PAPER 2

A CASE STUDY ANALYSIS ON MUNICIPAL WATER PIPE FAILURES

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ABSTRACT

The study assessed water pipe failure rates in a South African municipality to highlight the need for proper maintenance and compare results to acceptable norms. The study underscored the necessity of reliable data. A key observation was that linking pipe breaks to precise locations is essential for accurate analysis. About 83% of reported breaks investigated in this study could be geographically linked. To address this problem, it is recommended that case reports need to include coordinates for all pipe breaks, which can be easily captured using modern mobile devices. A literature review provided pipe break benchmark values based on pipe age, material, diameter, pressure, and seasonal variations. The study area included approximately 795km of pipelines. About 36% of all pipes were categorised in the 90-125mm diameter range, with only 8% exceeding 450 mm diameter. Additionally, 30% of the pipes were older than 45 years. Approximately 40% of all pipes operate within the 40–60m pressure range.

The response time to repair pipe failures was also analysed. In ~50% of all cases, a team was dispatched within 4 hours, while 35% of repairs took longer than 15 hours to initiate. Once on-site, 70% of breaks were repaired within 6 hours. Breaks reported between midnight and 06h00 typically had a 9-hour response time, whereas those reported between 06h00 and 18h00 were attended to within 2 hours. However, repair durations remained consistent, with over 70% of repairs completed within 6 hours, regardless of reporting time. Failure rate was found to be proportional to pipe age, with pipes over 46 years exhibiting a failure rate of 0.669 failures/km·year, compared to 0.1 failures/km·year for relatively new pipes. The highest failure rates (0.789 failures/km·year) were observed in small-diameter pipes (90–125mm). The study found no correlation between pipe failures and rainfall or seasonal changes. Spatial analysis did not reveal specific failure hotspots, though 11% of failures were classified as recurring within 60 days and 50m of a prior break – lower than the internationally reported values of 22–46%. The average failure rate of 0.45 failures/km·year in the study area was higher than 89% of various global benchmarks.

1. INTRODUCTION

1.1 Background

This study investigates pipe failures of a typical municipal treated water network. The purpose of the study was to analyse the available pipe failure data for the period July 2013 to June 2024 (11 years) to understand causes and trends in pipe burst frequency and to compare the results to available benchmarks.

1.2 Confidentiality

For reasons of confidentially, the name of the municipality and the related location of the study area were not disclosed in this manuscript. This factor was not considered limiting in terms of the results and key findings reported here. Conclusions presented in this paper are aimed at a wider audience and are not site-specific. Ultimately, outcomes of this study would also be used by the relevant municipality to inform appropriate remedial steps to ensure a well-maintained water network (although not reported here).

2. KNOWLEDGE REVIEW – BENCHMARKING

2.1 Terminology and KPIs

Barton et al. (2019) provided clarity around terminology and pointed out that the terms leak, burst or failure are used when a pipe break and water is released. These terms are often synonymously used with pipe failures. Pipe breakages can contribute to significant water losses in water distribution networks and negatively impact service delivery. Sufficient high-quality data is needed to enable a better understanding of how well a water network is managed in the context of breaks or failures. Information is needed regarding the network characteristics, the logging/reporting of various pipe failures and the associated response times to address the failures.

One of the key indicators used for comparison is the failure rate for pipe breaks, indicating the number of pipe failures per year per unit of pipe length. Various distance units are used in literature, with the most common expressing the number of failures per 1 000, 100 or 1km. In this study the unit consistently used to describe pipe failure rate is failures per km per year (failures/km·year).

2.2 Factors influencing pipe failure

Barton et al. (2019) presents a review of factors influencing pipe failure and sort the factors into three
groups, viz. pipe intrinsic factors, environmental factors and operational factors.

- Pipe intrinsic factors include material, joint systems, coating and lining, manufacturing defects, damage from handling, storage and third parties, corrosion and chemical degradation, pipe age and diameter.
- Environmental factors include seasonality, temperatures and soil movement as well as other soil and ground movement.
- Operational factors are internal pipe pressure and previous failures.

Wengstrom (1993) completed a literature review on pipe failures to investigate various factors that influence failure rate. Among others, the following key factors i.e. age, diameter, pipe material, seasonal variation, soils, pressure and previous failures, were listed. The review of factors for this study was based on the work by Barton et al. (2019), with emphasis on factors that were more prominent in the case study.

Failure rate is known to increase with pipe age, with failure rate increasing notably after a pipe reaches a certain age (typically with zero remaining useful life). Barton et al. (2019) collected data from 308 water companies in the USA and Canada and reported that the average age of pipe failure is 50 years.

Barton et al. (2019) also confirms that pipe age has a linear relationship with failure rate, with older pipes being more likely to fail, but the relationship is more complex. Failures rates are typically higher in the months immediately following installation, then drop to a low rate of failure for several decades, before increasing with age. Giustolisi and Berardi (2009) reported that failure rate of a pipe is roughly constant during the "in-usage" phase (normal service) and increases with time as the pipe approaches the end of its life cycle ("wear-out" phase).

In addition to pipe age, the installation year – linked to pipe material – has been found to influence failure rate. Certain periods in history could be linked to relatively poorer installation methods of certain pipe materials than other periods (Andreou, 1986), also because construction methods improved over time.

Few studies report failure rate for different materials separately – some are noted in Table 1. Pipe failure analysis suggests a strong relationship between failure rate and pipe diameter (Barton et al. 2019). The highest failure rate is typically reported in pipes with relatively small diameters, e.g. <200mm in diameter. Higher failure rates in small diameter pipes have been investigated in previous studies and could be linked to low resilience to ground movement, corrosion (the smaller diameter pipes have relatively thinner walls), poor joint reliability and susceptibility to nearby construction activities especially in urban areas and at shallower depths Internal pressure was found to influence pipe failure rate, with higher pressures leading to increased failure rate (Andreou, 1986). However, few studies report on the relationship between pressure and failures.

Walski (1982) confirmed that pipe failure rates are seasonal; pipe failures were found to increase during the winter months (in the USA), as reported by Andreou (1986). Dehghan et al. (2009) conducted statistical analysis of the structural failures of water pipes in Melbourne, Australia. The pattern of rainfall in the region was compared with the pattern of failure rate variations and in 70% of the times the two patterns are observed to be consistent. In other words, a strong link was established between rainfall and failure rate. Dehghan et al. (2009) also highlighted that between 22% and 46% of all pipe failures do have a strong link to previous failures and that in 60% of these cases the re-leak occurred within 3 months of the previous failure. They concluded that previous failures are one of the most significant impact factors in the analysis of pipe failures. Seasonal failure patters with typically more failures in winter months, were also confirmed with an interesting link to water temperature, with higher water temperature typically resulting in more failures.

Some of the factors listed above are more relevant to the current study mainly due to available data. The review of factors influencing pipe failures for this study was based on the work by Barton et al. (2019), with emphasis on factors that were more prominent in the case study.

From the literature it was concluded that pipe age, diameter, pressure as well as rainfall need to be evaluated to ensure informed decision making. The relationship between pipe failures, using indicative benchmark values, will also be evaluated over time to determine whether the Municipality is gaining or falling behind in terms of their maintenance / pipe replacement efforts.

TABLE 1: *Pipe failure rates – Overview from literature*

Reference	Description / Location	Failure rate (failures/km·year)
Goulter & Bouchart (1990)	25mm diameter	1.55
	610mm	0.026
Gupta & Bhave (1994)	150mm to 400mm	1.04 to 0.05
Fujiwara & DeSilva (1990); Fujiwara & Tung (1991)	100mm to 350mm	1.36 to 0.05
Shamir & Howard (1979)	N/A	0.01 to 0.15
Walski & Pelliccia (1982)	N/A	0.0207 to 0.0137
Kleiner & Rajani (1999)	N/A	0.001 to 0.188
Mailhot et al. (2003)	N/a	0.01 to 0.19
SA WRC Benchmark Newsletter No 6	Western Australia – 2003	0.1013
	Western Australia – best figures over 4 years	0.0147 to 0.0361
Andreou (1986)	Houston, USA, Total network length 6 417km with ave age 70 years	0.806
Andreou (1986)	New Orleans, USA, Total length 2,295km	0.320
Andreou (1986)	Detroit, Milwaukee, Philladelphia, Kansas City, Baltimore, Denver, 6 systems with average failure rates	0.101 to 0.189
Andreou (1986)	Columbia, San Francisco, NY, St Louis, Chicago, Boston, LA, Seattle, New Haven, 10 systems in USA with low failure rates	0.05 to 0.079
Dehghan et al. (2008)	Melbourne Zone 1, Australia, Highest failure rate reported in Australia	1.0
Dehghan et al. (2008)	Melbourne Zone 2, Australia	0.5
Dehghan et al. (2008)	Melbourne Zone 3, Australia	0.3
Barton et al. (2019)	UK Combined data set, Iron pipes	0.189
Barton et al. (2019)	UK Combined data set, AC pipes	0.161
Barton et al. (2019)	UK Combined data set, PVC pipes	0.162
Barton et al. (2019)	UK Combined data set, PE pipes	0.034
Barton et al. (2019)	UK Combined data set, Steel & DI pipes	0.047
Barton et al. (2019)	UK Combined data set, All data combined	0.129
Jacobs et al (2025)	Combined 2000–2023, Dunedin New Zealand	0.205
Cabral et al. (2024)	Unsure (Portugal / Brazil), system has >75% of pipes with diameter < 250mm	0.222
Vega (2022)	Auckland, main pipes	0.278

2.3 Failure rate

A comprehensive review of reported failure rates from various case studies is presented in **Table 1**. Neelakanta et al. (2008) sited various international researchers to summarise failure rates, frequently linked to pipe diameter. In a study by Vega (2022) the number of pipe failures were investigated for Auckland. The author differentiates between service pipe failure and main pipe failures, with service pipe failures typically linking the households with the network. The research recorded an average main network failure rate of 0.278 failures/km·year. The Water Research Commission (WRC, n.d.) also reported some case study values from Australia in their Benchmark newsletter (issue No 6), also included in Table 1.

While generalised international benchmark values are not readily available (most are within a specific context), Cabral et al. (2024) present a pipe conditional matrix indicating that 0 failures per year is good, while 1 failure per year can be considered as average, with 2 failures per year as unsatisfactory. However, when considering the values provided in Table 1, it can be concluded that any failure rate > 1 can be high. Comprehensive analysis of pipe failure data in Jacobs et al (2025) showed that the failure rate was less than ~0.4 failures/km·year for 80% of all annual values (for all pipe materials over 24 years), with an average of 0.2 failures/km·year.

Melbourne Water in its Water Main Renewal Study (cited in Dehghan et al. 2008) noted that the western region of Melbourne (CWW) was experiencing a disproportionately high rate of failures. It reported a failure rate three times that of Melbourne's other two water supply systems. For example, between 1972 and 1990 the annual average water main failure rate throughout the first study area was approximately 1 failure/km·year, while this value was 0.3–0.5 failure/km·year for the other two regions.

3. METHODOLOGY

3.1 Research methodology

This study comprised collection, collation and subsequent analyses of available information relating to pipe failures in the study area. Typical characteristics of water supply infrastructure were evaluated, considering the following independent variables: diameter, length, age, operating pressure. Subsequently the results of pipe failure, as function of various parameters, is presented. The data were evaluated in the context of the municipal financial year, from 1 July to 30 June of the following year. The analysis covers an 11-year period from 1 July 2013 to 30 June 2024.

3.2 Data collection

Data was obtained directly from the municipal pipe asset database as well as previous reports. Eight water distribution regions were included in the study area, with the main source of data being the IMQS data base. The original input to IMQS was sourced through various role-players and staff members over time.

The key source of data used in the analysis was derived from the pipe failure reports. The availability of reliable data also influenced the level of detailed analysis possible for the various regions, and it was only possible to assess the information considering all the data together, as opposed to an analysis for each region on its own. The quantity and quality of data was considered sufficient to draw reliable conclusions.

The data used in this pipe failure analysis originated primarily from the monthly pipe failure reports. The original report forms were completed in hard copy format by the team supervisor responsible for managing the maintenance team doing the pipe repair. One report form was complete per pipe repair incident. Information from report forms was subsequently captured in excel format by municipal staff. The data received from the Municipality in MS Excel was assumed to be accurately captured and additional verification was considered beyond the scope of this study.

3.3 Research focus

The focus of the investigation was on physical pipe characteristics and how these variables impacted pipe failure rate. The physical parameters were considered useful because it was possible to compare the results to reported values from studies elsewhere. Although this study also considered rainfall and temperature correlations to explain seasonal trends, the related findings were inconclusive and were excluded from this paper.

3.4 Spatial identification of pipe failures

One of the critical data challenges is to identify the position of a reported pipe failure accurately in terms of position, the correct pipe segment and diameter. The typical position of a failure is reported in the pipe failure reports in the form of a sketch/explanation. The pipe failure coordinates were recorded in IMQS, allowing each pipe failure record to be linked to the closest pipe GIS-feature. Pipe failure positions which could not be linked in this manner, were linked to the reported street address. The address was linked to the closes pipe GIS-feature to within 50m, using the reported same pipe diameter from the pipe failure case report. A total of 3910 failures could be linked to a specific position, which was almost 83% of all the reported pipe failures in the database.

4. RESULTS

4.1 Pipe failure reporting

Each pipe failure is associated with significant water losses. A quick response time to repair these failures/leaks is important to minimise water losses and prevent poor service delivery. The analysis into the response time, with reference to the time it took from a failure being reported till an action was taken, provide results summarised in Figure 1, with 50% of all failures been responded to within 4h.

The repair time, which can be influenced by many aspects, indicated that 70% of all failures were repaired within 6h. The time and day of the week a failure was reported, did not provide any reason for concern. 50% of all reported failures between 00h00 and 06h00 were attended to within 9h, while for the response time for failures reported between 06h00 and 18h00, 60% were attended to within 2h. For failures reported between 18h00 and 24h00, only 20% of the reported failures were attended to within 8h. Repair time were however not influenced by the time of the day it was reported or the day of the week.

4.2 Pipe failure rates linked to age distribution

The number of failures per annum in the municipality is gradually increasing, which is to be expected, given the aging and expansion of the network over time. While there are no significant differences, slightly more pipe failures were experienced in the months of September and October. Considering the age distribution of pipes which failed, Figure 2 clearly highlighted that about 40% of these failures occurred at pipes older than 46 years. Also important to note is that new pipes were installed where about 15% of the pipe failures occurred, indicated as the category "new" in Figure 2. This is indicative that pipe replacement took place on pipes with a high risk of failure.

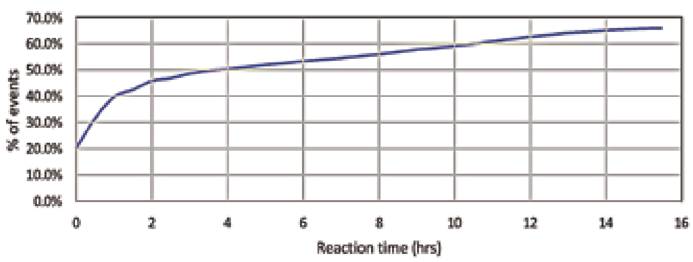

FIGURE 1: *Reaction time to start of reported pipe failure repair*

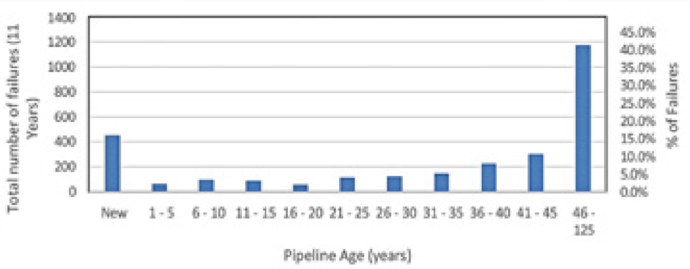

FIGURE 2: *Distribution of age of linked pipe failures*

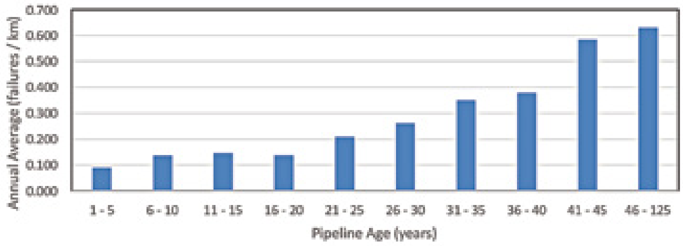

FIGURE 3: *Distribution of pipe failure rate according to age*

As expected, the rate of pipe failure systematically increases with age, with newly installed pipes reflecting a value of 0.1 failures/km·year, while the two oldest categories of pipes (all pipes older than 40 years) proofs to have a failure rate of 0.669 failures/km·year to 0.695 failures/km·year, almost 7 times higher. Figure 3 illustrates a markable increase in failure rate of pipes from age 41 and older, which is in line with international experience that pipe typically fail at age 50.

4.3 Pipe failure rates linked to diameter distribution

The failure rate for different pipe diameter categories is illustrated in Figure 4. The smaller diameters (50mm and smaller) experienced the highest failure rates, with values ranging from 0.5 failures/km·year to 0.94 failures/km·year over the years, with an average of 0.789 failures/km·year. These values are in line with international literature.

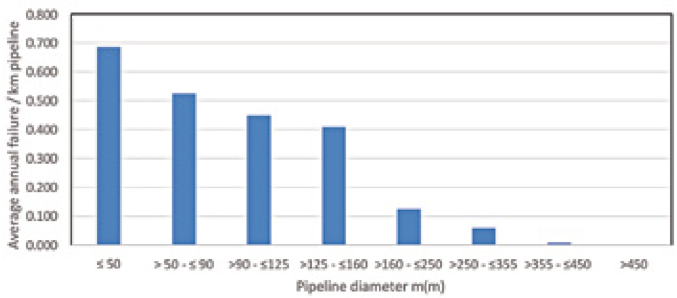

FIGURE 4: *Distribution of average pipe failure rate according to diameter*

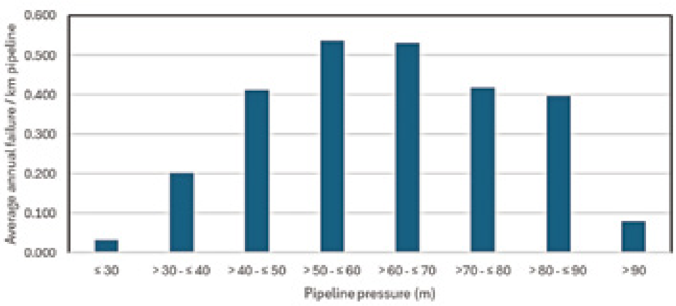

FIGURE 5: *Distribution of average pipe failure rate according to pressure*

4.4 Pipe failure rates linked to Pressure distribution

The static pressure from IMQS was interpreted as the average pressure between the start and end of each pipe length. The pressure values were not measured pressures, but theoretical static pressure. The failure rate for different pipe diameter categories is illustrated in Figure 5. The average failure rate for all pressure zones from 40 to 90m is above about 0.4, with the highest rate of average pipe failures in the 50 to 70m pressure category with values of between 0.53 failures/km·year to 0.54 failures/km·year. The failure rate in the 70 to 90m pressure zone consistently increased during the past 3 years.

4.5 Seasonal variation in pipe failures

Rainfall data from a representative rainfall station was used to investigate any correlation with pipe failures. No correlation between pipe failures and hourly, daily or 7-day rainfall could be found. The seasonal pattern of pipe failures was further investigated using the rainfall pattern as guiding indicator. Figure 6 illustrated that while Spring on average account for the highest number of pipe failures, no clear correlation could be obtained from the available data.

4.6 Repetitive pipe failures

The reoccurrences of a pipe failure might be indicative of poor repair procedures and was therefore also analysed and the results presented in Figure 7. 11% of all failures can be considered as reoccurring failures (failures occurring within 50m of the original failure) taking a 60-day period (days between the first and second failure) into consideration. The repetitive failures within a 5-year period are in line with international literature values.

5. DISCUSSION AND CONCLUSIONS

The main objective of this paper was to highlight the key findings in the assessment of the pipe failure rate of all the water supply pipelines in the municipality experienced during July 2013 to June 2024 . Due to challenges experienced with the data collection and analysis process, only 82.9% of all reported failures could be linked to a specific pipeline network.

A comprehensive literature review provided a range of benchmark values for pipe failure depending on age, material, pipe diameter, pressure as well as seasonal variations. Since the dataset did not have a variety of different pipeline material, only benchmark values for age, pipe diameter and pressure were calculated. Pipe age was identified as a significant challenge for the municipality. Almost 38.5 % off all pipe lengths are being operated in the 40 to 60m pressure range.

An analysis of the response time (how quickly a team was sent to attend to a pipe failure after report) revealed that in 50% of the cases a team was sent out within 4h. About 35% of the repairs took longer than 15h to attend to. Once on site, 70% of the failures were repaired within 6h, with about 20% taking longer than 20h. About 50% of all pipe failures reported between 00h00 and 06h00 took approximately 9h to attend too, while 60% of those reported between 06h00 and 18h00 took only 2h to attend to. For failures reported after 18h00, only 20% was responded to within 8h. The repair time were however not influenced by the time of the day and more than 70% of the failures were repaired within 6h. The day on which a pipe failure was reported on, was not found to influence the repair time.

About 82.9% of all pipe failures could be linked to a specific position, which enabled a more detailed analysis of the link between pipe failures, age, pressure and diameter. As expected, more than 40% of all failures occurred in pipelines older than 46 years, in line with international experience indicating that pipes typical fail at age 50. With more than 30% of all pipes older than 46 years, a significant increase in pipe failures can be expected in the future.

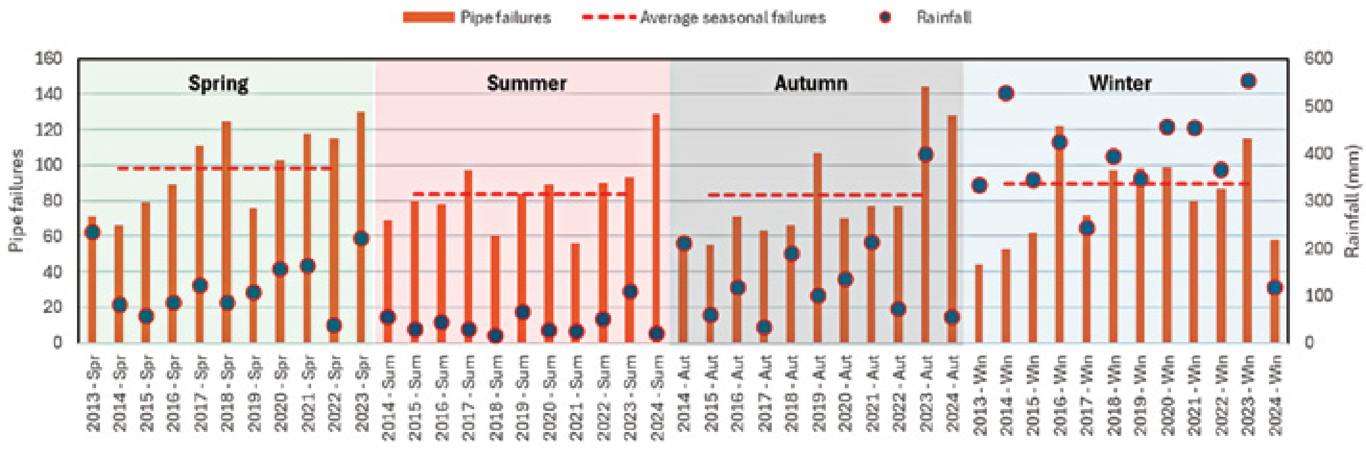

FIGURE 6: *Seasonal variation in pipe failures*

For comparative purposes, taking pipe length into consideration, the failure rate increased from 0.1 failures/km·year for newly installed pipes to 0.669 failures/km·year for pipes older than 46 years.

Almost 70% of all pressure pipe failures occurred in the 40-70m pressure zone, with the highest average rate of failure between 0.53 and 0.54 failures/km·year. 46.9% of all failures, taking pipe size into consideration, occurred in the 90 to 125mm diameter category. The failure rate in terms of pipe diameter was found to be the highest in the small diameter pipes, with 0.789 failures/km·year. The failure rate for pipe diameters >250mm dropped significantly to 0.072 failures/km·year. There is no indication of any systematic increase in failure rate for pipe size over time.

An analysis into the impact rainfall and different seasons might have on the number of pipe failure was inconclusive. No link to the monthly rainfall was detected or to the cumulative 7-day rainfall prior to a failure. Evaluating the number of pipe failures occurring in the different seasons, were also inconclusive, with only marginal increased average pipe failures observed in spring.

Assessing the spatial distribution of pipe failures within the context of this study was challenging. GIS plots did not highlight any particular "hot spot" areas. An analysis into the possibility of re-occurring pipe failures provided interesting results. Only 11% of all values were identified as possible re-occurring failures, which a significantly lower than the international reported 22% to 46%, with 60% occurring within 3 months.

Some contrasting results were obtained when comparing the pipe failure rates with other entities. At an international level, the distribution network experienced average pipe failure rates of approximately 0.45 failures/km·year which is higher than 89% of the international reported failure rates.

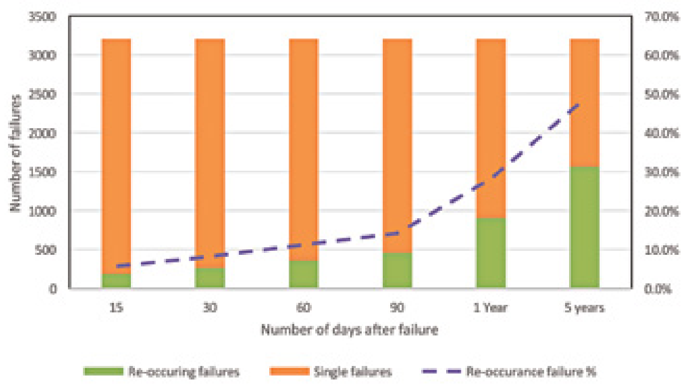

FIGURE 7: *Re-occurring pipe failures for different time periods*

The international comparison using pipe diameter as an indicator reflects that the municipality experience the same trends reported internationally.

6. RECOMMENDATIONS

It is clear from the research that municipalities face a significant challenge to ensure that their water pipe networks will keep up with growing demands. To facilitate a sustainable water pipe network management strategy, it is recommended that municipal engineers consider the flowing as part of their sustainable Maintenance Action Plans (MAPs):

- Up to date asset register for all water pipes, which include age.
- Accurate logging/reporting of the positions of pipe breaks on their pipe break reporting system.
- The reporting of actual pressures against design pressures as part of the reporting system
- Consider pressure reduction in areas with pressure significantly higher than design / min requirements.
- Accredited (standardised) training to all plumbers responsible for maintenance.
- The development of a standard reporting system at National/Provincial level for various pipe break benchmarks to facilitate funding allocations.

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