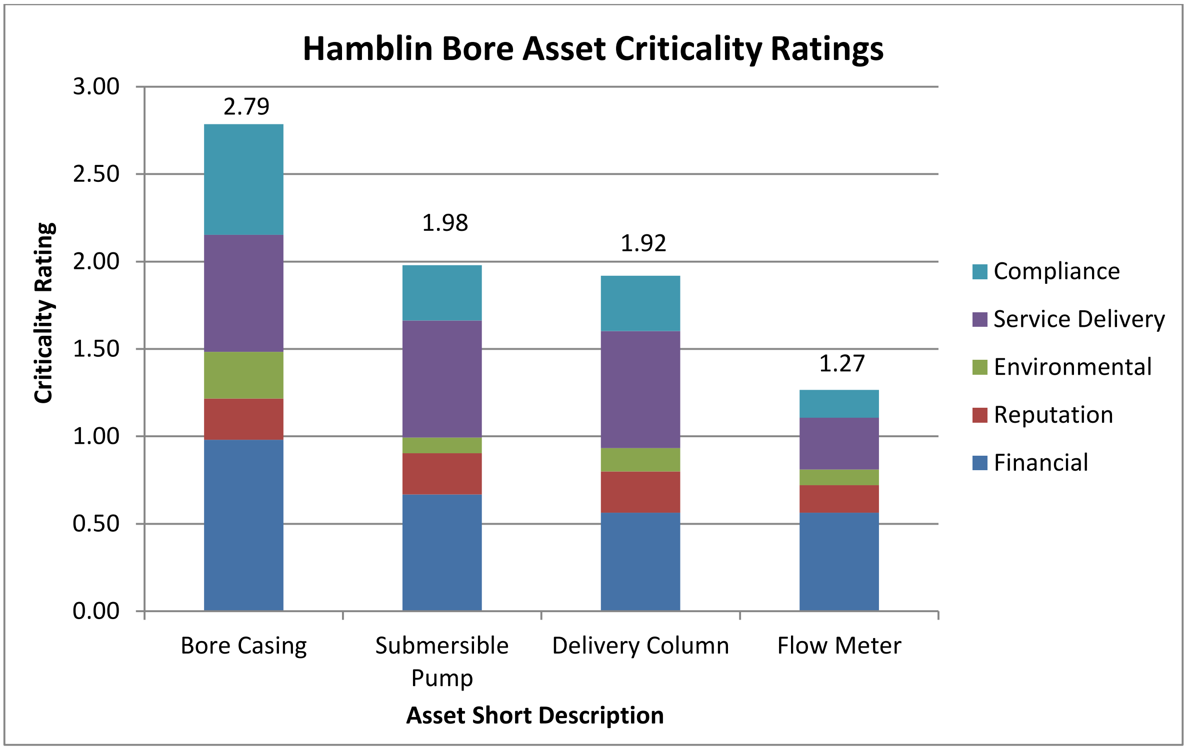

Figure 6.7: Criticality ratings and consequence score distribution for assets within Hamblin Bore site

The bore casing received the highest criticality rating of 2.65 which is feasible, mainly due to high replacement costs in comparison to the other assets analysed. This was reflected in the consequence scores with financial being the largest component with a score of 0.98/1.49. However, the environmental consequence component appears to be quite small with a score of 0.27/0.44. In most cases, raw and potable water does not have a large effect on the environment. However, the failure of a bore casing has the potential for infiltration into the aquifer which may have significant environmental effects. The low score can be attributed to the low weighting applied to the environmental consequence category.

In contrast, the bore flow meter received the lowest criticality rating of 1.27. The purpose of the bore flow meter is to measure raw water flow pumped from the bore to the contact tank. The main consequence of failure would be related to the asset cost and repair difficulty which was reflected by the highest consequence score of 0.56/1.49 in the financial category.

6.2.8 Mackenzie Bore

The results of the criticality analysis performed on five random assets at Mackenzie Bore are displayed in Figure 6.8 below.

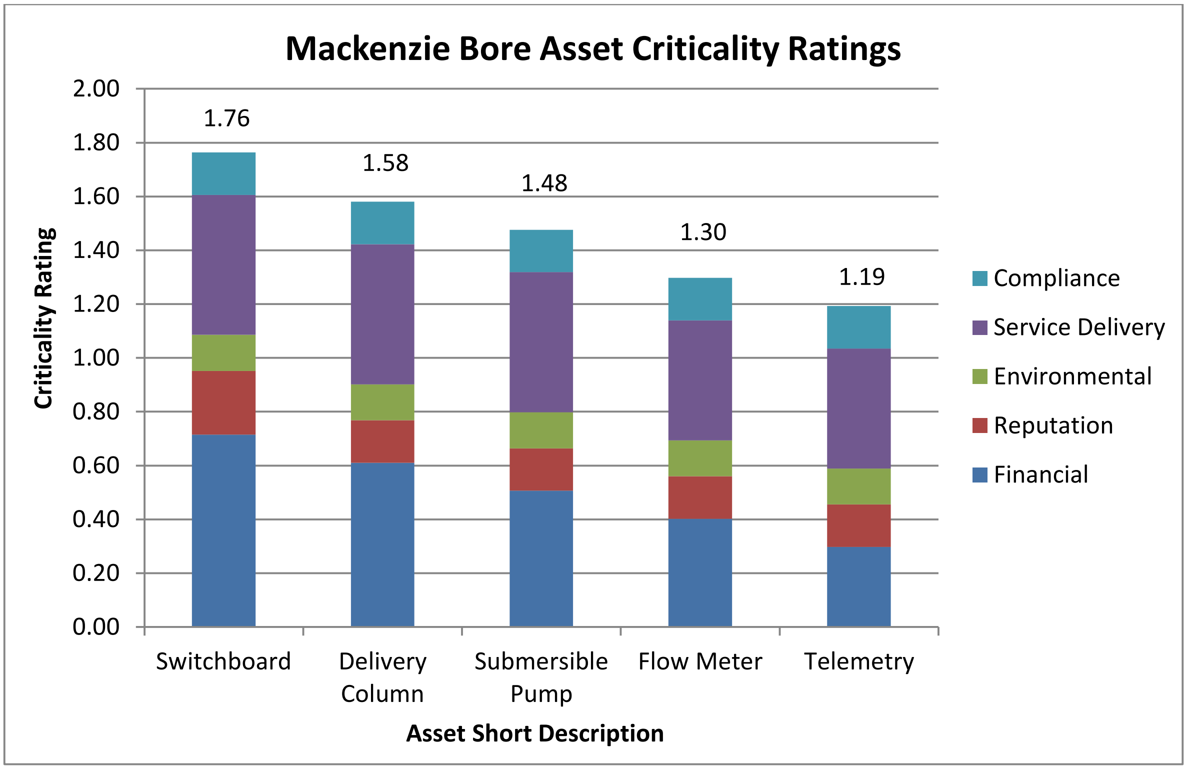

Figure 6.8: Criticality ratings and consequence score distribution for assets within Mackenzie Bore site

The switchboard received the highest criticality rating of 1.76 which is feasible as the switchboard is an expensive component responsible for powering a majority of the equipment on site. Switchboard failure was comprised of predominantly financial and service delivery consequences, which received individual category scores of 0.72/1.49 and 0.52/1.49 respectively.

At the other end of the scale, the telemetry received the lowest criticality rating of 1.19 which is a realistic value. The telemetry forms part of the communication system and is generally cheap and easy to fix, as suggested by low financial consequence score of 0.3/1.49. In this scenario, the highest consequence of failure was in the service delivery category which obtained a score of 0.45/1.49 which was attributed to the potential loss of communication.

6.2.9 Toowoomba Oakey Pipeline

The results of the criticality analysis performed on 52 segments of the Toowoomba Oakey Pipeline are displayed in Figure 6.9 below.

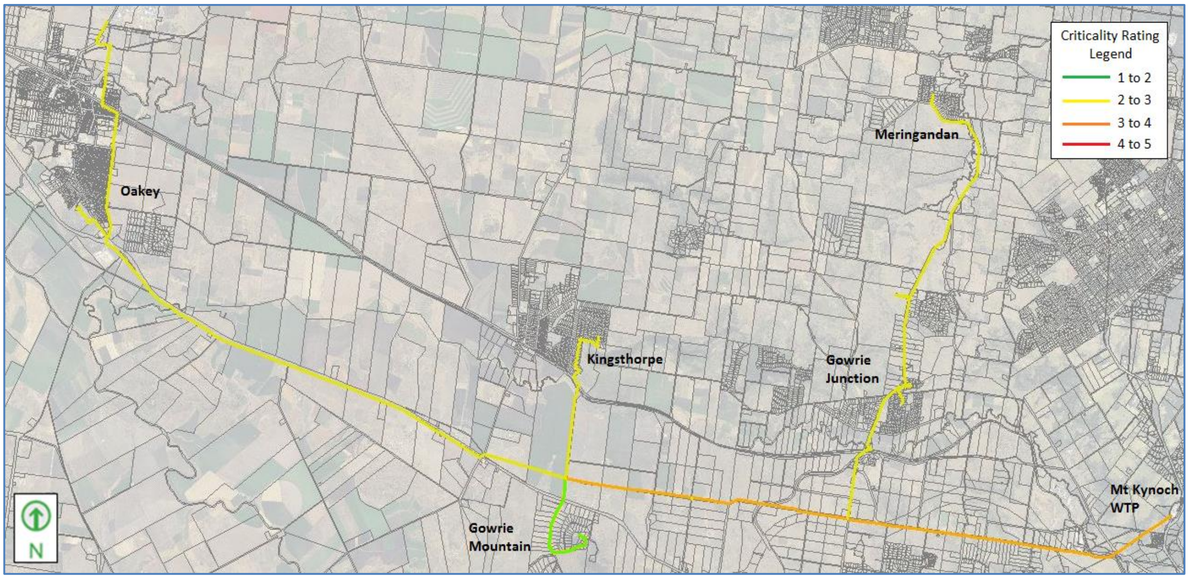

Figure 6.9: Representation of the Toowoomba Oakey Pipeline colour coded by criticality rating

As shown in Figure 6.9, the resulting criticality ratings remained between 1 and 4 over the length of the Toowoomba Oakey Pipeline and a small portion of the Western Trunk Main. The highest criticality rating obtained on the 675mm diameter Western Trunk Main prior to the Toowoomba Oakey Pipeline off-take was 3.58. The highest criticality rating obtained on the Toowoomba Oakey Pipeline was 3.37 at the start of the off-take. Both results are feasible as the Western Trunk Main conveys water to the western half of Toowoomba and to the Toowoomba Oakey Pipeline. The failure of these pipe segments would have a significant impact on service which was reflected in the service delivery consequence score of 1.19/1.49. The highest service delivery score was not obtained due to a small amount of failure tolerance in the system caused by storage reservoirs. At the other end of the scale, the lowest criticality rating obtained was 1.72 for a 100mm water main that services Gowrie Mountain. This was a feasible score due to the ease of repair, pipe location, and low population served.

6.2.10 Blue Mountain Heights Pipeline Network

The results of the criticality analysis performed on 227 pipe segments within the Blue Mountain Heights pressure zone are displayed in Figure 6.10 below.

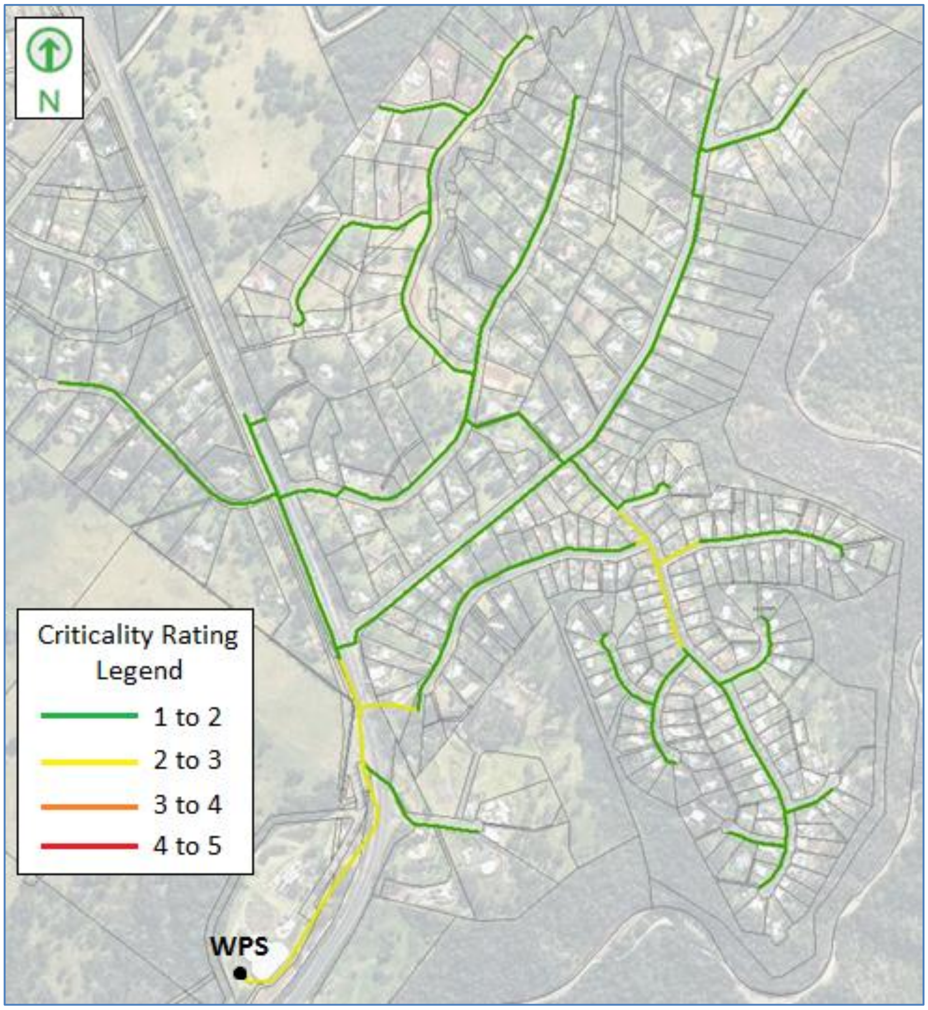

Figure 6.10: Representation of the Blue Mountain Heights pipeline network colour coded by criticality rating

As shown in Figure 6.10, the resulting criticality ratings remained between 1 and 3 throughout the network. The highest criticality rating obtained was 2.32 at the longest segment immediately downstream of the Blue Mountain Heights WPS. This is a realistic result as the failure of a pipe immediately downstream of the WPS would result in full service loss to the entire pressure zone. This was reinforced by the service delivery consequence score of 0.67/1.49 for that particular segment of pipe.

However, there were additional pipe segments located within the residential area that received a criticality between 2 and 3 as indicated by the yellow lines on Figure 6.10. This was an interesting result, particularly because the surrounding pipes received a criticality rating below 2 as depicted by the green lines on Figure 6.10. On closer inspection, the results were realistic due to the configuration of isolation valves in that particular area.

Figure 6.11: Configuration of isolation valves within the Blue Mountain Heights pipeline system

Figure 6.11 shows the isolation valves with a basic numbering scheme. If the pipe segment between Valves 1-2 was to break, the segment would need to be isolated using a valve upstream of Valve 1. This would cut supply to a large number of properties upstream of the pipe break and result in a high service delivery consequence score for that segment. As another example, if the pipe segment between Valves 5-6 was to break, supply would be cut to all residents downstream. Again, this would result in a high service delivery consequence score.

6.3 Wastewater Criticality Ratings

A criticality analysis was performed on a random selection of assets within each wastewater study site. A total of 886 assets were analysed and the results are discussed in the following sections. A full list of the wastewater criticality analysis results is located in Appendix D.

6.3.1 Wetalla Water Reclamation Facility

The results of the criticality analysis performed on eight random assets at Wetalla WRF are displayed in Figure 6.12 below.

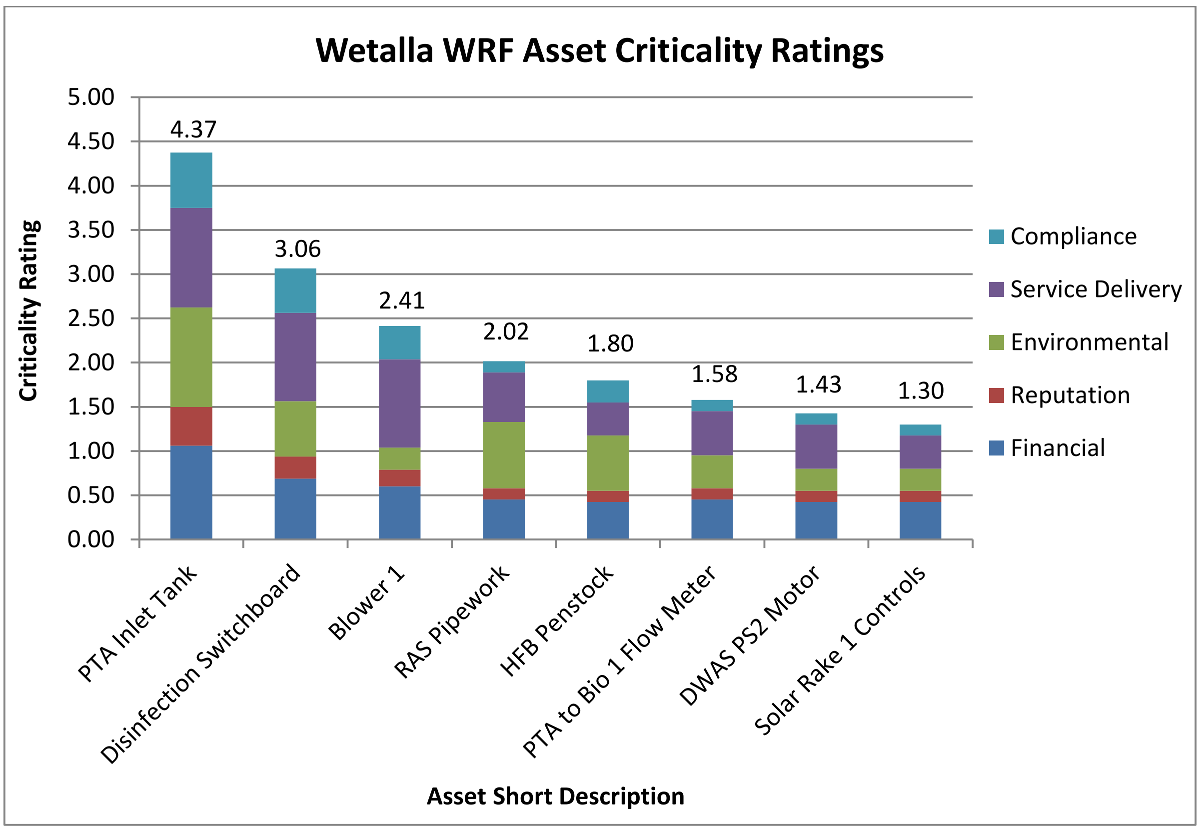

Figure 6.12: Criticality ratings and consequence score distribution for assets within Wetalla WRF site

The preliminary treatment area inlet tank received the highest criticality rating of 4.37 which is viable as the inlet tank is an expensive concrete structure that receives all raw sewage inflow to the plant. The inlet tank was comprised of predominantly financial, environmental and service delivery consequences, which received individual scores of 1.06/1.25, 1.13/1.25 and 1.13/1.25 respectively. These scores are realistic, because if the inlet tank were to structurally fail, the plant would be shut down until it was repaired. This would have a significant effect on the budget, the environment due to large sanitary sewer overflows, and service delivery due to the inability to treat wastewater.

At the other end of the spectrum, the solar rake 1 controls received the lowest criticality rating of 1.30. Again, this seems feasible as the solar rake 1 controls is one of three separate systems designed to control three separate solar rakes which operate on a duty-standby arrangement. If one solar rake control system was to fail, a standby solar rake could be operated so there would be no significant impact to the WWTP. This was reflected in the consequence scores, where the highest value obtained was 0.43/1.25 in the financial category as a direct result of the control price and repair difficulty.

6.3.2 Yarraman Wastewater Treatment Plant

The results of the criticality analysis performed on seven random assets at Yarraman WWTP are displayed in Figure 6.13 below.

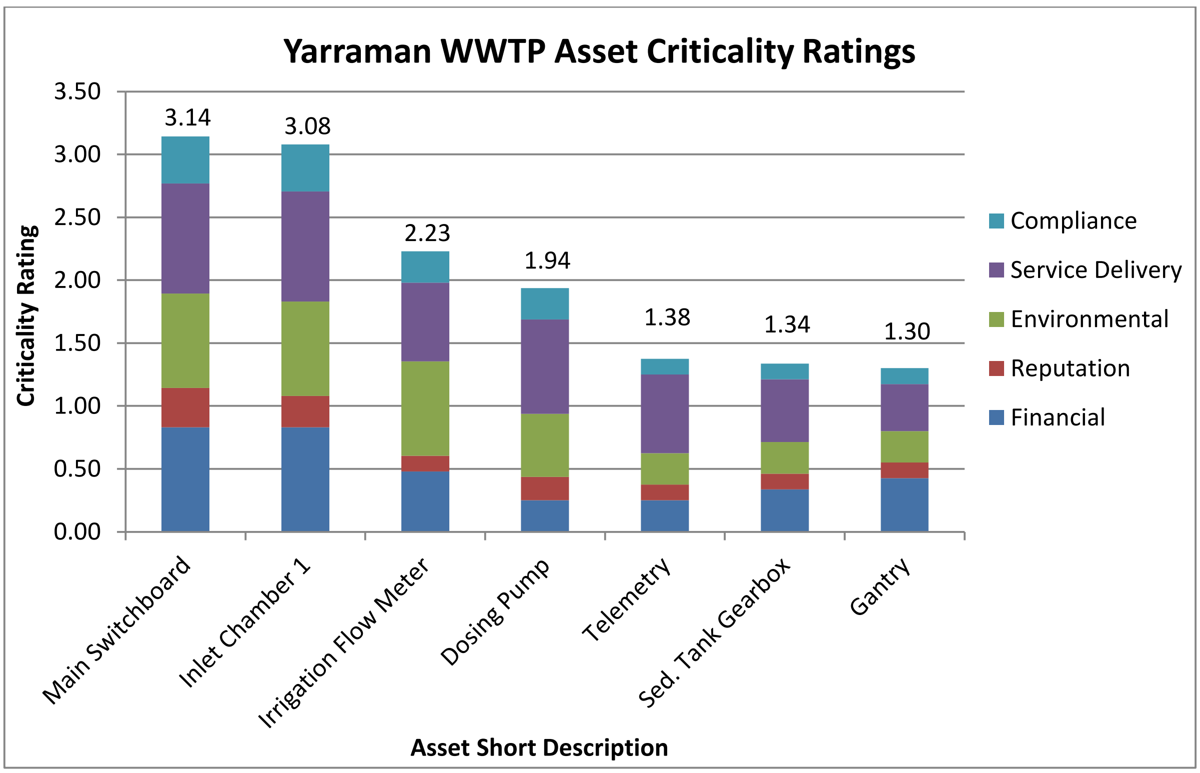

Figure 6.13: Criticality ratings and consequence score distribution for assets within Yarraman WWTP site

The main switchboard received the highest criticality rating of 3.14 which is feasible as the switchboard is an expensive component responsible for powering and controlling a majority of the equipment. Switchboard failure was comprised of predominantly financial, environmental and service delivery consequences, which received individual category scores of 0.83/1.25, 0.75/1.25 and 0.88/1.25 respectively.

Conversely, the gantry received the lowest criticality rating of 1.30. The gantry is designed to assist with the removal of effluent pumps and has no significant influence on plant operation. This was reflected in the consequence scores, where the highest value obtained was 0.43/1.25 in the financial category as a direct result of the asset price and repair difficulty.

6.3.3 Gowrie Junction Wastewater Pump Station

The results of the criticality analysis performed on eight random assets at Gowrie Junction WWPS are displayed in Figure 6.14 below.

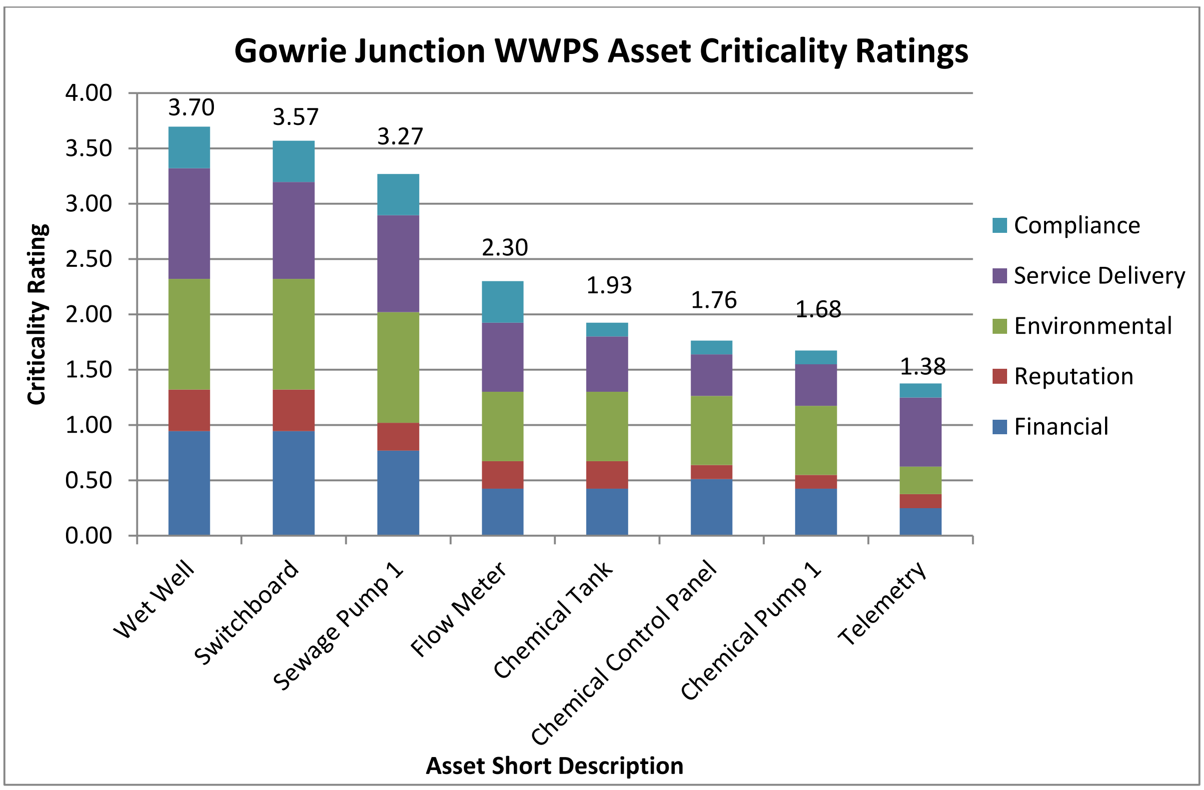

Figure 6.14: Criticality ratings and consequence score distribution for assets within Gowrie Junction WWPS site

The wet well received the highest criticality rating of 3.70 which is viable as the wet well is an expensive item that is required to keep the pump station operational. The wet well obtained a higher rating than the main switchboard which has a small amount of failure tolerance due to available storage in the wet well and overflow tank. Wet well failure was comprised of predominantly financial, environmental and service delivery consequences, which received individual category scores of 0.95/1.25, 1.00/1.25 and 1.00/1.25 respectively.

In contrast, the chemical pump received the lowest criticality rating of 1.68. The chemical pump is one of two pumps responsible for dosing wastewater with Magnesium Hydroxide designed to reduce gas production and associated odour. If the chemical pump were to fail, it would not have an impact on operation due to redundancy in the system.

6.3.4 Boundary Street Wastewater Pump Station (TOPS11)

The results of the criticality analysis performed on seven random assets at Boundary Street WWPS are displayed in Figure 6.15 below.

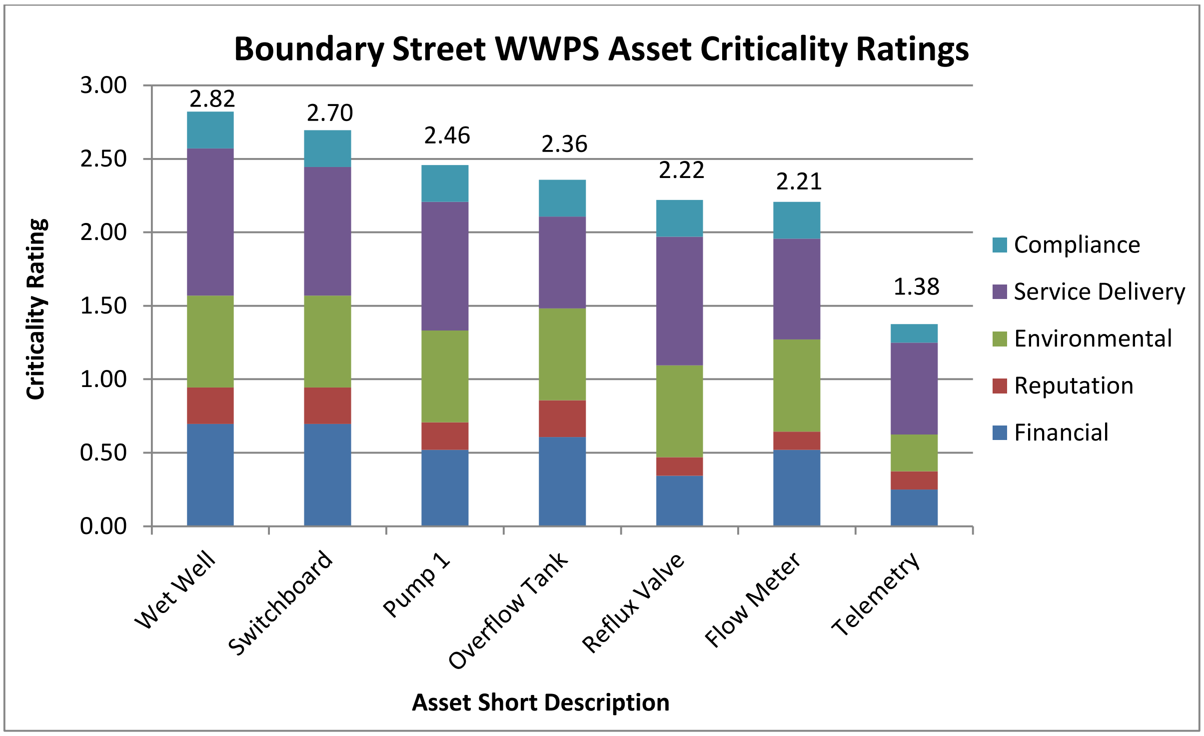

Figure 6.15: Criticality ratings and consequence score distribution for assets within Boundary St WWPS site

The wet well received the highest criticality rating of 2.82 which is reasonable as the wet well is an expensive item that is required to keep the pump station operational. The wet well obtained a higher rating than the main switchboard which has a small amount of failure tolerance due to available storage in the wet well and overflow tank. Wet well failure was comprised of predominantly financial, environmental and service delivery consequences, which received individual category scores of 0.70/1.25, 0.63/1.25 and 1.00/1.25 respectively.

At the other end of the scale, the telemetry received the lowest criticality rating of 1.38 which is a realistic value. The telemetry forms part of the communication system and is generally cheap and easy to fix, as suggested by the low financial consequence score of 0.25/1.25. In this scenario, the highest consequence of failure was in the service delivery category which obtained a score of 0.63/1.25. This was attributed to the potential loss of communication.

6.3.5 Boundary Street Wastewater Pump Station (TOPS11) Pipeline Network

The results of the criticality analysis performed on 52 segments of the Boundary Street WWPS pipeline network are displayed in Figure 6.16 below.

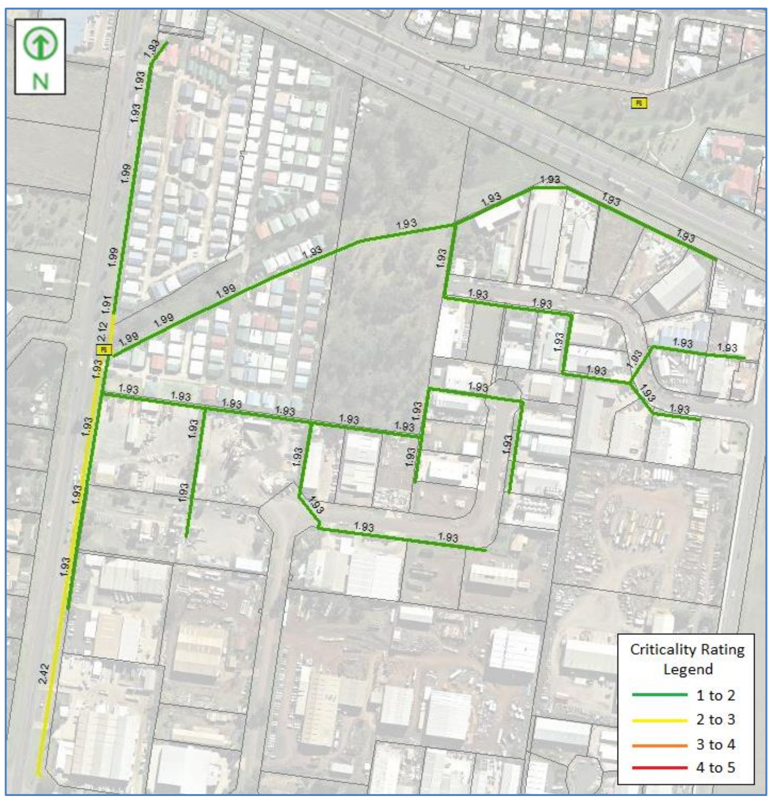

Figure 6.16: Representation of the Boundary St WWPS pipeline network colour coded by criticality rating

As shown in Figure 6.16, the resulting criticality ratings remained between 1 and 3 throughout the network. The highest criticality rating obtained was 2.42 for the longest segment of rising main from TOPS11 to a discharge manhole. This was a realistic result as the rising main conveys wastewater from the entire TOPS11 catchment and its failure would result in a pressurised sanitary sewer overflow. The second highest criticality rating obtained was 2.41 for a small gravity segment that feeds from a manhole directly into TOPS11. Like the pressure segment, it conveys wastewater from the entire TOPS11 catchment and its failure would result in a large sanitary sewer overflow.

A majority of the gravity segments obtained a criticality rating below 2 which was mainly due to the small amount of customers feeding each pipeline. This was an expected result as the TOPS11 catchment is small and a majority of the pipes are not located near a sensitive environmental area.

6.3.6 Gowrie Junction Wastewater Pump Station Rising Main

The results of the criticality analysis performed on six segments of the Gowrie Junction WWPS rising main are displayed in Figure 6.17 below.

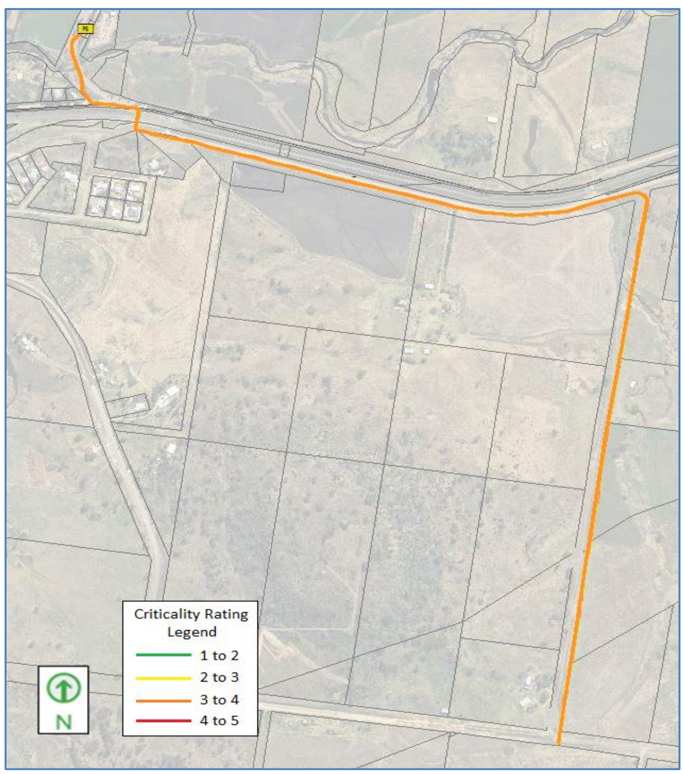

Figure 6.17: Representation of the Gowrie Junction WWPS rising main colour coded by criticality rating

As shown in Figure 6.17, the resulting criticality ratings remained between 3 and 4 along the 375 mm diameter rising main. The highest criticality rating obtained was 3.23 for a 1500 m long segment that crosses a large waterway. This was an expected result due to the size of the pipeline, the amount of wastewater it conveys and its close proximity to a sensitive area.

Although it cannot be seen on Figure 6.17, the lowest criticality rating obtained was 2.76 for a 3.6m long section of pipe from the pump to the next rising main segment which obtained the highest criticality rating. This was an unexpected result as the small segment conveyed the same amount of wastewater, it was located in a similar proximity to a waterway and had a comparable amount of media exposure in the event of failure. The only difference was the length of the pipe which had an impact on the asset cost due to the way the severity criteria was developed.

6.3.7 Highfields Wastewater Pipeline Network

The results of the criticality analysis performed on 798 segments of the Highfields pipeline network are displayed in Figure 6.18 below.

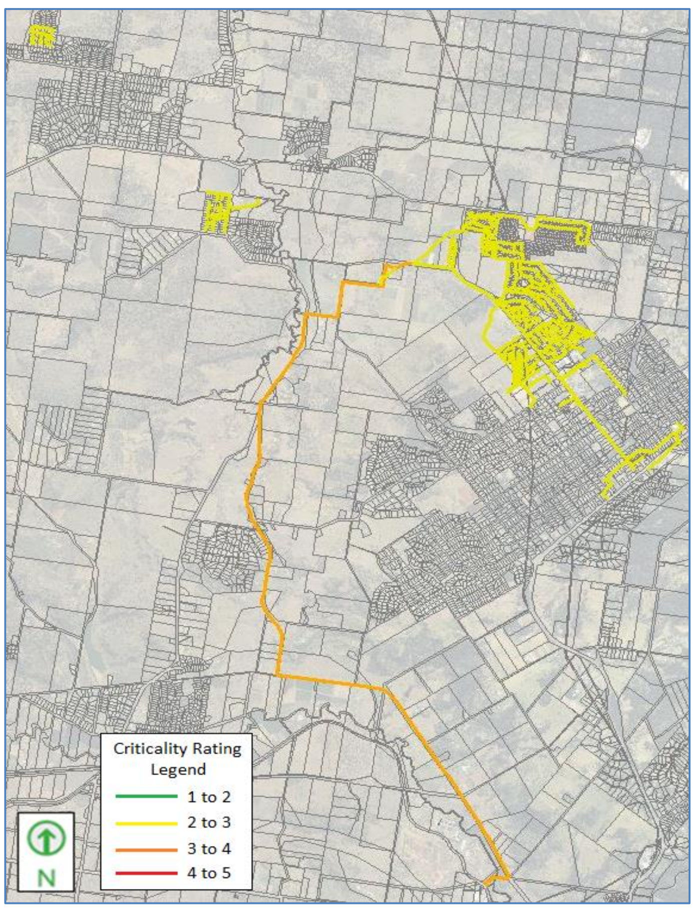

Figure 6.18: Representation of the Highfields pipeline network colour coded by criticality rating

As shown in Figure 6.18, the resulting criticality ratings remained between 2 and 4 throughout the network. The highest criticality rating obtained was 3.50 for a long section of 750mm diameter gravity main designed to cater for the population of Highfields. This rating was plausible due to the size of the pipe, the amount of customers served and the fact that it was located near a waterway. The second highest criticality rating obtained was 3.32 for a long segment of 300 mm diameter TWIP rising main that discharges to Wetalla WRF. Again, this rating was realistic as the pipe segment conveyed all wastewater from Highfields and crossed a waterway.

A majority of the gravity segments obtained a criticality rating between 2 and 3, most of which were closer to 2. Again, this was a viable result due to the residential density in Highfields which created high wastewater flows and increased the chance of third party damage and public health and safety risks.

6.4 Additional Observations

There were a number of observations made that were common to a majority of the results. These outcomes indicated that the asset cost criteria needed to be modified to cater for small segments of pipe. As discussed in section 6.3.5 and 6.3.6, there were small segments of pipe that performed the same function as larger segments but received a substantially lower criticality rating. This was due to the asset cost criteria which determined the total cost of each pipe segment by multiplying the unit rate by the distance. This was an accurate reflection of the pipe segment but not of the replacement cost in the event of failure. The asset cost criteria could be improved by basing the value on a unit rate, pipe diameter or a unit rate multiplied by a fixed replacement length for passive assets. This would ensure the criteria focuses on the function of the asset without being influenced by the segment length.

Similarly, the asset cost criteria should be modified to provide more granularity for expensive assets. As observed in section 6.2.5 and 6.2.6, Top Camp reservoir received the same asset cost severity score as Horner's reservoir even though Horner's was significantly larger and more expensive than Top Camp. This could be improved by increasing the scale of the severity criteria to cater for more expensive assets. However, the criteria weightings would require a review in order to reflect the relative importance of the asset cost criteria based on the new severity scores.

In addition, it was evident that existing pipe segmentation rules influenced the application of severity criteria. In GIS, WaterGEMS and the WIS asset register, pipelines are segmented at a junction, valve or change in physical attribute such as pipe diameter or material. Pipe segments may be kilometres long before a change is encountered. This caused difficulty in assigning a severity score, particularly when a pipe segment crossed multiple locational boundaries or passed through a sensitive environmental area. This was apparent in the Highfields wastewater pipeline network where a 6000 metre rising main segment was within the proximity of a waterway for approximately 2000 metres. However, the entire segment was allocated a major severity score which increased the criticality rating of the 2000 metre portion of pipe. This could be improved by creating additional layers in GIS to segment assets at a change of location. For example, pipes could be segmented at road crossings, waterways and at the boundary of planning zones to ensure the severity score is accurately represented across the entire asset length.

6.5 Maintenance Recommendations

The criticality analysis provided a range of results that were assessed against Table 3.12 to propose a particular asset maintenance or monitoring technique. A total of 324 water assets and 886 wastewater assets were analysed and the distribution of criticality ratings are displayed in Table 6.1 below.

Table 6.1: Distribution of water and wastewater criticality ratings

Criticality Rating	Number of Water Assets	Number of Wastewater Assets
1 to 2	227	59
2 to 3	84	806
3 to 4	13	20
4 to 5	0	1

It should be noted that the distribution of criticality ratings was representative of the assets analysed in this dissertation only and would differ if performed on the entire water and wastewater asset base. For instance, the Highfields pipeline network accounted for approximately 90.1% of wastewater assets analysed in this dissertation which skewed a majority of the criticality ratings between 2 and 3.

6.5.1 Non-Critical Assets

As discussed in Table 6.1, approximately 70.1% of the water assets and 6.7% of the wastewater assets received a criticality rating between 1 and 2. Assets within this range have minor failure consequences and are not deemed as critical. The criticality rating indicated that these assets would benefit from RTF management or basic condition monitoring.

6.5.2 Partially Critical Assets

As discussed in Table 6.1, approximately 25.9% of the water assets and 91% of the wastewater assets received a criticality rating between 2 and 3. Assets within this range have moderate failure consequences and are considered partially critical. The criticality rating indicated that these assets would benefit from a PM approach and basic condition monitoring.

6.5.3 Critical Assets

As discussed in Table 6.1, approximately 4% of the water assets and 2.3% of the wastewater assets received a criticality rating between 3 and 4. Assets within this range have major failure consequences and are deemed as critical. These assets would benefit from a PM approach, detailed condition monitoring and RCM if resources permit.

6.5.4 Extremely Critical Assets

As discussed in Table 6.1, no water assets and approximately 0.113% of the wastewater assets received a criticality rating between 4 and 5. Assets within this range have catastrophic failure consequences and are considered as extremely critical. These assets would benefit from PdM, RCM, detailed condition assessments and performance monitoring to reduce the risk of unexpected asset failure.

Chapter 7 – Conclusions

7.1 Introduction

The aim of this dissertation was to develop the methodology and tools required for TRC to perform an asset criticality analysis on its water and wastewater asset base. This chapter compiles significant outcomes from the dissertation and summarises them in the structure outlined below:

- Research limitations encountered.
- Further research and recommendations to improve the criticality framework.
- General conclusions.
- Suggestions for future work.

7.2 Limitations

Notable limitations were encountered throughout the development of this dissertation. Due to time constraints, the study was conducted on a small sample of assets which was not truly representative of the water and wastewater asset base. It was difficult to identify whether the distribution of criticality ratings was realistic without performing a criticality analysis on a large sample size. This made it challenging to assess the performance of the criticality criteria and identify whether severity scales and guidelines required calibration. However, this limitation could be addressed by increasing the size of the dataset in future studies.

The results were dependent on the quality of data used in the criticality analysis. It was expected that data obtained from TechnologyOne, GIS, WaterGEMS, SCADA and operator knowledge was recently validated and suitable for use in a criticality analysis. If the data used to assign severity scores was incorrect it would affect the criticality ratings and provide inaccurate results. This could have consequential effects on decision making and lead to incorrect prioritisation of maintenance activities. Where possible, asset information was validated as part of this dissertation and a conscious effort was made to obtain data from recent hydraulic models.

The results were influenced by the type and availability of data used in the analysis. There was a substantial variation in the precision of available data which prompted the use of a mixture of qualitative and semi-quantitative severity criteria. This meant that severity criteria were potentially influenced by personal biases, opinions or exaggeration. The impact of the limitation was controlled by introducing criteria guidelines to provide consistency around the application of qualitative data and criteria. However, this limitation could be significantly reduced by introducing additional severity score guidelines or progressively updating data and revising criteria as quantitative information becomes available.

In addition, there was a lack of detailed research studies available on the topic of asset criticality for water and wastewater infrastructure. A majority of the literature only provided examples of the methodology used to determine equipment criticality specific to a particular organisation or field. Similarly, the analysis performed in this dissertation was specific to TRC which meant there was no baseline or metrics available to measure the success of results. The effects of this limitation were reduced by performing a qualitative analysis of results using the knowledge of WIS assets to determine the feasibility of results.

7.3 Conclusion

Three primary objectives were announced in the preliminary phase of this dissertation. The first was to create and document customised criticality framework and methodologies for water and wastewater infrastructure at TRC. Typical failure modes and effects of water and wastewater infrastructure were identified and used to influence the development of criticality criteria. Detailed consequence factors were created and aligned to the corporate risk policy to ensure consequences were assessed in accordance with the interests of the organisation. Severity scores and guidelines were produced to quantify the intensity of the consequence factors. The consequence factors were weighted using a pairwise comparison approach that accounted for the opinions of WIS managers, engineers and maintenance planners. A method was established to derive an overall criticality rating based on the combination of severity scores and criteria weights. Overall, Chapter 3 resulted in a detailed criticality analysis methodology for water and wastewater infrastructure at TRC which could easily serve as a self-contained document. The methodology was developed with consideration for the current asset structure, risk policies and the availability of data to provide a customised solution for

WIS. In addition, the methodology could be adapted to suit other organisations. However, consequence criteria and severity criteria would differ due to business priorities and the availability of data or resources.

The second objective was to develop a partially automated calculator to obtain a criticality rating for water and wastewater assets. This objective was achieved by creating multiple MS Excel calculators based on the criticality analysis methodologies established in Chapter 3. A pipe analysis calculator was created which automatically produced severity scores based on data extracted from hydraulic models. A second calculator was created which automatically generated criticality ratings based on severity scores input by the user. The calculators were user friendly, easily customisable and were able to reduce the time required to process a large amount of data. The calculators were designed with hyperlinked navigation buttons and a dashboard to automatically summarise and display important information. Overall, the calculators performed the required function and could be adopted by TRC without modification. Alternatively, the same concepts and formulas could be incorporated into TRC's EAM system as time and resources permit.

The final objective was to determine the criticality of all assets within the scope of the study using the partially automated MS Excel calculators. The criticality analysis methodology and MS Excel calculators were applied to a range of water and wastewater assets to obtain criticality ratings. The most critical and the least critical asset at each study site were analysed separately to determine whether the results were feasible. The results obtained for active water and wastewater assets were all realistic and each criticality rating accurately reflected the relative importance of each asset. Similarly, the results for the passive water and wastewater assets were credible but it was evident that the asset cost criteria required modification to obtain more accurate criticality ratings.

Overall, the development of water and wastewater asset criticality framework was an important step toward the implementation of a total asset management system at TRC. The methodology and tools developed in this dissertation provide a comprehensive foundation for WIS to standardise decision-making, identify critical assets and prioritise asset management activities to optimise the distribution of funds and resources.

7.4 Future Work

There is a great potential for future research. Firstly, the analysis could be applied to a larger dataset to analyse the effectiveness of the criticality framework. Based on the results, recommendations could be provided to optimise the severity criteria, criticality ratings and criticality calculators. The optimised criticality analysis framework could be integrated with TRC's current EAM system to reduce data handling and retain a single point of truth.

Secondly, the framework and methodology required to determine the likelihood of asset failure could be developed for water and wastewater infrastructure. The results could be combined with a criticality analysis to obtain an overall business risk which could be used to forecast maintenance budget requirements or develop an asset renewal plan.

Finally, a standardised criticality framework and methodology could be developed for different levels of organisational maturity. A maturity assessment process could be established to analyse available data and resources which could then be used to recommend the appropriate level at which to perform a criticality analysis. A standard set of qualitative, semi-quantitative and quantitative guidelines could be established ready for immediate use based on the outcome of the maturity assessment. A set of standardised templates could be created to accompany the standardised criticality framework. This approach would allow a criticality assessment to be implemented as fast as possible without the need for a lengthy development process and would avoid the need to reinvent the wheel.

Chapter 8 – References

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Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION (CONFIDENTIAL)

FOR: **CAMPBELL OLSEN**

TOPIC: DEVELOPMENT AND EXECUTION OF ASSET CRITICALITY AND MAINTENANCE FRAMEWORK: A QUANTATIVE STUDY OF WATER AND WASTEWATER INFRASTRUCTURE AT TOOWOOMBA REGIONAL COUNCIL

SUPERVISORS: Nateque Mahmood

ENROLMENT: ENG4111 (S1, 2015) and ENG4112 (S2, 2015)

PROJECT AIM: To develop and apply asset criticality and maintenance framework to a pilot group of water and wastewater infrastructure at Toowoomba Regional Council.

SPONSORSHIP: Toowoomba Regional Council

PROGRAMME: Issue A, 13th March 2015

1. Research background information relating to Enterprise Asset Management (EAM) and compare idealised concepts with the structure at Toowoomba Regional Council.

2. Narrow the research to focus on asset maintenance and prioritisation techniques with a particular emphasis on the criticality aspect of Failure Modes and Effects Criticality Analysis (FMECA).

3. Develop customised criticality framework and methodologies for water and wastewater infrastructure at TRC. This will involve:

    a. Identification of critical asset groups and asset types.

    b. Development of risk based assessment criteria (likelihood x consequence) for each asset group in line with TRC risk policies. This will include documentation and justification of all outcomes.

4. Develop a partially automated risk tool/model based on the risk criteria identified in the previous step.

5. Apply the criticality framework and risk tool/model to a pilot group of water and/or wastewater assets at TRC and examine the outputs. This will include:

    a. Analysis of the results to determine successes, issues and differences between expected and actual outputs etc.

    b. Adjust or calibrate the tool based on findings and repeat the process.

    c. Use the results from the calibrated tool to identify high priority "critical" infrastructure (biggest risk to TRC's organisational values) which must be placed on a strict maintenance or condition assessment routine.

Appendix B – Criticality Analysis Calculator

Appendix B1 – Examples of Navigation Tab

NAVIGATION	
SUMMARY	
Dashboard of Statistics	Provides an overview of key statistics.
CRITICALITY ANALYSIS	
Pipe Criticality	Calculates the criticality rating of wastewater pipelines based on severity data.
WWTP and WWPS Criticality	Calculates the criticality rating of active wastewater assets based on severity data.
Combined Criticality Data	Combines the pipe criticality, WWTP and WWPS data into one common sheet.
CRITERIA DEVELOPMENT	
Severity Guidelines	A copy of the severity guidelines developed for wastewater assets. Also used for automatic pipe calculations.
Criteria Weightings	Provides a summary of weightings used in water calculations. There is also an option to manually override weightings.
Pairwise Comparisons	Contains all pairwise comparisons and associated calculations to derive criteria weightings.

Figure B 1: Screenshot of navigation tab

Appendix B2 – Examples of Dashboard Tab

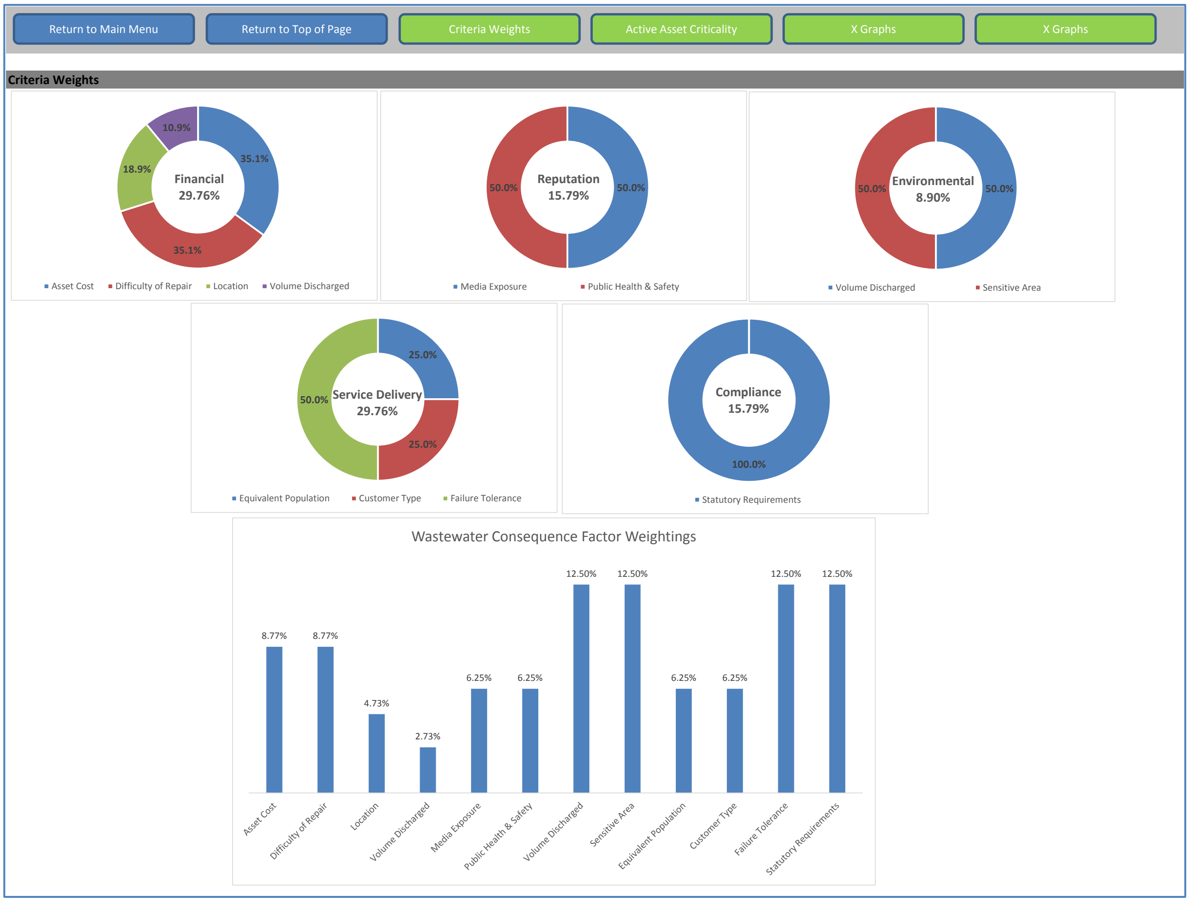

Figure B 2: Screenshot of dashboard tab

Appendix B3 – Examples of Pipe Criticality Calculator Tab

Asset No.	Label	Start Node	Stop Node	Pipe Length (m)	Diameter	Cover Start (m)	Cover Stop (m)	Cover	Max Flow (L/s)	Gravity EP	EP Affected	Unit Rate	Basic Asset Cost	Zone
TOPS11-G1	14376	9968	9967	6.3	150	1.577	1.862	0.285	0.0	0.0	12.7	259	1631.7	Industrial
TOPS11-G2	14781	2583	MH-124	7	150	2.86	1.47	1.39	0.7	0.0	175.8	259	1813	Industrial
TOPS11-G3	6283	13548	13549	15.6	150	1.363	1.052	0.311	0.5	0.0	135.0	259	4040.4	Industrial
TOPS11-G4	2667	1177	1179	25.7	150	0.894	1.718	0.824	0.0	4.5	4.5	259	6656.3	Industrial
TOPS11-G5	8975	14717	1180	27.5	150	1.512	1.28	0.232	0.2	32.9	37.4	259	7122.5	Industrial
TOPS11-G6	14375	9967	9966	30.3	150	2.192	2.117	0.075	0.0	0.0	12.7	259	7847.7	Industrial
TOPS11-G7	16061	1174	10428	31.4	150	1.908	2.329	0.421	0.0	1.7	7.3	259	8132.6	Industrial
TOPS11-G8	16916	13549	MH-124	33.7	150	1.132	1.47	0.338	0.5	0.0	135.0	259	8728.3	Industrial
TOPS11-G9	2758	12787	9578	34.4	150	1.759	1.225	0.534	0.0	1.3	1.3	259	8909.6	Industrial
TOPS11-G10	8974	1179	14717	35.1	150	1.758	1.512	0.246	0.0	0.0	4.5	259	9090.9	Industrial
TOPS11-G11	15751	2581	10426	36.4	150	1.927	2.143	0.216	0.0	7.5	12.1	259	9427.6	Industrial
TOPS11-G12	14293	1999	1998	37	150	2.217	1.755	0.462	0.0	0.0	10.4	259	9583	Industrial
TOPS11-G13	3955	2582	14718	37.2	150	3.324	2.91	0.414	0.7	0.0	175.8	259	9634.8	Industrial
TOPS11-G14	3956	14718	2583	38.4	150	2.91	2.37	0.54	0.7	0.0	175.8	259	9945.6	Industrial
TOPS11-G15	4091	10424	10426	40.8	150	1.674	2.143	0.469	0.0	1.3	4.4	259	10567.2	Industrial
TOPS11-G16	14782	2586	MH-124	41.9	150	2.194	1.47	0.724	0.3	0.0	83.9	259	10852.1	Industrial
TOPS11-G17	14787	2590	2588	43	150	2.603	2.257	0.346	0.1	0.0	22.2	259	11137	Industrial
TOPS11-G18	14294	2000	1999	43.1	150	1.246	1.847	0.601	0.0	1.4	1.4	259	11162.9	Industrial
TOPS11-G19	15734	1652	2581	45	150	1.139	1.267	0.128	0.0	4.6	4.6	259	11655	Industrial
TOPS11-G20	14786	2589	2588	46.4	150	1.464	2.177	0.713	0.1	16.3	41.9	259	12017.6	Industrial
TOPS11-G21	1501	1996	1999	46.9	150	1.865	2.137	0.272	0.0	2.8	9.1	259	12147.1	Industrial
TOPS11-G22	15110	2587	2586	47	150	2.006	1.924	0.082	0.2	5.5	69.6	259	12173	Industrial
TOPS11-G23	14785	2588	2587	50.7	150	2.257	2.006	0.251	0.2	0.0	64.1	259	13131.3	Industrial
TOPS11-G24	15919	9578	10424	52	150	2.315	1.634	0.681	0.0	1.8	3.1	259	13468	Industrial
TOPS11-G25	14763	1997	2589	54.4	150	2.745	1.464	1.281	0.1	1.4	25.6	259	14089.6	Industrial
TOPS11-G26	15927	10425	10423	56.2	150	1.32	1.504	0.184	0.1	3.4	21.6	259	14555.8	Industrial
TOPS11-G27	15707	10423	1166	60	150	1.534	1.281	0.253	0.1	1.4	23.0	259	15540	Industrial
TOPS11-G28	15705	1166	1165	60.9	150	1.311	1.542	0.231	0.1	3.1	26.1	259	15773.1	Industrial
TOPS11-G29	14788	2592	2591	62.3	150	1.791	1.53	0.261	0.0	0.0	14.3	259	16135.7	Industrial
TOPS11-G30	15928	10426	10425	62.9	150	2.193	1.29	0.903	0.1	1.6	18.2	259	16291.1	Industrial
TOPS11-G31	14291	1998	1997	67	150	2.095	2.335	0.24	0.0	1.1	11.6	259	17353	Industrial
TOPS11-G32	14784	2591	2586	68.9	150	1.55	1.924	0.374	0.0	0.0	14.3	259	17845.1	Industrial
TOPS11-G33	15706	1165	10429	70.1	150	1.582	2.292	0.71	0.1	12.9	39.0	259	18155.9	Industrial
TOPS11-G34	14292	9966	1997	71.9	150	2.117	2.745	0.628	0.0	0.0	12.7	259	18622.1	Industrial
TOPS11-G35	15663	57	1164	72	150	2.836	1.867	0.969	0.0	5.1	5.1	259	18648	Industrial
TOPS11-G36	5808	13550	13548	74.4	150	1.375	1.333	0.042	0.5	0.0	135.0	259	19269.6	Industrial
TOPS11-G37	14327	9970	9969	75.1	150	1.383	1.237	0.146	0.0	12.7	12.7	259	19450.9	Industrial
TOPS11-G38	14760	1657	2592	76.9	150	1.895	1.761	0.134	0.0	14.3	14.3	259	19917.1	Industrial
TOPS11-G39	14759	1656	2590	80.3	150	1.611	2.603	0.992	0.1	22.2	22.2	259	20797.7	Industrial
TOPS11-G40	2317	10428	10429	80.8	150	2.349	2.342	0.007	0.0	0.8	8.1	259	20927.2	Industrial
TOPS11-G41	15704	1164	1174	83.4	150	1.897	1.888	0.009	0.0	0.5	5.6	259	21600.6	Industrial
TOPS11-G42	14377	9969	9968	83.4	150	1.267	1.507	0.24	0.0	0.0	12.7	259	21600.6	Industrial
TOPS11-G43	14301	13061	2580	87.9	150	1.573	2.616	1.043	0.0	2.6	2.6	259	22766.1	Industrial
TOPS11-G44	15736	2580	1996	88.7	150	2.686	1.795	0.891	0.0	3.7	6.3	259	22973.3	Industrial
TOPS11-G45	3465	1180	13550	89.6	150	1.31	1.355	0.045	0.5	97.6	135.0	259	23206.4	Industrial
TOPS11-G46	8250	1175	1182	89.8	150	1.664	3.007	1.343	0.2	3.0	51.5	259	23258.2	Industrial
TOPS11-G47	6147	10429	1175	90.8	150	2.372	1.634	0.738	0.2	1.4	48.5	259	23517.2	Industrial
TOPS11-G48	3466	1182	2582	90.8	150	3.027	3.294	0.267	0.7	124.4	175.8	259	23517.2	Industrial
TOPS11-G49	CO-14	MH-124	TOPS11	3.2	150	1.47	1.49	0.02	1.4	0.0	394.7	259	828.8	Industrial
TOPS11-P1	P-32	J-19	2479	407.6	100 -	-	-		10.1 -		394.7	210	85596	Industrial
TOPS11-P2	P-33	TOPS11	PMP-7	3.3	100 -	-	-		10.1 -		394.7	210	693	Industrial
TOPS11-P3	P-34	PMP-7	J-19	3.6	100 -	-	-		10.1 -		394.7	210	756	Industrial

Figure B 3: Partial screenshot of pipe criticality tab - asset details

Asset No.	Asset Cost	Difficulty of Repair	Volume Discharged	Location	Media Exposure	Potential for Injury	Proximity to Sensitive Area	Population Affected	Customer Type	Failure Tolerance	Statutory Requirements
TOPS11-G1	1	1	1	3	1	1	2	1	3	5	1
TOPS11-G2	1	1	1	3	1	1	3	2	3	5	1
TOPS11-G3	1	1	1	3	1	1	2	2	3	5	1
TOPS11-G4	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G5	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G6	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G7	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G8	2	1	1	3	1	1	3	2	3	5	1
TOPS11-G9	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G10	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G11	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G12	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G13	2	1	1	3	1	1	2	2	3	5	1
TOPS11-G14	2	1	1	3	1	1	2	2	3	5	1
TOPS11-G15	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G16	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G17	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G18	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G19	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G20	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G21	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G22	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G23	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G24	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G25	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G26	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G27	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G28	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G29	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G30	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G31	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G32	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G33	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G34	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G35	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G36	2	1	1	3	1	1	2	2	3	5	1
TOPS11-G37	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G38	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G39	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G40	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G41	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G42	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G43	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G44	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G45	2	1	1	3	1	1	2	2	3	5	1
TOPS11-G46	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G47	2	1	1	3	1	1	2	1	3	5	1
TOPS11-G48	2	1	1	3	1	1	2	2	3	5	1
TOPS11-G49	1	1	1	3	2	2	4	2	3	5	2
TOPS11-P1	4	1	1	3	2	2	2	2	3	5	2
TOPS11-P2	1	1	1	3	2	2	2	2	3	5	2
TOPS11-P3	1	1	1	3	2	2	2	2	3	5	2

Figure B 4: Partial screenshot of pipe criticality tab - severity scores

Asset No.	Financial Score	Reputation Score	Environmental Score	Service Delivery Score	Compliance Score	CRITICALITY RATING	DATA CONFIDENCE
TOPS11-G1	0.34	0.13	0.38	0.88	0.13	1.84	High
TOPS11-G2	0.34	0.13	0.50	0.94	0.13	2.03	High
TOPS11-G3	0.34	0.13	0.38	0.94	0.13	1.91	High
TOPS11-G4	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G5	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G6	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G7	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G8	0.43	0.13	0.50	0.94	0.13	2.12	High
TOPS11-G9	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G10	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G11	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G12	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G13	0.43	0.13	0.38	0.94	0.13	1.99	High
TOPS11-G14	0.43	0.13	0.38	0.94	0.13	1.99	High
TOPS11-G15	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G16	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G17	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G18	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G19	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G20	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G21	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G22	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G23	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G24	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G25	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G26	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G27	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G28	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G29	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G30	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G31	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G32	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G33	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G34	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G35	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G36	0.43	0.13	0.38	0.94	0.13	1.99	High
TOPS11-G37	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G38	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G39	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G40	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G41	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G42	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G43	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G44	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G45	0.43	0.13	0.38	0.94	0.13	1.99	High
TOPS11-G46	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G47	0.43	0.13	0.38	0.88	0.13	1.93	High
TOPS11-G48	0.43	0.13	0.38	0.94	0.13	1.99	High
TOPS11-G49	0.34	0.25	0.63	0.94	0.25	2.41	High
TOPS11-P1	0.61	0.25	0.38	0.94	0.25	2.42	Med
TOPS11-P2	0.34	0.25	0.38	0.94	0.25	2.16	Med
TOPS11-P3	0.34	0.25	0.38	0.94	0.25	2.16	Med

Figure B 5: Partial screenshot of pipe criticality tab - consequence scores and criticality ratings

Appendix B4 – Examples of Active Asset Criticality Tab

Asset No.	Asset Description	Asset Group	Asset Sub-Group
		Wastewater Treatment Plant	Parent
00715412	Wetalla WRF - Preliminary Treatment (PTA) - General - Preliminary Treatment Structure	Wastewater Treatment Plant	Civil
00715414	Wetalla WRF - Biological Treatment - Anaerobic/Anoxic Digestion Bioreactor 1 - Pipework (RAS Pump Stations To Tanks 1, 7 & 8)	Wastewater Treatment Plant	Civil
00715055	Wetalla WRF - Electricals & Controls - Biosolids & Solar Dryer MCC - Solar Rake PLC 1 (Tiller Controls)	Wastewater Treatment Plant	Control
00715018	Wetalla WRF - Electricals & Controls - Disinfection MCC - Switchboard	Wastewater Treatment Plant	Electrical
00714804	Wetalla WRF - Digested Sludge Dewatering - Digested WAS Pump Station 2 - Motor 1 (7.5 kW)	Wastewater Treatment Plant	Electrical
00715448	Wetalla WRF - Preliminary Treatment (PTA) - Flow Splitting - Flow Splitter To Bioreactor 1 Flow Meter	Wastewater Treatment Plant	Instrumentation
00714603	Wetalla WRF - Aerobic Digestion - Aerobic Digester Blowers - Blower 1	Wastewater Treatment Plant	Mechanical
00714811	Wetalla WRF - High Flow Bypass - Penstock 1	Wastewater Treatment Plant	Mechanical
		Wastewater Treatment Plant	Parent
00012257	Yarraman STP - Inlet Chamber 1	Wastewater Treatment Plant	Civil
00012295	Yarraman STP - Effluent Pump Station - Gantry	Wastewater Treatment Plant	Civil
00173500	Yarraman STP - Electricals & Controls - Remote Telemetry Unit	Wastewater Treatment Plant	Control
00012366	Yarraman STP - Electricals & Controls - Main Switchboard and Controls	Wastewater Treatment Plant	Electrical
00173473	Yarraman STP - Effluent Disposal - Effluent Irrigation Pump Station - Flow Meter (DN100, Magflow)	Wastewater Treatment Plant	Instrumentation
00012265	Yarraman STP - Primary Sedimentation - Tank 1 - Drive Assembly Gearbox	Wastewater Treatment Plant	Mechanical
00173444	Yarraman STP - Disinfection and Discharge - Sodium Hypochlorite Dosing - Dosing Pump (Grundfos)	Wastewater Treatment Plant	Mechanical
		Wastewater Pump Station	Parent
00716834	Gowrie St SPS 66 - Wet Well - Wet Well Structure	Wastewater Pump Station	Civil
00716804	Gowrie St SPS 66 - Chemical Dosing - Storage Tank	Wastewater Pump Station	Civil
00716828	Gowrie St SPS 66 - Electricals & Controls - Telemetry	Wastewater Pump Station	Control
00716839	Gowrie St SPS 66 - Electricals & Controls - Switchboard	Wastewater Pump Station	Electrical
00716805	Gowrie St SPS 66 - Chemical Dosing - Control Panel	Wastewater Pump Station	Electrical
00716838	Gowrie St SPS 66 - Flow Meter (DN375)	Wastewater Pump Station	Instrumentation
00716840	Gowrie St SPS 66 - Pump Set 1 - Pump 1	Wastewater Pump Station	Mechanical
00716801	Gowrie St SPS 66 - Chemical Dosing - Pump 1	Wastewater Pump Station	Mechanical
		Wastewater Pump Station	Parent
00001515	Boundary St SPS 11 - Structure - Wet Well Structure	Wastewater Pump Station	Civil
00013745	Boundary St SPS 11 - Structure - Overflow Storage	Wastewater Pump Station	Civil
00006804	Boundary St SPS 11 - Electricals & Controls - Telemetry	Wastewater Pump Station	Control
00719032	Boundary St SPS 11 - Electricals & Controls - Switchboard (24 kW)	Wastewater Pump Station	Electrical
00006753	Boundary St SPS 11 - Instrumentation - Flow Meter	Wastewater Pump Station	Instrumentation
00719030	Boundary St SPS 11 - Pump & Motor 1 (Forrer 12 kW)	Wastewater Pump Station	Mechanical
00006748	Boundary St SPS 11 - Valves & Fittings - Valve Reflux	Wastewater Pump Station	Mechanical

Figure B 6: Partial screenshot of active assets tab - asset details

Asset No.	Asset Cost	Difficulty of Repair	Volume Discharged	Location	Media Exposure	Potential for Injury (Public)	Proximity to Sensitive Area	Population Affected	Customer Type	Failure Tolerance	Statutory Requirements
	5	5	5	1	4	3	4	5	3	5	5
00715412	5	5	5	1	4	3	4	5	3	5	5
00715414	2	2	2	1	1	1	4	2	3	2	1
00715055	2	2	1	1	1	1	1	1	3	1	1
00715018	3	4	1	1	2	2	4	5	3	4	4
00714804	2	2	1	1	1	1	1	1	3	2	1
00715448	2	2	2	1	1	1	1	1	3	2	1
00714603	3	3	1	1	2	1	1	5	3	4	3
00714811	2	2	1	1	1	1	4	1	3	1	2
	4	4	3	1	2	3	3	3	3	4	3
00012257	4	4	3	1	2	2	3	3	3	4	3
00012295	2	2	1	1	1	1	1	1	3	1	1
00173500	1	1	1	1	1	1	1	1	3	3	1
00012366	4	4	3	1	2	3	3	3	3	4	3
00173473	2	2	3	1	1	1	3	3	3	2	2
00012265	1	2	1	1	1	1	1	1	3	2	1
00173444	1	1	1	1	1	2	3	3	3	3	2
	5	4	4	1	3	3	4	3	3	5	3
00716834	5	4	4	1	3	3	4	3	3	5	3
00716804	2	2	1	1	1	3	4	1	1	3	1
00716828	1	1	1	1	1	1	1	1	1	4	1
00716839	5	4	4	1	3	3	4	3	3	4	3
00716805	2	3	1	1	1	1	4	1	1	2	1
00716838	2	2	1	1	3	1	4	1	3	3	3
00716840	4	3	4	1	3	1	4	3	3	4	3
00716801	2	2	1	1	1	1	4	1	1	2	1
	3	3	1	3	2	2	4	2	4	5	2
00001515	3	3	1	3	2	2	4	2	4	5	2
00013745	3	2	1	3	2	2	4	2	4	2	2
00006804	1	1	1	1	1	1	1	1	1	4	1
00719032	3	3	1	3	2	2	4	2	4	4	2
00006753	2	2	1	3	1	1	4	1	4	3	2
00719030	2	2	1	3	2	1	4	2	4	4	2
00006748	1	1	1	3	1	1	4	2	4	4	2

Figure B 7: Partial screenshot of active assets tab - severity scores

Asset No.	Financial Score	Reputation Score	Environmental Score	Service Delivery Score	Compliance Score	CRITICALITY RATING	DATA CONFIDENCE
	1.06	0.44	1.13	1.13	0.63	4.37	Med
00715412	1.06	0.44	1.13	1.13	0.63	4.37	Med
00715414	0.45	0.13	0.75	0.56	0.13	2.02	Med
00715055	0.43	0.13	0.25	0.38	0.13	1.30	Med
00715018	0.69	0.25	0.63	1.00	0.50	3.06	Med
00714804	0.43	0.13	0.25	0.50	0.13	1.43	Med
00715448	0.45	0.13	0.38	0.50	0.13	1.58	Med
00714603	0.60	0.19	0.25	1.00	0.38	2.41	Med
00714811	0.43	0.13	0.63	0.38	0.25	1.80	Med
	0.83	0.31	0.75	0.88	0.38	3.14	Med
00012257	0.83	0.25	0.75	0.88	0.38	3.08	Med
00012295	0.43	0.13	0.25	0.38	0.13	1.30	Med
00173500	0.25	0.13	0.25	0.63	0.13	1.38	Med
00012366	0.83	0.31	0.75	0.88	0.38	3.14	Med
00173473	0.48	0.13	0.75	0.63	0.25	2.23	Med
00012265	0.34	0.13	0.25	0.50	0.13	1.34	Med
00173444	0.25	0.19	0.50	0.75	0.25	1.94	Med
	0.95	0.38	1.00	1.00	0.38	3.70	Med
00716834	0.95	0.38	1.00	1.00	0.38	3.70	Med
00716804	0.43	0.25	0.63	0.50	0.13	1.93	Med
00716828	0.25	0.13	0.25	0.63	0.13	1.38	Med
00716839	0.95	0.38	1.00	0.88	0.38	3.57	Med
00716805	0.51	0.13	0.63	0.38	0.13	1.76	Med
00716838	0.43	0.25	0.63	0.63	0.38	2.30	Med
00716840	0.77	0.25	1.00	0.88	0.38	3.27	Med
00716801	0.43	0.13	0.63	0.38	0.13	1.68	Med
	0.70	0.25	0.63	1.00	0.25	2.82	Med
00001515	0.70	0.25	0.63	1.00	0.25	2.82	Med
00013745	0.61	0.25	0.63	0.63	0.25	2.36	Med
00006804	0.25	0.13	0.25	0.63	0.13	1.38	Med
00719032	0.70	0.25	0.63	0.88	0.25	2.70	Med
00006753	0.52	0.13	0.63	0.69	0.25	2.21	Med
00719030	0.52	0.19	0.63	0.88	0.25	2.46	Med
00006748	0.34	0.13	0.63	0.88	0.25	2.22	Med

Figure B 8: Partial screenshot of active assets tab - consequence scores and criticality ratings

Appendix B5 – Examples of Criteria Weighting Summary Tab

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Wastewater Criteria Weighting Summary				
Criteria	**Pairwise Weighting**	**Manual Override**	**Weightings Used for Calculations**	**Final Consequence Factor Weighting**
Financial	**25.00%**		**25.00%**	
Asset Cost	35.07%		35.1%	**8.77%**
Difficulty of Repair	35.07%		35.1%	**8.77%**
Location	18.92%		18.9%	**4.73%**
Volume Discharged	10.93%		10.9%	**2.73%**
Reputation	**12.50%**		**12.50%**	
Media Exposure	50.00%		50.0%	**6.25%**
Public Health & Safety	50.00%		50.0%	**6.25%**
Environmental	**25.00%**		**25.00%**	
Volume Discharged	50.00%		50.0%	**12.50%**
Sensitive Area	50.00%		50.0%	**12.50%**
Service Delivery	**25.00%**		**25.00%**	
Equivalent Population	25.00%		25.0%	**6.25%**
Customer Type	25.00%		25.0%	**6.25%**
Failure Tolerance	50.00%		50.0%	**12.50%**
Compliance	**12.50%**		**12.50%**	
Statutory Requirements	100.00%		100.0%	**12.50%**

Figure B 9: Screenshot of criteria weighting summary tab

Appendix B6 – Examples of Pairwise Comparison Tab

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ENTERPRISE CONSEQUENCE CATEGORY WEIGHTINGS (WASTEWATER)					
	Financial	Reputation	Environmental	Service Delivery	Compliance
Financial	1	2.0000	1.0000	1.0000	2.0000
Reputation	0.5000	1	0.5000	0.5000	1.0000
Environmental	1.0000	2.0000	1	1.0000	2.0000
Service Delivery	1.0000	2.0000	1.0000	1	2.0000
Compliance	0.5000	1.0000	0.5000	0.5000	1
SUM	4	8	4	4	8

NORMALISED

	Financial	Reputation	Environmental	Service Delivery	Compliance	Avg	Consistency Measure	Weight
Financial	0.25	0.25	0.25	0.25	0.25	0.25000	5	**25.00%**
Reputation	0.125	0.125	0.125	0.125	0.125	0.12500	5	**12.50%**
Environmental	0.25	0.25	0.25	0.25	0.25	0.25000	5	**25.00%**
Service Delivery	0.25	0.25	0.25	0.25	0.25	0.25000	5	**25.00%**
Compliance	0.125	0.125	0.125	0.125	0.125	0.12500	5	**12.50%**

Figure B 10: Partial screenshot of pairwise comparison tab

Appendix C – Water Criticality Results

Appendix C1 – Active Water Assets

Table C 1: Active water asset criticality ratings

Asset No.	Asset Description	Criticality Rating
00717326	Mount Kynoch - Water Treatment Plant - Disinfection - Chlorination - Disinfection - Chlorination Drum 1	2.60
00717413	Mount Kynoch - Water Treatment Plant - Pre-treatment - Inlet Tank - Structure - Inlet Tank Structure	3.84
00006070	Mount Kynoch - Water Treatment Plant - Electricals & Controls - Citect Computer Control System - Computer Operation Control	2.20
00006112	Mount Kynoch - Water Treatment Plant - Electricals & Controls - General - Clear Water Main Pump Room Switchboard	2.68
00717463	Mount Kynoch - Water Treatment Plant - Flocculation - Flocculator 1 - Flocculator Motor	1.31
00001253	Mount Kynoch - Water Treatment Plant - Filtration - Service Water - Service Water Flow Meter	1.36
00717564	Mount Kynoch - Water Treatment Plant - Chemical Dosing - Magnasol Dosing - Dosing Pump 1	1.96
00006203	Mount Kynoch - Water Treatment Plant - Filtration - Filter 1 - Valves & Fittings - Filter Inlet Actuated Penstock	1.46
00718371	Perseverance WTP - Filtration - Filter - Vessel 1	2.12
00718392	Perseverance WTP - Inflow - Pipes & Fittings	1.96
00718377	Perseverance WTP - Electricals & Controls - SCADA / Telemetry	1.49
00718381	Perseverance WTP - Electricals & Controls - Switchboard	2.25
00718391	Perseverance WTP - Inflow - Flow Meter	1.45
00718365	Perseverance WTP - Booster Pumping - Pump Set 1 - Pump 1	1.76
00718350	Perseverance WTP - Filtration - Backwash - Manual Butterfly Valve (Filter)	1.55
00716445	Anzac Avenue - Water Pump Station (Gabbinbar) - Discharge Main - Common Discharge Pipes & Fittings	2.79
00716456	Anzac Avenue - Water Pump Station (Gabbinbar) - Buildings - Gantry (W.L.L. 2000 kg)	1.63
00716458	Anzac Avenue - Water Pump Station (Gabbinbar) - Remote Telemetry Unit (Elpro)	1.30
00716483	Anzac Avenue - Water Pump Station (Gabbinbar) - Electrical & Controls - Switchboard	2.61
00716454	Anzac Avenue - Water Pump Station (Gabbinbar) - Pump Set 1 - Motor 1 (Teco, 250 kW)	2.38
00716466	Anzac Avenue - Water Pump Station (Common) - Disinfection - Chlorine Analyser (Grundfos Alldos)	1.59

Asset No.	Asset Description	Criticality Rating
00716457	Anzac Avenue - Water Pump Station (Gabbinbar) - Pump Set 1 - Pump 1 (Borg Warner,250x300x500)	2.61
00716427	Anzac Avenue - Water Pump Station (Gabbinbar) - Pump Set 1 - Discharge Non Return Valve	2.46
00717118	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - General Pipes & Fittings	2.46
00717104	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Electrical & Controls - Switchboard	2.58
00717092	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Instrumentation - Chlorine Analyser	1.59
00717116	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Pump Sets - Pressure Pump 1	1.85
00717099	Mount Kynoch - Water Pump Stations - Export Clear Water - Hydrovar Pump Station - Valves & Fittings - Reflux Valve	1.94
00713889	Horners Reservoir R19 - Structure	3.82
00713892	Horners Reservoir R19 - Pipes & Fittings	2.88
00713893	Horners Reservoir R19 - Telemetry Unit	1.45
00713899	Horners Reservoir R19 - Instrumentation - Pressure Gauge	1.00
00713894	Horners Reservoir R19 - Valves & Fittings - Inlet Gate Valve	2.78
00171756	Claudia Ct Reservoir 1 - Pipes & Fittings	2.34
00012694	Claudia Ct Reservoir 1 - Structure	3.20
00012695	Claudia Ct Reservoir 1 - Telemetry	1.60
00171735	Hamblin Bore 5 - Pipes & Fittings - Bore Casing	2.79
00171737	Hamblin Bore 5 - Pipes & Fittings - Delivery Column	1.92
00171739	Hamblin Bore 5 - Pipes & Fittings - Flow Meter (Bore)	1.27
00171736	Hamblin Bore 5 - Pump Set 1 - Submersible Pump and Motor	1.98
00719443	Mackenzie Street Bore - Pipes & Fittings (Delivery Column)	1.58
00718564	Mackenzie Street Bore - Electrical & Controls - Telemetry Unit	1.19
00718562	Mackenzie Street Bore - Electrical & Controls - Switchboard	1.76
00718594	Mackenzie Street Bore - Instrumentation - Flow Meter	1.30
00718697	Mackenzie Street Bore - Pump Set 1 - Submersible Pump	1.48

Appendix C2 – Toowoomba Oakey Pipeline

Table C 2: Toowoomba Oakey Pipeline criticality ratings

Asset No.	Label	Start Node	Stop Node	Criticality Rating
OTM-1	P-4891	J-849	ISO-1	3.40
OTM-2	P-5239	ISO-8	J-1395	3.58
OTM-3	P-5245	J-1236	J-849	3.48
OTM-4	P-5242	J-1395	J-1236	2.72
OTM-5	WP11296	J-1235	J-1395	3.37
OTM-6	WP11297	J-1235	J-1236	3.27
OTM-7	P-164	J-7877	ISO-2	3.24
OTM-8	P-4891	ISO-1	J-7877	3.32
OTM-9	P-7176	J-7877	Gowrie Junction Offtake	2.41
OTM-10	P-165	J-6923	ISO-3	3.24
OTM-11	P-164	ISO-2	J-6923	3.24
OTM-12	P-5944	J-6923	Steger Rd PRV	2.62
OTM-13	P-4887	J-11043	ISO-7	2.62
OTM-14	P-5963	J-11043	ISO-6	2.62
OTM-15	4W0137640000	J-11043	ISO-4	2.82
OTM-16	P-2	Chamberlain Rd PRV	J-11043	2.83
OTM-17	P-4892	J-11150	ISO-9	2.58
OTM-18	P-4354	J-11150	ISO-5	2.79
OTM-19	4W0137640000	ISO-4	J-11150	2.87
OTM-20	P-5117	Oakey Reservoir 3	ISO-11	2.77
OTM-21	4W0137720000	Oakey Reservoir 3	ISO-10	2.98
OTM-22	P-4348	Rowland Ct Reservoir	J-11031	1.80
OTM-23	P-4349	J-11031	Rowland Ct High	1.80
OTM-24	P-4350	Rowland Ct High	J-4561	1.72
OTM-25	P-7128	J-4561	Rowland Ct HL Reservoir	1.93
OTM-26	P-4358	Gowrie Mtn Fill Valve	Rowland Ct Reservoir	1.72
OTM-27	P-5963	ISO-6	J-11237	2.57
OTM-28	P-5960	J-11237	Emmanulla Fill Valve	2.31
OTM-29	P-5962	Simon's Fill Valve	J-11237	2.10
OTM-30	P-7075	Simon's Reservoir	J-11241	2.39
OTM-31	P-4352	Simon's Fill Valve	Simon's Reservoir	2.18
OTM-32	P-7073	Emmanulla Dr Reservoir	J-11240	2.31
OTM-33	P-5961	Emmanulla Fill Valve	Emmanulla Dr Reservoir	2.10
OTM-34	P-5296	J-11130	Junction Dr Fill Valve	2.36
OTM-35	P-7222	J-11130	J-11256	2.36
OTM-36	P-7223	J-11256	Burkes Fill Valve	2.36

Asset No.	Label	Start Node	Stop Node	Criticality Rating
OTM-37	P-7177	Gowrie Junction Offtake	J-11130	2.36
OTM-38	P-6779	Junction Dr Reservoir	J-3014	2.39
OTM-39	P-5929	J-3014	J-8152	2.03
OTM-40	P-7119	J-8152	J-9987	2.39
OTM-41	P-6598	J-9987	J-4865	2.31
OTM-42	7W0118360000	J-4865	J-8152	2.31
OTM-43	7W0119080000	Tower Cr Reservoir	J-4865	2.21
OTM-44	P-6950	J-3014	J-9987	2.39
OTM-45	P-5297	Junction Dr Fill Valve	Junction Dr Reservoir	2.18
OTM-46	7W0119720000	J-10032	Burkes Reservoir	2.32
OTM-47	P-7129	117	J-10032	2.36
OTM-48	P-5295	Burkes Fill Valve	Burkes Reservoir	2.26
OTM-49	P-165	ISO-3	Chamberlain Rd PRV	3.24
OTM-50	P-4354	ISO-5	Oakey Fill Valve	2.75
OTM-51	P-5117	ISO-11	Oakey Fill Valve	2.54
OTM-52	P-4887	ISO-7	Gowrie Mtn Fill Valve	2.24

Appendix C3 – Blue Mountain Heights Pipeline Network

Table C 3: Blue Mountain Heights pipeline network criticality ratings

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-1	P-408	J-12	26	2.01
BMH-2	P-331	J-12	24	2.01
BMH-3	P-286	23	J-38	2.01
BMH-4	P-256	J-38	J-12	2.32
BMH-5	P-299	J-14	53	2.16
BMH-6	5	Reservoir1	J-14	2.16
BMH-7	P-304	J-114	22	2.01
BMH-8	P-299	53	J-113	2.16
BMH-9	P-336	Booster Pump Station	J-114	2.01
BMH-10	P-335	J-113	Booster Pump Station	2.16
BMH-11	P-286	J-107	23	2.22
BMH-12	P-304	22	J-107	2.22
BMH-13	P-141	J-8	62	2.01
BMH-14	42	J-8	60	2.01
BMH-15	21	J-16	27	2.01
BMH-16	P-408	26	J-11	2.01
BMH-17	P-332	25	J-11	2.01
BMH-18	P-160	J-16	J-83	2.01
BMH-19	27	J-83	J-8	2.22
BMH-20	P-159	J-11	J-16	2.01
BMH-21	P-103	J-44	39	2.01
BMH-22	P-268	108	15	2.01
BMH-23	P-48	40	J-43	2.01
BMH-24	98	18	J-43	2.01
BMH-25	P-139	J-44	110	2.01
BMH-26	P-175	110	109	2.11
BMH-27	P-267	109	108	2.11
BMH-28	99	J-43	J-44	2.11
BMH-29	P-181	107	1	2.01
BMH-30	P-268	15	J-46	2.01
BMH-31	P-73	J-46	107	2.11
BMH-32	P-63	J-52	38	1.85
BMH-33	P-87	J-51	13	1.95
BMH-34	P-125	J-47	36	1.85
BMH-35	P-182	37	J-47	1.85

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-36	P-129	J-73	14	1.85
BMH-37	P-136	12	J-52	1.85
BMH-38	P-76	97	J-52	1.95
BMH-39	P-75	J-51	97	1.85
BMH-40	P-8	98	J-51	1.95
BMH-41	P-244	99	98	1.95
BMH-42	P-243	100	99	1.95
BMH-43	P-207	J-73	100	1.95
BMH-44	P-49	J-73	106	1.95
BMH-45	P-50	106	J-47	1.95
BMH-46	P-182	PRV-2	37	1.85
BMH-47	P-181	1	PRV-2	1.85
BMH-48	98	J-30	18	1.95
BMH-49	75	J-27	42	1.95
BMH-50	79	43	J-27	1.85
BMH-51	67	41	J-30	1.85
BMH-52	P-114	85	J-30	1.95
BMH-53	P-113	J-27	85	1.95
BMH-54	75	42	86	1.95
BMH-55	P-26	117	J-98	1.95
BMH-56	P-345	J-98	PRV-3	1.95
BMH-57	P-226	8	117	1.95
BMH-58	P-225	86	8	1.95
BMH-59	78	J-77	44	1.90
BMH-60	P-337	26	4	1.70
BMH-61	34	J-50	32	1.70
BMH-62	P-179	J-50	136	1.80
BMH-63	P-180	136	135	1.80
BMH-64	P-124	135	J-71	1.70
BMH-65	P-51	J-71	134	1.80
BMH-66	P-52	134	J-72	1.70
BMH-67	P-169	J-72	24	1.80
BMH-68	P-170	24	25	1.80
BMH-69	P-122	25	J-77	1.70
BMH-70	P-69	J-77	26	1.80
BMH-71	P-245	27	19	1.70
BMH-72	P-346	PRV-3	27	1.70
BMH-73	P-163	J-75	5	1.70
BMH-74	P-338	45	J-75	1.70
BMH-75	P-120	133	J-90	1.70
BMH-76	P-168	132	133	1.80

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-77	P-167	J-89	132	1.80
BMH-78	P-22	131	J-89	1.70
BMH-79	P-242	130	131	1.80
BMH-80	P-241	129	130	1.80
BMH-81	P-201	J-86	129	1.70
BMH-82	P-112	128	J-86	1.80
BMH-83	P-111	J-76	128	1.80
BMH-84	P-68	127	J-76	1.80
BMH-85	P-187	J-75	127	1.80
BMH-86	P-338	PRV-1	45	1.70
BMH-87	P-337	4	PRV-1	1.70
BMH-88	P-213	J-55	29	1.70
BMH-89	P-245	19	J-6	1.70
BMH-90	P-95	J-55	122	1.80
BMH-91	P-91	122	J-62	1.80
BMH-92	P-72	121	J-55	1.70
BMH-93	P-71	J-29	121	1.80
BMH-94	80	J-28	J-29	1.70
BMH-95	P-186	120	J-28	1.70
BMH-96	P-185	119	120	1.70
BMH-97	P-61	118	119	1.80
BMH-98	P-236	9	118	1.80
BMH-99	P-235	J-6	9	1.80
BMH-100	106	J-5	J-6	1.70
BMH-101	P-183	11	34	1.70
BMH-102	P-99	J-58	35	1.70
BMH-103	P-125	36	10	1.70
BMH-104	P-89	J-58	11	1.70
BMH-105	P-126	10	J-58	1.80
BMH-106	P-48	88	40	1.70
BMH-107	P-165	55	45	1.80
BMH-108	P-101	J-57	137	1.80
BMH-109	P-102	137	J-53	1.80
BMH-110	P-97	J-53	138	1.80
BMH-111	P-17	138	91	1.80
BMH-112	P-205	91	90	1.90
BMH-113	P-206	90	J-65	1.70
BMH-114	P-55	J-65	89	1.80
BMH-115	P-47	89	88	1.80
BMH-116	P-166	45	J-57	1.80
BMH-117	P-271	112	16	1.80

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-118	P-103	39	111	1.80
BMH-119	P-115	111	112	1.80
BMH-120	79	J-26	43	1.70
BMH-121	78	44	J-26	1.70
BMH-122	P-65	57	46	1.70
BMH-123	P-282	84	J-26	1.70
BMH-124	P-281	83	84	1.80
BMH-125	P-239	82	83	1.80
BMH-126	P-238	81	82	1.80
BMH-127	P-237	80	81	1.80
BMH-128	P-222	79	80	1.80
BMH-129	P-254	78	79	1.80
BMH-130	P-253	J-79	78	1.80
BMH-131	P-66	46	J-79	1.80
BMH-132	P-81	J-18	61	1.70
BMH-133	34	32	J-18	1.80
BMH-134	P-65	J-33	56	1.70
BMH-135	42	60	J-32	1.90
BMH-136	P-151	J-34	51	1.90
BMH-137	P-152	51	52	1.80
BMH-138	P-40	52	J-18	1.80
BMH-139	37	J-33	J-34	1.80
BMH-140	30	J-32	J-33	1.80
BMH-141	36	J-19	59	1.80
BMH-142	P-81	61	50	1.70
BMH-143	35	33	J-19	1.70
BMH-144	P-82	50	J-19	1.70
BMH-145	P-272	17	113	1.80
BMH-146	P-134	114	115	1.80
BMH-147	P-133	J-81	114	1.80
BMH-148	P-172	113	J-81	1.80
BMH-149	P-272	PRV-4	17	1.70
BMH-150	P-271	16	PRV-4	1.70
BMH-151	P-129	14	103	1.80
BMH-152	P-46	104	105	1.80
BMH-153	P-45	J-70	104	1.80
BMH-154	P-130	103	J-70	1.80
BMH-155	P-192	3	J-87	1.70
BMH-156	35	35	33	1.80
BMH-157	P-29	J-49	36	1.80
BMH-158	P-251	36	37	1.80

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-159	P-252	37	38	1.80
BMH-160	P-232	38	J-87	1.80
BMH-161	P-78	35	J-49	1.80
BMH-162	P-227	J-97	7	1.80
BMH-163	P-277	J-97	6	1.70
BMH-164	P-163	5	55	1.80
BMH-165	P-150	58	J-97	1.80
BMH-166	P-260	57	58	1.80
BMH-167	P-259	56	57	1.80
BMH-168	P-164	55	56	1.80
BMH-169	P-183	34	12	1.80
BMH-170	86	12	34	1.80
BMH-171	P-99	35	139	1.80
BMH-172	P-128	140	141	1.80
BMH-173	P-127	139	140	1.80
BMH-174	P-87	13	101	1.80
BMH-175	62	J-37	102	1.80
BMH-176	P-88	101	J-37	1.70
BMH-177	67	87	41	1.70
BMH-178	69	J-35	116	1.80
BMH-179	68	87	J-35	1.80
BMH-180	21	27	J-17	1.70
BMH-181	P-143	J-15	52	1.70
BMH-182	22	J-22	J-17	1.70
BMH-183	23	31	J-22	1.80
BMH-184	P-59	J-15	31	1.80
BMH-185	P-63	38	94	1.70
BMH-186	P-64	94	93	1.80
BMH-187	P-277	6	59	1.70
BMH-188	P-42	63	64	1.80
BMH-189	P-148	62	63	1.80
BMH-190	P-280	61	62	1.80
BMH-191	P-279	60	61	1.80
BMH-192	P-278	59	60	1.80
BMH-193	P-143	52	54	1.80
BMH-194	P-177	54	J-85	1.80
BMH-195	P-19	J-93	9	1.70
BMH-196	P-117	J-93	8	1.70
BMH-197	P-227	7	65	1.80
BMH-198	P-233	69	66	1.80
BMH-199	P-234	66	J-93	1.70

Asset No.	Label	Start Node	Stop Node	Criticality Rating
BMH-200	P-228	65	69	1.80
BMH-201	P-213	29	124	1.80
BMH-202	P-216	126	J-100	1.70
BMH-203	P-215	125	126	1.80
BMH-204	P-214	124	125	1.80
BMH-205	P-136	95	12	1.80
BMH-206	P-135	96	95	1.80
BMH-207	P-117	8	67	1.80
BMH-208	P-174	68	J-94	1.80
BMH-209	P-173	67	68	1.80
BMH-210	P-165	44	55	1.70
BMH-211	P-141	62	92	1.90
BMH-212	P-142	92	J-67	1.80
BMH-213	P-53	J-67	44	1.70
BMH-214	P-192	40	3	1.70
BMH-215	P-191	39	40	1.80
BMH-216	P-85	J-31	58	1.70
BMH-217	36	59	49	1.80
BMH-218	32	J-31	47	1.80
BMH-219	33	49	J-31	1.80
BMH-220	P-85	58	48	1.70
BMH-221	P-86	48	J-36	1.70
BMH-222	P-19	9	70	1.80
BMH-223	P-200	71	72	1.80
BMH-224	P-199	70	71	1.80
BMH-225	P-332	PSV-1	25	1.70
BMH-226	P-331	24	PSV-1	1.70
BMH-227	P-65	56	57	1.80

Appendix D – Wastewater Criticality Results

Appendix D1 – Active Wastewater Assets

Table D 1: Active wastewater asset criticality ratings

Asset No.	Asset Description	Criticality Rating
00715412	Wetalla WRF - Preliminary Treatment (PTA) - General - Preliminary Treatment Structure	4.37
00715414	Wetalla WRF - Biological Treatment - Anaerobic/Anoxic Digestion Bioreactor 1 - Pipework (RAS Pump Stations To Tanks 1, 7 & 8)	2.02
00715055	Wetalla WRF - Electricals & Controls - Biosolids & Solar Dryer MCC - Solar Rake PLC 1 (Tiller Controls)	1.30
00715018	Wetalla WRF - Electricals & Controls - Disinfection MCC - Switchboard	3.06
00714804	Wetalla WRF - Digested Sludge Dewatering - Digested WAS Pump Station 2 - Motor 1 (7.5 kW)	1.43
00715448	Wetalla WRF - Preliminary Treatment (PTA) - Flow Splitting - Flow Splitter To Bioreactor 1 Flow Meter	1.58
00714603	Wetalla WRF - Aerobic Digestion - Aerobic Digester Blowers - Blower 1	2.41
00714811	Wetalla WRF - High Flow Bypass - Penstock 1	1.80
00012257	Yarraman STP - Inlet Chamber 1	3.08
00012295	Yarraman STP - Effluent Pump Station - Gantry	1.30
00173500	Yarraman STP - Electricals & Controls - Remote Telemetry Unit	1.38
00012366	Yarraman STP - Electricals & Controls - Main Switchboard and Controls	3.14
00173473	Yarraman STP - Effluent Disposal - Effluent Irrigation Pump Station - Flow Meter (DN100, Magflow)	2.23
00012265	Yarraman STP - Primary Sedimentation - Tank 1 - Drive Assembly Gearbox	1.34
00173444	Yarraman STP - Disinfection and Discharge - Sodium Hypochlorite Dosing - Dosing Pump (Grundfos)	1.94
00716834	Gowrie St SPS 66 - Wet Well - Wet Well Structure	3.70
00716804	Gowrie St SPS 66 - Chemical Dosing - Storage Tank	1.93
00716828	Gowrie St SPS 66 - Electricals & Controls - Telemetry	1.38
00716839	Gowrie St SPS 66 - Electricals & Controls - Switchboard	3.57
00716805	Gowrie St SPS 66 - Chemical Dosing - Control Panel	1.76
00716838	Gowrie St SPS 66 - Flow Meter (DN375)	2.30
00716840	Gowrie St SPS 66 - Pump Set 1 - Pump 1	3.27
00716801	Gowrie St SPS 66 - Chemical Dosing - Pump 1	1.68
00001515	Boundary St SPS 11 - Structure - Wet Well Structure	2.82
00013745	Boundary St SPS 11 - Structure - Overflow Storage	2.36
00006804	Boundary St SPS 11 - Electricals & Controls - Telemetry	1.38
00719032	Boundary St SPS 11 - Electricals & Controls - Switchboard (24 kW)	2.70

Asset No.	Asset Description	Criticality Rating
00006753	Boundary St SPS 11 - Instrumentation - Flow Meter	2.21
00719030	Boundary St SPS 11 - Pump & Motor 1 (Forrer 12 kW)	2.46
00006748	Boundary St SPS 11 - Valves & Fittings - Valve Reflux	2.22

Appendix D2 – Boundary Street WWPS Pipeline Network

Table D 2: Boundary Street WWPS pipeline network criticality ratings

Asset No.	Label	Start Node	Stop Node	Criticality Rating
TOPS11-G1	14376	9968	9967	1.84
TOPS11-G2	14781	2583	MH-124	2.03
TOPS11-G3	6283	13548	13549	1.91
TOPS11-G4	2667	1177	1179	1.93
TOPS11-G5	8975	14717	1180	1.93
TOPS11-G6	14375	9967	9966	1.93
TOPS11-G7	16061	1174	10428	1.93
TOPS11-G8	16916	13549	MH-124	2.12
TOPS11-G9	2758	12787	9578	1.93
TOPS11-G10	8974	1179	14717	1.93
TOPS11-G11	15751	2581	10426	1.93
TOPS11-G12	14293	1999	1998	1.93
TOPS11-G13	3955	2582	14718	1.99
TOPS11-G14	3956	14718	2583	1.99
TOPS11-G15	4091	10424	10426	1.93
TOPS11-G16	14782	2586	MH-124	1.93
TOPS11-G17	14787	2590	2588	1.93
TOPS11-G18	14294	2000	1999	1.93
TOPS11-G19	15734	1652	2581	1.93
TOPS11-G20	14786	2589	2588	1.93
TOPS11-G21	1501	1996	1999	1.93
TOPS11-G22	15110	2587	2586	1.93
TOPS11-G23	14785	2588	2587	1.93
TOPS11-G24	15919	9578	10424	1.93
TOPS11-G25	14763	1997	2589	1.93
TOPS11-G26	15927	10425	10423	1.93
TOPS11-G27	15707	10423	1166	1.93
TOPS11-G28	15705	1166	1165	1.93
TOPS11-G29	14788	2592	2591	1.93
TOPS11-G30	15928	10426	10425	1.93
TOPS11-G31	14291	1998	1997	1.93
TOPS11-G32	14784	2591	2586	1.93
TOPS11-G33	15706	1165	10429	1.93
TOPS11-G34	14292	9966	1997	1.93
TOPS11-G35	15663	57	1164	1.93

Asset No.	Label	Start Node	Stop Node	Criticality Rating
TOPS11-G36	5808	13550	13548	1.99
TOPS11-G37	14327	9970	9969	1.93
TOPS11-G38	14760	1657	2592	1.93
TOPS11-G39	14759	1656	2590	1.93
TOPS11-G40	2317	10428	10429	1.93
TOPS11-G41	15704	1164	1174	1.93
TOPS11-G42	14377	9969	9968	1.93
TOPS11-G43	14301	13061	2580	1.93
TOPS11-G44	15736	2580	1996	1.93
TOPS11-G45	3465	1180	13550	1.99
TOPS11-G46	8250	1175	1182	1.93
TOPS11-G47	6147	10429	1175	1.93
TOPS11-G48	3466	1182	2582	1.99
TOPS11-G49	CO-14	MH-124	TOPS11	2.41
TOPS11-P1	P-32	J-19	2479	2.42
TOPS11-P2	P-33	TOPS11	PMP-7	2.16
TOPS11-P3	P-34	PMP-7	J-19	2.16

Appendix D3 – Gowrie Junction Rising Main

Table D 3: Gowrie Junction Rising Main criticality ratings

Asset No.	Label	Start Node	Stop Node	Criticality Rating
GJ-P1	P-14	PMP-2	J-14	2.76
GJ-P2	P-52	J-26	41526	3.02
GJ-P3	P-59	J-14	J-30	3.23
GJ-P4	P-60	J-30	J-26	3.11
GJ-P5	P-111	Gowrie Junction SPS	J-41	3.13
GJ-P6	P-112	J-41	PMP-2	3.13

Appendix D4 – Highfields Wastewater Pipeline Network

Table D 4: Highfields wastewater pipeline network criticality ratings

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G1	412	348	347	2.32
HF-G2	419	356	354	2.17
HF-G3	416	353	352	2.32
HF-G4	751	538	537	2.17
HF-G5	311	177	255	2.17
HF-G6	414	350	351	2.17
HF-G7	307	256	162	2.17
HF-G8	741	693	684	2.32
HF-G9	407	345	346	2.32
HF-G10	55	5	4	2.08
HF-G11	456	133	390	2.17
HF-G12	752	537	273	2.08
HF-G13	639	609	608	2.17
HF-G14	285	232	229	2.08
HF-G15	155	106	316	2.08
HF-G16	371	312	324	2.17
HF-G17	754	704	705	2.17
HF-G18	613	602	601	2.17
HF-G19	742	684	685	2.53
HF-G20	140	94	93	2.08
HF-G21	614	601	600	2.17
HF-G22	738	696	695	2.23
HF-G23	534	516	515	2.17
HF-G24	113	59	60	2.08
HF-G25	718	671	672	2.62
HF-G26	74	21	22	2.08
HF-G27	757	707	708	2.17
HF-G28	85	34	35	2.08
HF-G29	292	238	239	2.08
HF-G30	369	313	312	2.17
HF-G31	467	400	399	2.23
HF-G32	356	301	49	2.17
HF-G33	644	610	612	2.17
HF-G34	733	691	692	2.23
HF-G35	472	403	402	2.08
HF-G36	381	77	323	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G37	195	150	151	2.08
HF-G38	570	548	546	2.17
HF-G39	612	2	SPS2	2.14
HF-G40	198	152	153	2.08
HF-G41	228	349	176	2.08
HF-G42	709	281	SPS11	2.14
HF-G43	330	359	275	2.17
HF-G44	571	549	548	2.08
HF-G45	363	305	306	2.17
HF-G46	750	702	507	2.08
HF-G47	27	449	451	2.08
HF-G48	52	3	2	2.14
HF-G49	72	24	23	2.08
HF-G50	222	170	169	2.08
HF-G51	643	424	610	2.17
HF-G52	339	264	278	2.32
HF-G53	454	389	95	2.17
HF-G54	82	MH-27	37	2.08
HF-G55	582	554	553	2.08
HF-G56	446	381	387	2.17
HF-G57	698	662	651	2.17
HF-G58	268	216	215	2.08
HF-G59	702	650	649	2.17
HF-G60	477	411	410	2.17
HF-G61	743	685	686	2.53
HF-G62	621	594	593	2.17
HF-G63	83	25	37	2.08
HF-G64	549	505	508	2.17
HF-G65	469	401	290	2.17
HF-G66	345	MH-41	287	2.17
HF-G67	135	87	393	2.08
HF-G68	117	378	64	2.17
HF-G69	186	137	138	2.08
HF-G70	586	564	494	2.23
HF-G71	767	273	715	2.08
HF-G72	220	168	171	2.23
HF-G73	636	607	562	2.17
HF-G74	219	171	172	2.23
HF-G75	430	367	368	2.17
HF-G76	164	113	114	2.08
HF-G77	473	406	397	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G78	253	204	205	2.08
HF-G79	539	522	520	2.17
HF-G80	70	20	357	2.08
HF-G81	145	97	96	2.14
HF-G82	176	126	125	2.08
HF-G83	760	709	711	2.17
HF-G84	551	29	28	2.17
HF-G85	565	533	480	2.17
HF-G86	245	193	409	2.08
HF-G87	173	122	123	2.08
HF-G88	329	270	271	2.08
HF-G89	652	615	616	2.17
HF-G90	664	628	629	2.17
HF-G91	205	160	159	2.08
HF-G92	171	120	121	2.08
HF-G93	54	4	3	2.08
HF-G94	227	176	175	2.17
HF-G95	49	443	442	2.17
HF-G96	94	63	47	2.17
HF-G97	168	117	118	2.17
HF-G98	256	203	202	2.47
HF-G99	389	226	329	2.17
HF-G100	47	426	427	2.17
HF-G101	246	195	197	2.17
HF-G102	134	86	87	2.17
HF-G103	138	89	88	2.17
HF-G104	161	MH-32	108	2.17
HF-G105	575	553	551	2.17
HF-G106	677	652	641	2.17
HF-G107	484	419	418	2.17
HF-G108	638	608	607	2.17
HF-G109	295	242	173	2.23
HF-G110	590	570	566	2.17
HF-G111	699	663	662	2.17
HF-G112	585	494	499	2.23
HF-G113	659	623	622	2.17
HF-G114	353	296	294	2.17
HF-G115	439	376	375	2.17
HF-G116	732	697	692	2.56
HF-G117	630	586	587	2.23
HF-G118	367	310	311	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G119	192	146	147	2.17
HF-G120	347	291	401	2.17
HF-G121	464	396	194	2.17
HF-G122	392	331	220	2.17
HF-G123	366	MH-36	308	2.17
HF-G124	313	258	257	2.17
HF-G125	89	MH-38	40	2.17
HF-G126	337	280	281	2.23
HF-G127	688	665	664	2.17
HF-G128	121	67	63	2.17
HF-G129	331	275	274	2.17
HF-G130	42	429	428	2.17
HF-G131	426	362	361	2.17
HF-G132	276	224	226	2.17
HF-G133	221	169	168	2.17
HF-G134	543	535	702	2.17
HF-G135	655	619	618	2.17
HF-G136	61	8	9	2.17
HF-G137	237	186	185	2.17
HF-G138	147	99	98	2.23
HF-G139	108	54	53	2.17
HF-G140	124	70	69	2.17
HF-G141	474	407	400	2.17
HF-G142	445	289	380	2.08
HF-G143	634	MH-30	596	2.08
HF-G144	739	695	694	2.14
HF-G145	150	103	101	2.23
HF-G146	290	237	235	2.17
HF-G147	637	560	607	2.08
HF-G148	601	577	578	2.17
HF-G149	346	290	289	2.17
HF-G150	322	266	265	2.17
HF-G151	481	194	480	2.17
HF-G152	142	91	90	2.17
HF-G153	423	357	358	2.17
HF-G154	115	62	60	2.17
HF-G155	566	558	559	2.17
HF-G156	758	708	709	2.08
HF-G157	623	591	592	2.23
HF-G158	91	MH-43	41	2.17
HF-G159	151	102	103	2.23

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G160	266	214	367	2.17
HF-G161	178	129	128	2.17
HF-G162	137	90	88	2.17
HF-G163	550	509	508	2.08
HF-G164	617	598	597	2.17
HF-G165	542	510	506	2.17
HF-G166	764	438	714	2.23
HF-G167	501	481	475	2.17
HF-G168	304	249	248	2.17
HF-G169	274	282	221	2.17
HF-G170	309	254	255	2.17
HF-G171	342	148	282	2.17
HF-G172	143	92	91	2.17
HF-G173	199	154	152	2.17
HF-G174	223	167	168	2.23
HF-G175	379	322	321	2.17
HF-G176	489	383	421	2.17
HF-G177	288	235	236	2.17
HF-G178	653	617	616	2.17
HF-G179	409	30	346	2.17
HF-G180	594	573	575	2.17
HF-G181	587	565	564	2.23
HF-G182	264	212	211	2.17
HF-G183	470	402	127	2.17
HF-G184	338	276	277	2.08
HF-G185	132	84	85	2.17
HF-G186	417	352	26	2.40
HF-G187	567	547	558	2.17
HF-G188	261	207	208	2.25
HF-G189	69	18	19	2.17
HF-G190	146	420	97	2.23
HF-G191	24	469	434	2.17
HF-G192	522	487	488	2.17
HF-G193	157	108	107	2.17
HF-G194	548	504	505	2.08
HF-G195	452	387	386	2.17
HF-G196	521	493	494	2.17
HF-G197	560	544	543	2.17
HF-G198	525	528	527	2.17
HF-G199	398	220	335	2.17
HF-G200	449	333	696	2.32

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G201	596	571	569	2.17
HF-G202	380	323	322	2.08
HF-G203	196	149	150	2.17
HF-G204	185	141	138	2.17
HF-G205	457	391	423	2.23
HF-G206	753	703	704	2.17
HF-G207	152	98	102	2.23
HF-G208	273	221	222	2.17
HF-G209	130	83	82	2.23
HF-G210	131	85	405	2.17
HF-G211	433	366	201	2.40
HF-G212	7	MH-45	467	2.17
HF-G213	5	MH-46	448	2.17
HF-G214	254	205	211	2.17
HF-G215	544	507	506	2.17
HF-G216	11	MH-47	466	2.17
HF-G217	756	705	707	2.17
HF-G218	616	599	598	2.17
HF-G219	372	316	315	2.17
HF-G220	572	550	549	2.17
HF-G221	383	324	325	2.17
HF-G222	511	485	483	2.17
HF-G223	515	489	485	2.17
HF-G224	622	593	592	2.17
HF-G225	530	532	531	2.17
HF-G226	86	38	36	2.17
HF-G227	631	592	603	2.23
HF-G228	265	213	212	2.17
HF-G229	323	269	266	2.17
HF-G230	523	525	524	2.17
HF-G231	45	430	431	2.17
HF-G232	3	MH-48	439	2.17
HF-G233	267	215	214	2.17
HF-G234	746	688	689	2.62
HF-G235	187	140	137	2.17
HF-G236	632	603	604	2.23
HF-G237	736	682	683	2.44
HF-G238	486	423	422	2.23
HF-G239	224	183	167	2.23
HF-G240	8	MH-49	471	2.17
HF-G241	443	380	379	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G242	25	452	469	2.17
HF-G243	39	437	438	2.17
HF-G244	684	659	658	2.17
HF-G245	96	48	297	2.17
HF-G246	275	223	222	2.17
HF-G247	166	115	SPS10	2.17
HF-G248	660	559	626	2.17
HF-G249	33	467	449	2.17
HF-G250	160	111	110	2.17
HF-G251	574	551	550	2.17
HF-G252	170	119	120	2.17
HF-G253	703	666	648	2.17
HF-G254	314	174	258	2.25
HF-G255	597	572	571	2.17
HF-G256	647	611	610	2.17
HF-G257	520	495	499	2.17
HF-G258	527	531	529	2.17
HF-G259	663	629	627	2.17
HF-G260	650	613	614	2.08
HF-G261	377	320	319	2.17
HF-G262	301	247	339	2.23
HF-G263	260	206	207	2.25
HF-G264	263	208	365	2.25
HF-G265	197	153	155	2.17
HF-G266	635	MH-40	598	2.17
HF-G267	163	112	113	2.17
HF-G268	568	546	547	2.08
HF-G269	562	197	511	2.17
HF-G270	468	409	400	2.08
HF-G271	204	159	158	2.17
HF-G272	624	590	591	2.23
HF-G273	674	639	638	2.17
HF-G274	589	566	497	2.17
HF-G275	179	135	134	2.17
HF-G276	63	6	7	2.17
HF-G277	308	255	256	2.17
HF-G278	368	311	312	2.08
HF-G279	759	710	709	2.17
HF-G280	465	398	397	2.23
HF-G281	148	100	99	2.23
HF-G282	167	116	117	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G283	238	185	184	2.17
HF-G284	427	361	360	2.17
HF-G285	538	520	519	2.08
HF-G286	670	635	633	2.17
HF-G287	388	329	328	2.17
HF-G288	95	46	45	2.23
HF-G289	440	377	376	2.17
HF-G290	553	562	563	2.17
HF-G291	48	425	443	2.17
HF-G292	206	162	160	2.17
HF-G293	431	369	368	2.17
HF-G294	598	579	578	2.17
HF-G295	374	317	318	2.17
HF-G296	375	318	319	2.17
HF-G297	247	196	197	2.17
HF-G298	595	569	567	2.17
HF-G299	249	199	198	2.17
HF-G300	270	219	218	2.17
HF-G301	125	69	72	2.17
HF-G302	744	686	687	2.53
HF-G303	129	82	101	2.23
HF-G304	512	490	489	2.17
HF-G305	370	314	313	2.08
HF-G306	203	158	186	2.17
HF-G307	144	96	100	2.23
HF-G308	618	597	596	2.17
HF-G309	62	7	8	2.17
HF-G310	184	138	139	2.17
HF-G311	514	492	491	2.17
HF-G312	136	88	87	2.17
HF-G313	564	534	480	2.17
HF-G314	365	307	38	2.17
HF-G315	172	121	122	2.17
HF-G316	528	526	525	2.17
HF-G317	2	446	447	2.17
HF-G318	141	388	94	2.17
HF-G319	432	365	366	2.32
HF-G320	14	445	446	2.17
HF-G321	438	371	372	2.17
HF-G322	690	643	642	2.17
HF-G323	408	346	348	2.32

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G324	662	627	488	2.08
HF-G325	545	512	507	2.17
HF-G326	87	35	36	2.17
HF-G327	289	234	235	2.17
HF-G328	656	620	619	2.17
HF-G329	98	47	46	2.17
HF-G330	362	308	305	2.08
HF-G331	153	104	314	2.17
HF-G332	88	43	34	2.17
HF-G333	740	694	693	2.14
HF-G334	154	105	104	2.17
HF-G335	333	267	276	2.25
HF-G336	620	595	594	2.17
HF-G337	546	508	482	2.25
HF-G338	526	529	528	2.17
HF-G339	107	299	298	2.17
HF-G340	112	57	58	2.32
HF-G341	111	347	57	2.32
HF-G342	600	581	580	2.17
HF-G343	128	80	79	2.17
HF-G344	119	65	66	2.17
HF-G345	745	687	688	2.62
HF-G346	483	418	417	2.17
HF-G347	118	66	67	2.17
HF-G348	591	576	570	2.17
HF-G349	189	142	143	2.17
HF-G350	633	604	568	2.23
HF-G351	697	651	650	2.17
HF-G352	491	536	472	2.17
HF-G353	475	130	408	2.17
HF-G354	158	109	316	2.17
HF-G355	441	68	378	2.17
HF-G356	557	541	540	2.17
HF-G357	208	161	160	2.17
HF-G358	558	542	541	2.17
HF-G359	559	543	542	2.17
HF-G360	162	123	112	2.17
HF-G361	385	326	384	2.17
HF-G362	552	563	SPS4	2.17
HF-G363	507	498	500	2.47
HF-G364	536	518	517	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G365	127	79	78	2.17
HF-G366	324	261	269	2.17
HF-G367	704	1	667	2.14
HF-G368	376	319	1	2.17
HF-G369	182	330	136	2.23
HF-G370	393	341	332	2.32
HF-G371	232	181	182	2.17
HF-G372	723	669	670	2.62
HF-G373	509	499	496	2.23
HF-G374	735	681	682	2.23
HF-G375	236	187	186	2.17
HF-G376	81	36	25	2.17
HF-G377	435	374	370	2.17
HF-G378	505	501	203	2.38
HF-G379	555	539	538	2.17
HF-G380	556	540	539	2.17
HF-G381	57	12	11	2.17
HF-G382	436	373	374	2.17
HF-G383	105	698	284	2.56
HF-G384	399	336	337	2.17
HF-G385	207	189	158	2.17
HF-G386	599	580	579	2.17
HF-G387	317	260	268	2.17
HF-G388	335	278	279	2.32
HF-G389	297	250	241	2.17
HF-G390	99	45	297	2.23
HF-G391	700	649	666	2.08
HF-G392	689	642	637	2.17
HF-G393	44	431	432	2.17
HF-G394	627	587	588	2.23
HF-G395	453	95	388	2.08
HF-G396	463	395	396	2.17
HF-G397	429	211	367	2.08
HF-G398	239	184	183	2.17
HF-G399	58	13	12	2.17
HF-G400	271	218	335	2.17
HF-G401	731	699	698	2.38
HF-G402	640	606	609	2.17
HF-G403	235	188	187	2.17
HF-G404	442	379	378	2.17
HF-G405	18	450	455	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G406	487	394	422	2.17
HF-G407	259	209	210	2.17
HF-G408	455	390	389	2.08
HF-G409	672	636	637	2.17
HF-G410	490	530	473	2.23
HF-G411	510	497	496	2.17
HF-G412	502	482	472	2.25
HF-G413	180	131	135	2.17
HF-G414	447	81	681	2.23
HF-G415	651	614	615	2.17
HF-G416	40	435	438	2.17
HF-G417	300	246	247	2.23
HF-G418	59	10	21	2.17
HF-G419	437	372	373	2.17
HF-G420	683	658	657	2.17
HF-G421	149	101	81	2.23
HF-G422	243	134	190	2.17
HF-G423	349	76	292	2.17
HF-G424	588	567	565	2.23
HF-G425	725	678	677	2.62
HF-G426	499	475	536	2.25
HF-G427	519	484	206	2.25
HF-G428	593	578	575	2.17
HF-G429	642	616	Rosella Gardens Pumpout Tank	2.08
HF-G430	116	64	132	2.17
HF-G431	286	236	18	2.17
HF-G432	641	605	606	2.08
HF-G433	705	667	SPS7	2.14
HF-G434	701	MH-51	666	2.17
HF-G435	190	52	144	2.17
HF-G436	354	56	296	2.17
HF-G437	312	180	257	2.17
HF-G438	159	110	109	2.17
HF-G439	31	471	470	2.17
HF-G440	165	114	SPS10	2.17
HF-G441	516	486	484	2.34
HF-G442	654	618	617	2.17
HF-G443	518	483	484	2.17
HF-G444	671	637	635	2.17
HF-G445	466	399	398	2.14

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G446	373	315	317	2.17
HF-G447	554	561	560	2.17
HF-G448	193	145	146	2.17
HF-G449	279	338	227	2.17
HF-G450	139	93	89	2.17
HF-G451	328	271	272	2.08
HF-G452	682	657	656	2.17
HF-G453	26	451	452	2.17
HF-G454	46	427	424	2.17
HF-G455	43	428	432	2.17
HF-G456	402	342	217	2.56
HF-G457	34	464	465	2.17
HF-G458	9	456	470	2.17
HF-G459	77	42	31	2.17
HF-G460	50	442	625	2.17
HF-G461	364	306	307	2.17
HF-G462	761	711	712	2.17
HF-G463	327	272	273	2.17
HF-G464	257	370	201	2.17
HF-G465	348	292	291	2.17
HF-G466	378	321	318	2.17
HF-G467	15	447	455	2.17
HF-G468	242	190	407	2.17
HF-G469	648	612	613	2.17
HF-G470	191	147	148	2.17
HF-G471	341	283	282	2.17
HF-G472	506	500	501	2.38
HF-G473	410	32	345	2.32
HF-G474	90	40	41	2.17
HF-G475	425	364	363	2.17
HF-G476	156	107	106	2.17
HF-G477	629	585	586	2.17
HF-G478	459	405	394	2.17
HF-G479	673	638	636	2.17
HF-G480	277	225	328	2.17
HF-G481	513	491	490	2.17
HF-G482	325	268	266	2.17
HF-G483	645	624	625	2.17
HF-G484	1	444	445	2.17
HF-G485	231	182	180	2.17
HF-G486	35	465	457	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G487	29	461	468	2.17
HF-G488	602	568	567	2.23
HF-G489	229	351	177	2.17
HF-G490	462	413	395	2.17
HF-G491	343	284	285	2.56
HF-G492	38	460	437	2.17
HF-G493	461	393	392	2.17
HF-G494	20	440	454	2.17
HF-G495	19	439	450	2.17
HF-G496	97	49	48	2.17
HF-G497	30	462	461	2.17
HF-G498	123	71	70	2.17
HF-G499	4	441	440	2.17
HF-G500	326	715	274	2.17
HF-G501	666	631	630	2.17
HF-G502	696	MH-28	648	2.08
HF-G503	93	72	44	2.17
HF-G504	351	297	293	2.23
HF-G505	103	51	701	2.17
HF-G506	84	37	27	2.17
HF-G507	763	713	604	2.17
HF-G508	504	502	503	2.17
HF-G509	218	172	242	2.23
HF-G510	28	468	448	2.17
HF-G511	540	523	522	2.17
HF-G512	405	343	701	2.32
HF-G513	280	231	232	2.17
HF-G514	661	626	SPS3	2.17
HF-G515	665	630	628	2.17
HF-G516	359	303	308	2.17
HF-G517	541	521	518	2.17
HF-G518	628	MH-35	585	2.17
HF-G519	75	28	27	2.40
HF-G520	303	248	250	2.17
HF-G521	626	588	589	2.23
HF-G522	693	646	645	2.17
HF-G523	278	227	331	2.17
HF-G524	183	139	326	2.17
HF-G525	669	633	634	2.17
HF-G526	16	455	453	2.17
HF-G527	32	470	469	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G528	747	689	690	2.62
HF-G529	120	75	65	2.17
HF-G530	460	392	383	2.17
HF-G531	76	27	32	2.40
HF-G532	358	300	67	2.17
HF-G533	110	298	56	2.17
HF-G534	395	217	697	2.56
HF-G535	73	22	24	2.17
HF-G536	169	118	119	2.17
HF-G537	625	589	590	2.23
HF-G538	649	625	613	2.17
HF-G539	387	328	327	2.23
HF-G540	37	466	465	2.17
HF-G541	10	458	457	2.17
HF-G542	529	524	530	2.17
HF-G543	686	661	660	2.17
HF-G544	350	286	68	2.17
HF-G545	420	228	355	2.17
HF-G546	360	302	70	2.17
HF-G547	284	233	231	2.17
HF-G548	23	434	435	2.17
HF-G549	517	488	486	2.34
HF-G550	13	459	460	2.25
HF-G551	340	144	282	2.17
HF-G552	262	375	206	2.17
HF-G553	361	309	304	2.17
HF-G554	78	31	30	2.17
HF-G555	646	432	611	2.17
HF-G556	495	476	477	2.17
HF-G557	175	125	131	2.17
HF-G558	188	143	144	2.17
HF-G559	226	175	174	2.17
HF-G560	248	198	411	2.17
HF-G561	537	519	518	2.17
HF-G562	592	575	576	2.17
HF-G563	41	433	429	2.17
HF-G564	724	677	669	2.62
HF-G565	657	621	620	2.17
HF-G566	668	634	632	2.17
HF-G567	658	622	621	2.17
HF-G568	675	640	639	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G569	209	156	161	2.17
HF-G570	316	262	261	2.17
HF-G571	428	360	359	2.17
HF-G572	400	339	340	2.32
HF-G573	535	517	516	2.17
HF-G574	101	50	700	2.32
HF-G575	106	53	295	2.17
HF-G576	524	527	526	2.17
HF-G577	114	61	59	2.17
HF-G578	109	55	54	2.17
HF-G579	336	279	280	2.23
HF-G580	269	337	218	2.17
HF-G581	685	660	659	2.17
HF-G582	352	294	293	2.17
HF-G583	492	472	474	2.23
HF-G584	479	414	415	2.17
HF-G585	287	240	234	2.17
HF-G586	748	26	28	2.32
HF-G587	241	252	189	2.17
HF-G588	215	163	267	2.17
HF-G589	318	179	263	2.25
HF-G590	252	124	200	2.17
HF-G591	605	582	583	2.17
HF-G592	174	128	124	2.17
HF-G593	397	335	334	2.17
HF-G594	244	191	199	2.17
HF-G595	561	545	544	2.17
HF-G596	250	192	198	2.17
HF-G597	497	478	474	2.17
HF-G598	471	404	402	2.08
HF-G599	255	201	203	2.40
HF-G600	251	200	199	2.17
HF-G601	102	293	50	2.32
HF-G602	606	584	564	2.25
HF-G603	496	477	478	2.17
HF-G604	667	632	631	2.17
HF-G605	488	421	419	2.17
HF-G606	676	641	640	2.17
HF-G607	726	679	678	2.62
HF-G608	494	479	476	2.17
HF-G609	60	9	21	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G610	272	222	225	2.17
HF-G611	458	397	391	2.23
HF-G612	727	680	679	2.62
HF-G613	386	327	384	2.23
HF-G614	71	23	15	2.17
HF-G615	21	454	436	2.17
HF-G616	448	382	691	2.23
HF-G617	56	11	6	2.17
HF-G618	214	165	260	2.17
HF-G619	485	422	420	2.23
HF-G620	51	354	3	2.17
HF-G621	603	574	568	2.17
HF-G622	482	417	83	2.17
HF-G623	216	164	163	2.17
HF-G624	480	416	194	2.17
HF-G625	194	151	254	2.17
HF-G626	211	166	262	2.17
HF-G627	382	78	322	2.17
HF-G628	36	457	459	2.17
HF-G629	177	127	126	2.17
HF-G630	719	672	673	2.62
HF-G631	762	712	713	2.17
HF-G632	22	436	435	2.25
HF-G633	680	655	654	2.17
HF-G634	355	295	294	2.08
HF-G635	344	287	286	2.08
HF-G636	258	210	369	2.17
HF-G637	615	600	599	2.17
HF-G638	384	325	315	2.17
HF-G639	6	448	449	2.25
HF-G640	299	245	246	2.32
HF-G641	133	408	84	2.17
HF-G642	12	463	464	2.17
HF-G643	126	73	300	2.17
HF-G644	64	14	5	2.17
HF-G645	65	15	14	2.17
HF-G646	737	683	684	2.53
HF-G647	493	415	479	2.17
HF-G648	298	244	245	2.32
HF-G649	225	173	244	2.32
HF-G650	450	385	130	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G651	691	644	643	2.17
HF-G652	320	263	264	2.25
HF-G653	283	230	238	2.17
HF-G654	181	136	382	2.23
HF-G655	619	596	595	2.08
HF-G656	332	274	264	2.17
HF-G657	434	368	366	2.17
HF-G658	403	285	342	2.56
HF-G659	357	74	301	2.17
HF-G660	734	692	682	2.47
HF-G661	282	229	230	2.17
HF-G662	679	654	653	2.17
HF-G663	404	58	343	2.40
HF-G664	100	132	46	2.25
HF-G665	396	334	382	2.17
HF-G666	681	656	655	2.17
HF-G667	692	645	644	2.17
HF-G668	293	239	240	2.17
HF-G669	424	363	362	2.17
HF-G670	67	16	17	2.17
HF-G671	92	39	40	2.17
HF-G672	687	664	661	2.17
HF-G673	53	17	2	2.17
HF-G674	421	355	354	2.17
HF-G675	678	653	652	2.17
HF-G676	422	MH-42	357	2.17
HF-G677	391	MH-37	331	2.17
HF-G678	401	340	341	2.23
HF-G679	394	332	333	2.23
HF-G680	695	648	647	2.17
HF-G681	498	474	530	2.23
HF-G682	451	386	385	2.17
HF-G683	694	647	646	2.17
HF-G684	604	583	574	2.17
HF-G685	17	453	436	2.25
HF-G686	390	384	330	2.23
HF-G687	122	304	71	2.17
HF-G688	720	673	674	2.62
HF-G689	478	412	414	2.17
HF-G690	722	670	671	2.62
HF-G691	104	60	51	2.17

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G692	755	706	704	2.08
HF-G693	444	288	380	2.17
HF-G694	476	410	409	2.08
HF-G695	729	700	699	2.56
HF-G696	68	19	20	2.17
HF-G697	200	344	152	2.17
HF-G698	296	241	183	2.17
HF-G699	547	506	504	2.17
HF-G700	230	178	179	2.25
HF-G701	503	503	202	2.17
HF-G702	608	358	SPS1	2.14
HF-G703	210	253	162	2.25
HF-G704	508	496	498	2.38
HF-G705	728	690	680	2.62
HF-G706	334	277	278	2.17
HF-G707	302	251	243	2.25
HF-G708	321	265	264	2.17
HF-G709	294	243	242	2.25
HF-G710	315	259	258	2.17
HF-G711	500	480	481	2.17
HF-G712	319	257	263	2.17
HF-G713	730	701	700	2.32
HF-G714	202	157	251	2.25
HF-G715	563	511	512	2.08
HF-G716	305	155	248	2.17
HF-G717	CO-5	MH-67	SPS 6 Overflow	2.08
HF-G718	CO-10	33	30	2.08
HF-G719	CO-20	44	33	2.17
HF-G720	CO-29	41	33	2.17
HF-G721	CO-30	668	MH-67	2.17
HF-G722	CO-31	MH-67	SPS6	2.08
HF-G723	TWIP17	TWIP17	TWIP1	2.36
HF-G724	TWIP7	TWIP14	TWIP13	2.47
HF-G725	TWIP9	202	TWIP15	2.56
HF-G726	TWIP8	TWIP15	TWIP14	2.56
HF-G727	TWIP21	TWIP18	TWIP19	3.07
HF-G728	TWIP22	TWIP19	TWIP Emergency Overflow	3.07
HF-G729	TWIP2	TWIP3	TWIP2	2.56
HF-G730	TWIP20	TWIP18	TWIP SPS	3.11
HF-G731	TWIP18	674	TWIP17	2.44

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-G732	TWIP5	TWIP12	TWIP11	2.64
HF-G733	TWIP1	TWIP2	TWIP1	2.64
HF-G734	TWIP6	TWIP13	TWIP12	2.64
HF-G735	TWIP10	TWIP9	TWIP8	2.64
HF-G736	TWIP16	TWIP1	TWIP16	3.25
HF-G737	TWIP13	TWIP6	TWIP5	2.64
HF-G738	TWIP11	TWIP8	TWIP7	2.73
HF-G739	TWIP12	TWIP7	TWIP6	2.73
HF-G740	TWIP4	TWIP10	TWIP9	2.73
HF-G741	TWIP15	TWIP4	TWIP3	2.73
HF-G742	TWIP14	TWIP5	TWIP4	2.73
HF-G743	TWIP3	TWIP11	TWIP10	2.73
HF-G744	TWIP19	TWIP16	TWIP18	3.50
HF-G745	CO-34	515	587	2.08
HF-G746	CO-35	473	586	2.14
HF-G747	M111	M114	M115	2.23
HF-G748	M109	M112	M113	2.23
HF-G749	M110	M113	M114	2.23
HF-G750	M112	M115	M116	2.23
HF-G751	M113	M116	M117	2.23
HF-G752	CO-36	M117	Rosalie Downs SPS	2.32
HF-G753	CO-38	MH-75	M112	2.32
HF-G754	CO-39	714	MH-75	2.23
HF-G755	CO-40	MH-76	MH-77	2.25
HF-G756	CO-41	MH-77	MH-78	2.17
HF-G757	CO-42	MH-78	MH-79	2.25
HF-G758	CO-43	MH-79	TWIP18	2.25
HF-P1	PP-32	PJ-6	28	2.32
HF-P2	PP-33	PJ-4	677	2.25
HF-P3	PP-34	PJ-3	PJ-6	2.32
HF-P4	PP-35	PJ-1	PJ-3	2.40
HF-P5	PP-1	SPS1	SPS1 Duty Pump	2.14
HF-P6	PP-3	SPS2	SPS 2 Duty Pump	2.14
HF-P7	PP-5	SPS3	SPS3 Duty Pump	2.08
HF-P8	PP-7	SPS4	SPS 4 Duty Pump	2.08
HF-P9	PP-9	SPS6	SPS 6 Duty Pump	2.08
HF-P10	PP-11	SPS7	SPS 7 Duty Pump	2.14
HF-P11	PP-13	SPS10	SPS 10 Duty Pump	2.08
HF-P12	PP-15	SPS11	SPS 11 Standby Pump	2.14
HF-P13	PP-26	Rosella Gardens Pumpout Tank	Rosella Gardens Pumpout Pump	2.08

Asset No.	Label	Start Node	Stop Node	Criticality Rating
HF-P14	PP-27	Rosella Gardens Pumpout Pump	Rosella Gardens Pumpout Truck	2.08
HF-P15	PP-28	SPS 6 Duty Pump	PJ-8	2.08
HF-P16	PP-29	PJ-8	324	2.17
HF-P17	PP-30	SPS 6 Overflow	SPS6 OF Pump	2.08
HF-P18	PP-31	SPS6 OF Pump	PJ-8	2.08
HF-P19	PP-54	SPS3 Duty Pump	PJ-3	2.08
HF-P20	PP-55	SPS 4 Duty Pump	PJ-21	2.08
HF-P21	PP-56	PJ-21	PJ-6	2.25
HF-P22	PP-57	SPS 7 Duty Pump	PJ-22	2.14
HF-P23	PP-58	PJ-22	401	2.32
HF-P24	PP-59	SPS 11 Standby Pump	PJ-23	2.14
HF-P25	PP-60	PJ-23	159	2.32
HF-P26	PP-66	SPS 10 Duty Pump	PJ-4	2.17
HF-P27	PP-70	SPS1 Duty Pump	PJ-1	2.40
HF-P28	PP-86	SPS2	SPS 2 Standby Pump	2.14
HF-P29	PP-87	SPS 2 Standby Pump	PJ-31	2.14
HF-P30	PP-88	SPS 2 Duty Pump	PJ-31	2.14
HF-P31	PP-89	PJ-31	PJ-1	2.14
HF-P32	PP-90	TWIP SPS	TWIP Duty Pump	3.06
HF-P33	PP-91	TWIP Duty Pump	PJ-33	3.15
HF-P34	PP-94	PJ-33	PJ-37	3.32
HF-P35	PP-95	PJ-37	Highfields RM Discharge	3.32
HF-P36	PP-102	Rosalie Downs SPS	Rosalie Downs Duty Pump	2.23
HF-P37	PP-104	Rosalie Downs Duty Pump	PJ-38	2.49
HF-P38	PP-106	PJ-38	MH-76	2.49
HF-P39	PP-131	SPS11	SPS11 Duty Pump	2.14
HF-P40	PP-132	SPS11 Duty Pump	PJ-23	2.14

Appendix E – Risk Assessment

Appendix E1 Risk Assessment Guidelines

Risk assessment guidelines were obtained from the University of Southern Queensland's Risk Management Plan V1.0 which was adapted from AS436:2004. The guidelines presented below.

Table E 1: USQ table of consequences

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs e.g. workers compensation and property damage and indirect costs, e.g. impact of loss of research data and accident investigation time.

Table E 2: USQ table of probabilities (likelihood)

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

Table E 3: USQ risk rating table

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	**M**	**H**	**E**	**E**	**E**
B (Likely)	**M**	**H**	**H**	**E**	**E**
C (Possible)	**L**	**M**	**H**	**H**	**H**
D (Unlikely)	**L**	**L**	**M**	**M**	**M**
E (Rare)	**L**	**L**	**L**	**L**	**L**

Table E 4: USQ recommended action guide

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level.
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required.
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

Appendix E2 TRC Site Visits and Data Collection

As part of this project, a site visit is required to collect asset data at various water and wastewater facilities within TRC. The obvious risks involved in performing these activities are:

1. Potential exposure to hazards including machinery and moving objects (pumps, motors, macerators, blowers etc).
2. Potential exposure to hazards such as high levels of noise within operational facilities generally caused by machinery.
3. Potential exposure to hazards such as electrical equipment (switchboards, control panels, generators, transformers etc).
4. Potential exposure to dangerous liquids including corrosive chemicals and raw sewage (sodium hypochlorite, chlorine gas, fluoride, acids etc).
5. Potential exposure to hazards such as plant and vehicles (forklifts, trucks, cranes etc).
6. Potential exposure to other hazardous areas.

Main controls to minimise risks excluding the fact that appropriate training and qualifications have already been ascertained through TRC employment:

- Follow all TRC rules, regulations and induction policies.
- Wear appropriate PPE (ear plugs, protective eyewear, long sleeve shirt, long pants, steel capped boots, high visibility vest, hard hat in designated areas etc).
- Be aware and obey all signage and safety line markings.
- Provide notification of my presence to relevant staff and fill out attendance sheets.
- Attend sites with at least one other employee.

Table E 5: TRC site visits and data collections risks

No.	Risk Description	Consequence	Likelihood	Risk Rating	Risk Decision
1	Injury due exposure to machinery and moving objects	3	D	Moderate	Accept
2	Injury due to exposure to excessive noise	2	D	Low	Accept
3	Injury due to exposure to low and high voltage electrical equipment	4	D	Moderate	Accept
4	Injury due to exposure to corrosive chemicals, gasses and raw sewage	4	D	Moderate	Accept
5	Injury due to exposure to plant and vehicles	3	D	Moderate	Accept
6	Injury due to exposure to other hazardous areas or equipment	2	D	Low	Accept

Appendix E3 Ongoing Risks

The deliverables of this thesis have the potential for ongoing risks beyond the completion of this project. The following ongoing risks have been identified:

1. Potential for thesis work to be disregarded due to unmanaged employer expectations. This risk can be controlled through regular liaison with Managers and relevant staff to everyone remains on the same page throughout the project. For example, based on literature reviews I may take a different approach to what was originally agreed with TRC. If this is not well communicated, my thesis will not be well received and expectations will not be met which could hinder the success of this work.

2. Given the fact the outcome of this thesis is expected to be used by Asset Engineers within TRC, there is a risk that if the project work is not executed well (thoroughly) it could lead TRC down the wrong path and provide uninformative, useless results that waste resources. Even worse, it could provide misleading results that result in incorrect management of assets. This risk can be controlled by meeting with my Manager throughout the duration of the project to obtain advice. In addition, it could be controlled by performing a thorough, non-bias analysis of results within the thesis.

Table E 6: Ongoing risks

No.	Risk Description	Consequence	Likelihood	Risk Rating	Risk Decision
1	Potential for thesis work to be disregarded by employer	2	C	Moderate	Accept
2	Potential to lead employer down the wrong path if not executed correctly	3	C	High	Accept

Appendix E4 Working Conditions and Document Development

There are a number of risks associated with the development of the dissertation document, such as:

1. Injuries due to repetitive work including muscle strain, eye strain and headaches. These can be controlled by safely configuring workstations by ensuring adequate lighting, computer screen heights and ventilation. In addition, regular exercise breaks should be taken to reduce the chance of injury.

2. Illness due to stress factors such as long working hours and pressure due to work and university deadlines. Stress factors can be controlled with adequate planning, scheduling and sleep.

3. Unforeseen health issues such as injuries, viruses or diseases which may decrease productivity and result in additional stress or project failure. These can be controlled by reducing stress levels, getting adequate sleep and by reducing exposure to sick environments.

4. Loss of data due to unexpected equipment failure which may lead to project incompletion. This risk can be controlled by regularly backing up data on multiple devices and by using reliable equipment.

Table E 7: Working conditions and document development risks

No.	Risk Description	Consequence	Likelihood	Risk Rating	Risk Decision
1	Injuries due to repetitive work	2	C	Moderate	Accept
2	Illness due to stress	2	C	Moderate	Accept
3	Unforseen health issues	3	B	High	Accept
4	Project data loss	2	C	Moderate	Accept