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Infrastructure Cliff? Queensland's Ageing Water and Sewerage Assets. 2. Cost implications for in-ground assets.

QWRAP Research Report 5.2

Infrastructure Cliff? Queensland's ageing water and sewerage assets. 2. Cost implications for in-ground assets.

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Executive Summary

Queensland's urban water and sewerage infrastructure is conservatively valued at $38 billion dollars and is growing each year. More than half of this value exists in 'buried assets' - the water and sewer pipes that criss-cross all urban communities. Because these networks are expensive to replace and are not easily accessible, they require dedicated management.

Recent population growth in Queensland means that around a third of the underground assets have been installed since 2000 and are expected to provide ongoing service for some decades. The life expectancy for water and sewer pipes varies markedly depending on local conditions but most provide good service for at least 70 years. Beyond this age, or when conditions are particularly harsh, pipe breaks become increasingly common.

Some pipes may last longer than 70 years and their service life can be prolonged by repairing individual breaks. However, when failures become too severe, pipes must be fully replaced and this is an expensive process, particularly in highly-developed areas. These high costs mean that public utilities must decide on the optimal timing for replacement. Beginning too soon unnecessarily increases costs for customers and disrupts communities while the work is being carried out. Waiting too long risks water leaks, service interruptions, sewage spills and economic disruption, particularly during emergency repairs.

Striking the right balance between repair and replacement is particularly difficult for buried assets because they are hard to access and subject to local variation. While age is an imperfect indicator of pipe condition, it provides a surrogate to estimate replacement needs when information about the condition of individual pipes is unknown. In Queensland, by 2017 the replacement cost for all pipes over 70 years old (representing less than 4% of the total network) was $815 million. At current rates of replacement, this figure will rise to $1.8 billion by 2030 and $3.8 billion by 2040 when almost 20% of pipes will be over 70 years old.

The rapid increase in pipes nearing the end of their useful lives means that breaks will increase in coming years and business-as-usual investment will not keep pace with necessary repair and replacement. Until recently, Queensland utilities have had the advantage of rapid growth of relatively young networks. As the State moves into the next phase of the asset cycle for water and sewerage infrastructure, investment in replacement and repair will need to increase.

Achieving this new balance will be challenging for some (particularly regional) utilities. Optimal investment must be targeted at the most deteriorated (not always the oldest) pipes but moderated by knowledge about local constraints and cost drivers. This relies heavily on access to dependable local data (e.g. condition and risk assessments for aged pipes) and this is not readily available for many regional networks. Future investment must be balanced among renewals, repairs and improved systems to monitor and prioritise works and this will require significant change for regional councils.

This report examines changes needed in investment in ageing water and sewerage networks and recommends four mechanisms to ease the transition for regional communities.

Recommendations

This paper describes modelling of common investment approaches for renewals using case study data based on Queensland pipe sizes and ages. It confirms well-known principles that investment must be balanced across high and low criticality assets and targeted at poorest condition pipes. To achieve this, better targeting of renewals is essential, requiring improved monitoring and assessment of condition and criticality and tools for prioritising rehabilitation options.

The modelling also highlights the additional costs associated with the perverse incentives to rapidly increase investment without improving targeting of renewals. Over time, poorly directed capital investment magnifies total costs which rise dramatically as networks age. These costs become untenable for individual utilities and unsustainable for the Queensland sector as a whole. Fortunately, large savings are possible if modest investments are immediate but targeted.

In short, future investment to address Queensland ageing inground infrastructure must be balanced not only across repair and renewals, but also directed to condition assessment and prioritisation based on criticality. This will be difficult for individual councils in regional Queensland so four recommendations are provided that can address the issue using regional and state-scale collaboration.

Recommendation 1

A greater focus on collecting, collating and analysing network data than has previously been the case is urgently needed for many regional service providers. The necessary data includes improved assessment of condition and age but also of criticality, redundancy and vulnerability underpinning a more accurate and systematic assessment of pipes taking advantage of emerging technologies. The scope of sampling, monitoring and data collection must be carefully designed: exhaustive assessment of all reticulation networks would be impossible and consume resources needed for renewal or repair. Appropriate data collection and most importantly, analysis, will prove challenging for some (particularly small and remote) councils. A collaborative approach would allow optimisation of data collection, analysis and benchmarking by combining economies of scale with local knowledge and facilitating adoption of consistent methodologies and new technologies. **It is recommended that a regional approach is facilitated to refine condition assessment, failure analysis and attribution of criticality with data inserted back into local asset management systems and also shared across regions.**

Recommendation 2

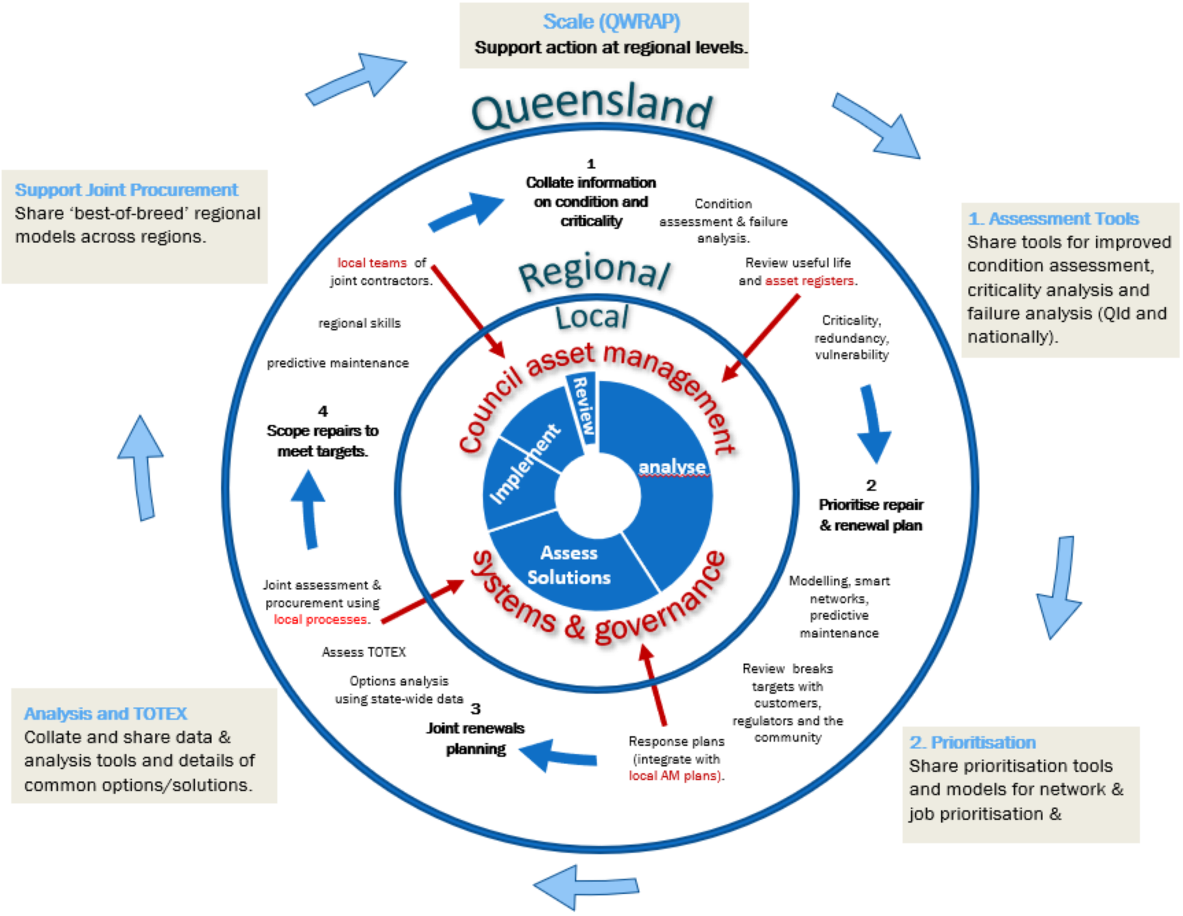
A more sophisticated prioritisation of pipe repair and renewal activities is critical but must also comprehend the many asset management systems used by individual service providers. Queensland councils have extensive experience in asset management, but systems are optimised for non-water and sewage assets. Fit-for-purpose prioritisation approaches must be developed with an eye to the needs of different sized councils and the expectations of their customers and regulators. Advanced prioritisation should move beyond like-for-like replacement considering down-sizing and decentralised alternatives or emerging technologies that reduce dependency on expensive network infrastructure. **It is recommended that processes for prioritising renewal and repair are supported at a regional scale to provide critical mass in negotiations with customers and regulators,**

facilitate data sharing across the state (and nationally), and build local knowledge and skills for regional sustainability.

Recommendation 3
Design and procurement processes for replacing and repairing networks can be improved particularly through analysis of whole-of-life expenditure (TOTEX) and a better understanding of past performance based on local, regional, state and national experience. This can be achieved only through collaboration at multiple scales. Future costs can be reduced through fit-for-purpose sizing and design and optimising installation and repair processes. Individual service providers can lack capacity and bargaining power to improve design and procurement processes but the benefits of regional cooperation in this domain have been well demonstrated though existing QWRAP projects. Coordination will become increasingly important as networks age and utilities concurrently seek to procure services in a limited supply market. **It is recommended that design and procurement of repair and renewal services be facilitated through regional cooperation to ensure appropriate TOTEX analysis and market sounding.**

Recommendation 4
An increased focus on network repairs to balance and the likelihood of higher rates of breaks in ageing networks with changing public expectations and increasing regulation will require regional service providers to evolve how they respond to breaks. Reactive repair programs will not suffice and must be augmented with predictive maintenance programs linked with increased communication with customers and with regulators. This process will be difficult for many individual service providers. **It is recommended that a regional approach is developed to facilitate sharing and development of information and skills on repair of water and sewerage networks with a stronger foundation for engaging regulators and customers.**

These four recommendations would change how in-ground assets are managed take account of the existing barriers to asset management for network infrastructure for regional councils. Individual service providers are not unable to deal with the ageing assets but capacity issues mean that many (even large utilities), accustomed to a predictable and low background degradation rates, will struggle to change their investment profiles in time to avoid cost imposts. The recommendations highlight the need to continually learn during the process to better understand the assets and the emerging costs for repair and renewal. The interactions among these recommendations are illustrated in the following Figure.



Scale (QWRAP)
Support action at regional levels.

1. Assessment Tools
Share tools for improved condition assessment, criticality analysis and failure analysis (Qld and nationally).

2. Prioritisation
Share prioritisation tools and models for network & job prioritisation &

Analysis and TOTEX
Collate and share data & analysis tools and details of common options/solutions.

Support Joint Procurement
Share 'best-of-breed' regional models across regions.

1 Background

This is the second of two reports investigating ageing water and sewerage networks in Queensland. Report 5.1 (Cosgrove and Fearon, 2017) reviewed studies from other jurisdictions including evidence from the USA, UK, Canada and Thailand showing that older networks are beginning to increase costs for communities (AWWA, 2013; UKWIR, 2017; Punurai & Davis, 2017; Folkman, 2018). Like these countries, Queensland saw rapid acceleration in construction of water and sewerage networks following World War II and many are reaching the end of their expected lives of 50-80 years in the next two decades. Unmanaged, this will result in an infrastructure cliff requiring significant investment.

The initial study assessed the age and likely rate of deterioration of networks using data about the length, size, material and age of water and sewer pipes from across Queensland. The report was released as an industry discussion paper and received positive feedback about the analysis and deterioration modelling but varying views about the timing and impact of deterioration of networks. Some utilities reported widespread failure of sections of their networks while others had experienced limited degradation of aged pipes due to favourable local conditions (such as less aggressive water and mobile soils). Utilities also continued to provide asset data about their networks. The dataset created for the initial paper now represents 95% of Queensland's water networks and 67% of the sewers and is the most comprehensive and accurate snapshot ever collated on Queensland's in-ground water and sewerage pipes.

Regardless of their views on the rate of deterioration, utilities broadly agreed that current rates of renewal were insufficient. The average rate of water network renewal 0.3% per year reported by some Australian utilities (see WSAA, 2013 and Fearon and Cosgrove, 2017) was seldom achieved by Queensland utilities and even at this rate, current replacement would fall well short of even the most optimistic life expectancies of ageing pipes. Two other common observations were that because only modest replacement had been required in the past and networks are 'out-of-sight and out-of-mind', renewals are notoriously difficult to fund. Better information is required on the likelihood and consequence of failures and the types of changes in management and investment in networks to minimise future costs.

This paper (Report 5.2) describes research on options for managing ageing networks and their likely costs at different scales. The report is structured as follows.

- Section 2 examines the costs to manage ageing networks in Queensland.
- Section 3 explores the trade-offs between investing in repair versus replacement.
- Section 4 considers the secondary costs associated with network repairs.
- Section 5 compares costs of renewal and repair taking into account secondary costs.
- Section 6 synthesises the findings of the report and provides 4 recommendations to optimise investment in regional networks.

2 The costs of managing ageing networks

2.1 Options for addressing ageing pipes

Failures water and sewerage networks manifest in the form of breaks, bursts and leaks and can be addressed in numerous ways, each with differing costs and benefits that are heavily influenced by local conditions. There are four broad categories for managing ageing pipes.

Repair of breaks and leaks is the most common option for damaged water and sewer mains as it can address a problem relatively rapidly using only minor works. Breaks arise from a multitude of causes ranging from pipe corrosion, cracks, or pitting to leaks at a fixture or fitting. Each has a range of repair options with costs depending on the size and location of the pipe. An important factor for water (cf sewer) breaks is that water leaks are driven by pressure and waste potentially expensive and limited water resources. Sewer breaks are typically gravity-driven but create potential public health and environmental risks. Repair costs for both water and sewer networks increase with increasing pipe diameter and depend on numerous external factors (e.g. depth, location, traffic control and ability to isolate the pipe being repaired).

Another option is to defer action until a later date. For example, allowing a small water leak to continue may have little immediate impact if it does not disrupt supply and wastes little water. Small leaks may not be economical to address immediately (despite loss of treated water) but their importance is also determined by customer perceptions and corporate reputation. For gravity sewers, small breaks may not lead to significant leaks, but any leak must be assessed for the potential to cause public or environmental harm. Another issue for sewer breaks is infiltration (when shallow ground water enters a sewer) which contributes to overloading pumping stations and sewage treatment plants. Nevertheless, given the need to prioritise maintenance responses, some leaks may not be an immediate priority or economical to locate or repair.

The third response is replacement (renewal) of entire sections of pipe. There are three broad categories of replacement (WSAA, 2013), namely:

- excavating and removing existing mains and construction of a new pipeline in the same alignment,
- bursting/splitting existing mains and inserting a new length of pipe in the same alignment,
- abandoning the old mains and constructing a new pipeline on a new alignment either by open trenching or ‘trenchless’ techniques (e.g. directional drilling).

Each technique has its own costs and benefits. There are additional factors to consider with some materials, particularly asbestos cement (AC) pipes which forms a large proportion of older networks. For example, bursting and splitting may increase the potential hazard of AC pipes and is no longer commonly practiced. Similarly, there is not yet a clear consensus on whether abandoned AC pipes should be left in the ground or removed, the latter being an extremely costly process that increases exposure risk.

The fourth type of response is ‘relining’ existing pipes. Many pipes can have a new internal lining applied *in situ* using a range of techniques that avoid the significant expenses of excavation and trenching. Relining is generally less expensive than replacement but does not result in full renewal of the network. Relining sewer mains is common across Queensland and many service providers have annual relining budgets for this purpose. Relining of water mains has recently become practical but is still relatively costly (see e.g. Ventia, 2018). Consequently, entities relining water mains have to date focussed on highly critical mains or alignments that cannot easily be accessed.

Allowing a break to go unaddressed is not a long-term option and some form of rehabilitation (i.e. repair, relining or replacement) will eventually be required. Any form of rehabilitation may impact levels of service and cause customer and public disruption (e.g. through interruption of supply, interfering with traffic or disrupting businesses). These impacts vary dramatically based on the location and criticality of the pipes. For example, replacement of the most common sized (100 mm) water main in the Brisbane CBD will have significantly higher impacts and costs than a similar main in a small suburb. Regardless of the technique used, denser urban areas generally face greater costs (because of impacts on traffic, access ways and disruptions to other services and businesses). Other key factors influencing rehabilitation costs include the type of soils, the size of the main, scale of works and the time in which the work needs to be done (e.g. to avoid disruptions to critical water users and customers). Some of these factors can be included in analysis of costs (see below) while other ‘secondary’ costs such as interruption of service and economic disruptions are difficult to quantify (and are considered further in Section 5.

Box 2.1: Criticality
The criticality of network assets can be rated in numerous ways but a common method is to assess the severity and consequence of different ways the system can fail. High criticality may be attributed to:

- large pipes or those essential to large areas of a network;
- networks serving hospitals and other essential services;
- sewers that may cause environmental or public health risks; and/or
- networks that are difficult to access or where failure will severely impact transport or business activities.

2.2 Costs of pipe repair and rehabilitation

The multiple factors impacting repairs and rehabilitation of water and sewer pipes complicate any estimation of likely costs. Only limited specific data on repairs and renewal costs were available from Queensland service providers as they are not consistently recorded across the sector. Anecdotal evidence suggested that costs varied markedly across the State so two methods were used to determine the range of likely impacts.

The first was a review of Australian utility websites, recent reports and news articles reporting rates for repair and rehabilitation (see Appendix 1) yielded costs from $200 to $3500 per metre with a median price of $836 per metre. It should be noted that these analyses include a range of very diverse scenarios, mostly in capital cities and do not consistently consider all secondary costs and risks such as safe handling of AC pipes or the scale and density of works nor costs of remoteness of regional sites. The second method compared ‘unit rates’ provided utilities nationally. Unit rates are commonly used to describe the average cost per meter to renew a given diameter pipe,[1] often with multipliers to allow for extra costs (e.g. for logistics, local geology, scale of the work and availability of labour).

Following the approach adopted by WSAA (2013) 'adopted unit rates' were developed for five size classes of water and sewerage pipes to best represent costs reported by Queensland service providers (Table 2.2.1). These adopted rates are highly conservative and provide a lower bound estimate of the costs of replacing Queensland water and sewer pipes.

Table 2.2.1. Adopted unit rates for pipe rehabilitation in Qld (see Appendix 1).

Type of rehabilitation	Cost per meter for five size classes of pipe (mm)					
	100	150	200	300	450	600
Water Replacement	**$200**	**$230**	**$275**	**$410**	**$650**	
Sewer Relining	**$100**	**$140**	**$190**	**$240**	**$400**	**$500**
Sewer Replacement	**$200**	**$280**	**$320**	**$400**	**$600**	

In contrast to renewal and relining, unit rates for repair were not readily available and an adopted rate was determined based on a survey of Queensland councils and network specialists. Costs of pipe repair ranged from a few hundred to many thousands of dollars depending on the size, type, depth and magnitude of the break. The majority of repairs were for small breaks resulting in a very skewed distribution of repair costs with the majority being lower-cost. Large repairs can be extremely expensive but are relatively uncommon compared with routine break repairs. A highly conservative adopted value of $1200 was used to capture the majority of (small routine) repairs even though this will under-represent the larger maintenance work. This figure does not take full account of overheads and ignores the secondary costs of repairs[2].

2.3 Replacement and repair costs of Queensland's networks

The adopted unit rates can be used to estimate the total replacement cost of the known length of Queensland networks. Table 2.3.1 compares these estimates with the costs calculated using unit rates adopted by WSAA (2013) which are the only published national estimate. The analysis was undertaken by grouping pipes into the nearest of five size classes and applying the adopted unit rates listed in Table 2.2.1.

The majority of the replacement cost for water networks is for 100 mm diameter pipes as they are most numerous in Queensland networks (see Figure 2.3.1). The total replacement cost of all 42,000 km of Qld water pipes in 2017 was $11.5 billion while for all pipes older

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[1] In this report 'urban' rates are used as an indication of costs in areas with a moderate density of development. Rates would be higher for metropolitan (CBD) areas but could be lower in rural towns or suburbs with low-density development and longer distances between connected properties

[2] It also ignores scale issues across utilities. For example, in very small utility overheads associated with maintaining equipment and staff could be disproportionate and some large utilities may be able to outsource network maintenance.

than 70 years (i.e. installed prior to 1948) it was $645million. For comparison, WSAA (2013) estimated that the 40,000 km of AC water mains in Australia would be $8.8 Billion. The same report found that "if the construction costs are increased to include the removal of the disused (abandoned) or burst/split AC pipe material, an increase in order of between 50% and 150% can be expected resulting in the national total rehabilitation cost for remaining AC water mains of between $13.2 Billion and $22 Billion" (WSAA, 2013, p. 41).

Table 2.4.1: Comparison of replacement costs for water pipes using adopted unit rates.

Unit rates used	**Replacement Cost ($mill)**	
	Water pipes in dataset (39,750 km)	All water pipes in Qld (42,000 km)
qldwater adopted unit rates (water pipes)	$10,930	$11,500
WSAA (2013) unit rates (water pipes)	$9,470	$9,950
	All sewers in dataset (22,750 km)	All sewers in Qld (33,500 km)
qldwater replacement unit rates (sewers)	$7,082	$9,420
qldwater relining unit rates (sewer relining)	$3,916	$5,210
WSAA (2013) average renewal rate (sewers)	$4,664	$6,868

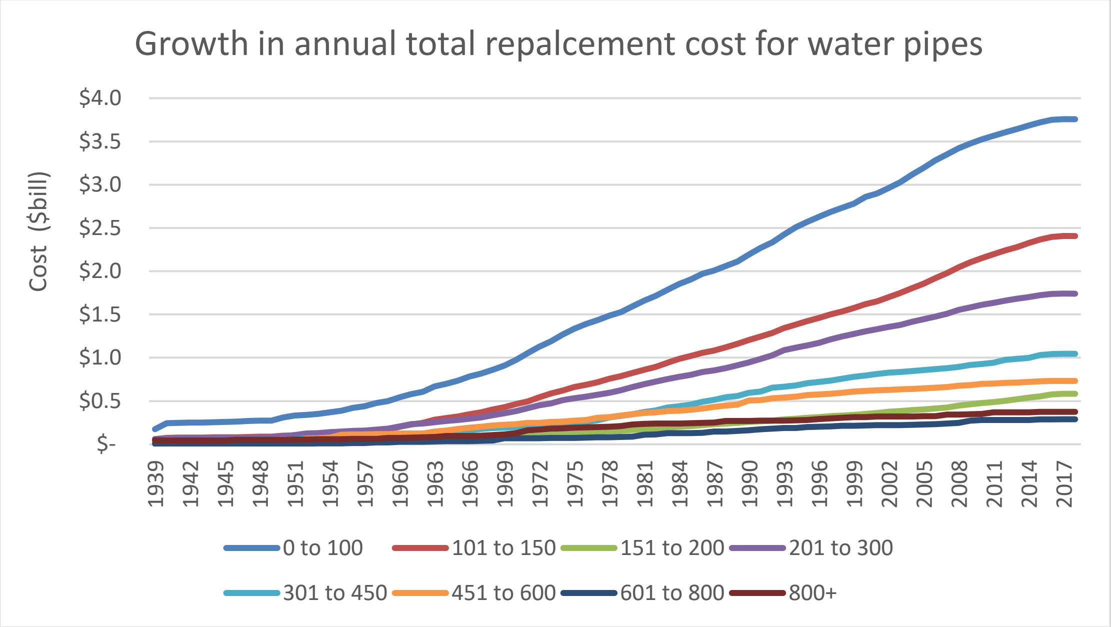

Figure 2.3.1: Cost to replace all water pipes of different sizes. For example, to replace all 0-100 mm pipes installed prior to 1969 (~50 years old) would cost ~ $1 bill.

The replacement cost for sewers was less than for water pipes because there are less sewers and they are typically younger than corresponding water networks (Table 2.4.1). The common practice of relining is around 50% less costly than full renewal, although it would not be possible to reline every sewer. The total replacement cost of all sewer mains at the adopted unit rates is $9.420 billion and the total cost for relining would be $5.210 billion indicating a 'total rehabilitation cost' somewhere between these extremes.

The conservative total replacement cost for all Queensland public networks is around $21 billion (assuming no relining of sewers). This represents around 60% of the $37 billion reported replacement cost for all local government assets (see Fearon, 2015). These are conservative estimates: real costs could be expected to be much higher, but most of the assets are not in immediate need of renewal. In 2018, 2362 km of Queensland water mains were over 70 years old with an estimated replacement cost of $645 million. By 2030 the length of pipes that are more than 70 years old increases to 5023 km ($1.4 bill replacement cost) and reaches 9627 km ($2.7 bill) by 2040. Sewers are generally younger: in 2018 only 570 km were over 70 years old with a replacement cost of $170 mill. By 2030 this increases to 1196 km ($365 mill) and is 3723 km by 2040 ($1.15 bill). This rapidly increasing renewal deficit (or 'infrastructure cliff') assumes an optimistic replacement rate of 0.3% per annum.

Estimates of annual rehabilitation costs are provided in Box 2.2 assuming the reported estimate of 0.3% per year for water networks (WSAA, 2013). This is expected to be optimistic rate in Queensland but even if replacement were raised to 1% per year, pipes must remain in service an average of 100 years to allow for effective replacement (in contrast to their expect life of 50-80 years). At a rate of 1%, 420 km of water mains would be replaced per year costing $114.7 million. The high cost of renewals, particularly compared with the cost of break repair highlights the case for ongoing repairs instead of full replacement. These trade-offs between replacement and repair are explored in Section 3, but the next section examines the regional distribution of aged pipes.

Box 2.2: Current Queensland repair and replacement.

There is no available data on how much each Queensland utility spends annually on rehabilitation programs. If all utilities replaced water pipes at the rate of 0.3% per year, total expenditure would be around $34.4 mill in 2017 (or $18.12 per connection). If all utilities repaired (the average reported) 24 breaks per 100 km of water network in 2016/17[3] then total repair expenditure would have been $7.79 mill for water and $7.78 mill for sewer pipes. These costs are in addition to the capital costs for new assets in the same period.

2.4 Regional impact of ageing networks.

The distribution of old mains is not uniform around the state, reflecting the historic rates of development and subsequent varied approaches to renewals. Figure 2.4.1 provides a summary of water network age across service providers that contributed data for this research (representing 95% of the total pipe length in the state). The proportion of water pipes that are over 40 years old is also graphed for small (Figure 2.4.2a) and large (Figure 2.4.2b) service providers and Figures 2.4.3a and 2.4.3b provide a similar representation for sewers.

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[3] SWIM (2017).

Figure 2.4.1: The age of water pipes in Queensland mapped for 36 regional councils outside SEQ that provided data. The missing regional councils (in grey) account for less than 5% of Queensland water mains. The intensity of colouring represents the percentage of pipes that were constructed prior to 1978 (i.e. > 40 years old) but are still operating.

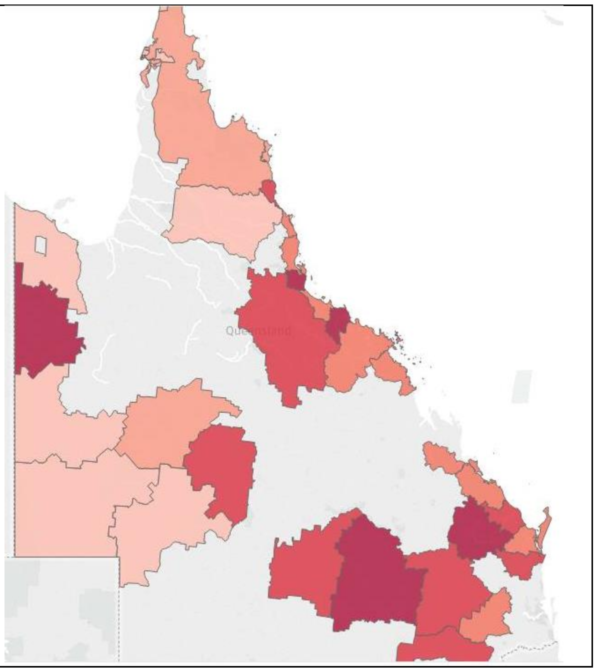


Figure 2.4.2a: Total pipe length in councils with less than 1000 km of water mains (or approx. 83,000 people/ 32,000 connections) showing the proportion installed before and after 1978.

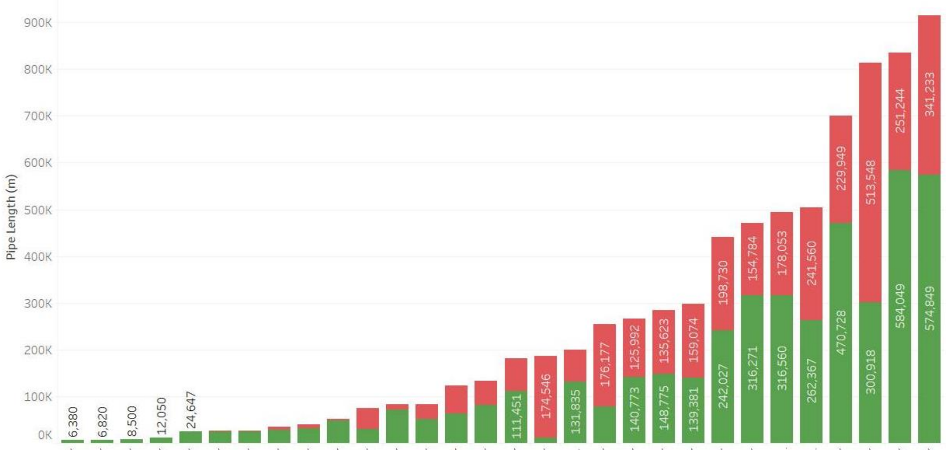


Figure 2.4.2b: Water pipe length for councils with more than 1000 km of water mains (or approx. 83,000 people/ 32,000 connections) showing the proportion installed prior to 1979.

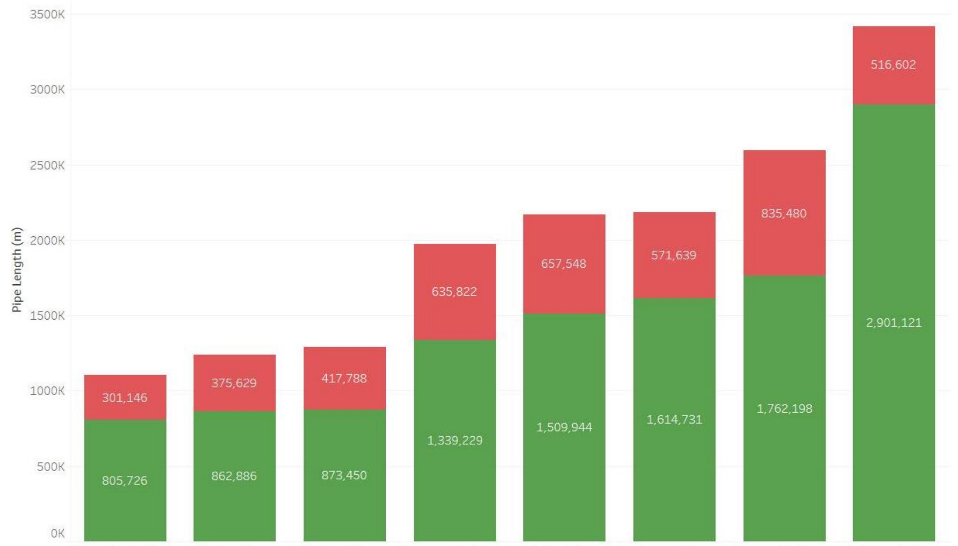


Figure 2.4.3a: Sewer length in councils with less than 750 km of sewers (or approx. 40,000 connections) showing the proportion installed prior to 1978.

🟥 Pre 1978 (>40yrs Old)
🟩 Post 1979 (<40yrs Old)

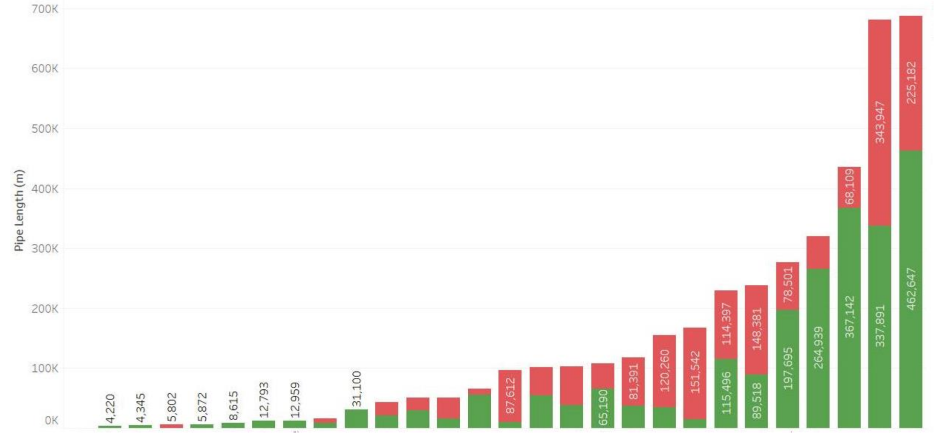
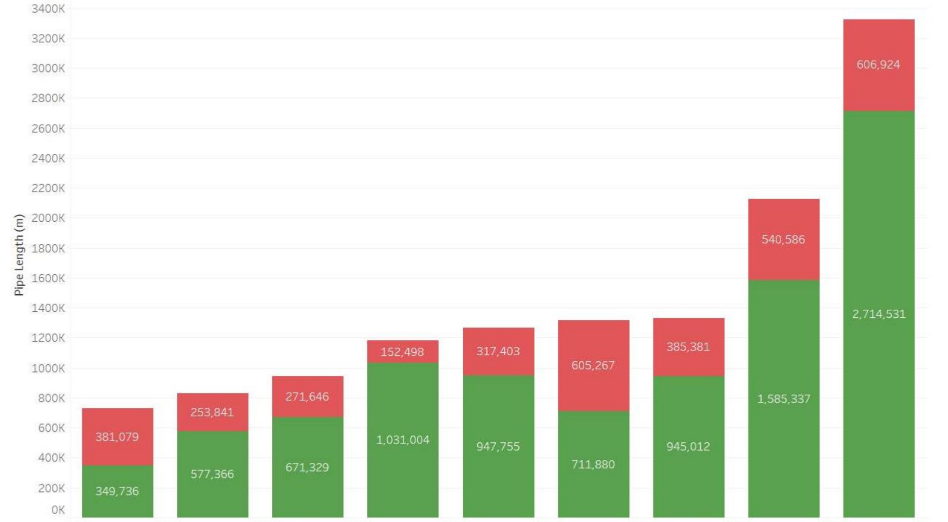


Figure 2.4.3b: Sewer length for councils with more than 750 km of sewers (or approx. 40,000 connections) showing the proportion installed prior to 1978.



These figures show that the distribution of aged pipes varies widely across regional Queensland. Despite the variation there is a tendency for councils of similar size to share similar proportion of aged pipes (despite some striking exceptions) and in general, there appears to be a trend for larger councils to have a smaller proportion of aged pipes. Regardless, the total number of old pipes in large councils dwarfs those of the smaller local governments. The demand for repair and replacement will therefore be much greater in the large councils, but the impact of renewals will be disproportionately high for small councils particularly given the small number of rate payers per km of main. This relationship is examined further in Section 4.

3 Balancing Repair and Replacement

3.1 Financial cost of repair versus replacement

Water utilities are routinely faced with decisions about rehabilitation of degraded network assets. “Although water utilities typically take action to manage and reduce pipe breaks through monitoring, preventing all pipe failures is impossible,” (Folkman, 2018, p. 8) meaning that a trade-off is necessary. The key questions are when to take action and whether to repair, renew or reline. During the collation of the research dataset, numerous examples were provided describing approaches to achieving this balance ranging from deferring action (temporarily accepting minor leaks and breaks) to annual sewer relining programs.

In practice, replacement or relining often is opportunistic driven by funding or by extending a scope of works to use a transient workforce (particularly for most small-medium communities in regional Queensland). Inevitably, this approach results in some pipes being replaced or relined prematurely, but it can also maximise scope and scale needed to make renewals viable. Nevertheless, if adopted to vigorously, broad-scale replacement unnecessarily inflates costs because, “it is not cost-effective to replace a pipe before, or even after, the first break” (Punurai and Davis, 2017, p. 6). Consequently, alternative mechanisms that promote economies of scale allowing for inconsistent renewal budgets are needed for replacement activities.

A common approach used by many service providers is the ‘three-strikes rule’. A ‘length of pipe’[4] that has failed and been repaired twice will be replaced (or relined) when a third break occurs. This heuristic seeks to balance the costs of repair and replacement with the advantage of not requiring extensive analysis of deterioration. A disadvantage of this approach is that it does not promote recording failure modes, rates, renewal processes and costs required to maintain different types of pipe. This means utilities lack data for predicting or pre-empting breaks in similar lengths of pipe. This technique is also not suitable for critical pipes where breaks are to be avoided at all costs.

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[4] A ‘length of pipe’ depends on the type of mains, how they were installed, their size and the material they are made from but is often defined as the length between joins or manholes.

For non-critical pipes, an acceptable level of breaks is often adopted by utilities to guide the trade-offs inherent to rehabilitation programs. Utilities set an acceptable number of breaks as part of their customer service standards, usually described by an annual number of breaks per 100 km of pipe. This target then determines the effort placed on renewals and repair in order to remain below the agreed limit.

In a survey of numerous utilities in the US and Canada, 86.2% of respondents used “the number of water main breaks per unit length to evaluate drinking water pipe performance” Folkman (2018, p.7). Annual break rates in the US averaged 13-19 breaks/100 km, but in the survey, “only 28% of the respondents said that they had a specific value (Folkman, 2018, p. 28). Australian examples for water mains breaks include Cairns (18 breaks/100 km), QUU (39 breaks/100 km) and SA Water (21 breaks/100 km) while the national average for large utilities was 16.1 breaks / 100 km with a median of 12.4 (NPR, 2017). Annual targets for sewers are less common but SA Water has reported a figure of 53 breaks/100 km and the median number of sewerage breaks and chokes from national data 16.5 breaks/100km with a range of 1 to 110 per 100km (NPR, 2017).

Annual data from Queensland service providers averaged 24 breaks per 100 km (with a median of 14) over the past six years (Figure 3.2). There is substantial variation across the State but the majority of councils that exceed 50 breaks / 100 km are typically small remote and arid communities with network much shorter than 100 km. In such cases, the impact of even a minor break is magnified by this metric. Setting an appropriate level of breaks depends on the relative costs of repair and replacement and the needs of the community.

To explore this relationship, the financial benefits of deferring replacement through ongoing repairs were modelled using Queensland data and models created for report 5.1 (Cosgrove and Fearon, 2017). The financial cost of repairs required to maintain a target number of breaks were compared with the financial costs of full renewal (see Appendix 2) and the total cost for repair and eventual replacement were compared for the different targets. The modelling considered only a subset of the Queensland dataset and had a number of assumptions but was relatively robust to the unit costs used (see Appendix 3) and clearly demonstrated broad trends.

Figure 3.1 summarises total costs for repair and replacement if break rate of 14, 24, 39 and 50 per 100 km are tolerated. Allowing only 14 breaks per 100 km (the current Queensland median) results in early renewal of pipes and has the highest immediate and ongoing cost over the next three decades. This is because expensive renewals are required to maintain low numbers of breaks as pipes age and begin to deteriorate. Allowing successively higher targets decreases costs by hundreds of millions of dollars but has diminishing returns beyond a certain point (illustrated but the small difference between 50 versus 39 breaks per 100 km). This reflects the well-known financial benefit of deferred replacement in favour of repair when replacement (or relining) costs are so much higher than the financial costs for individual repairs.

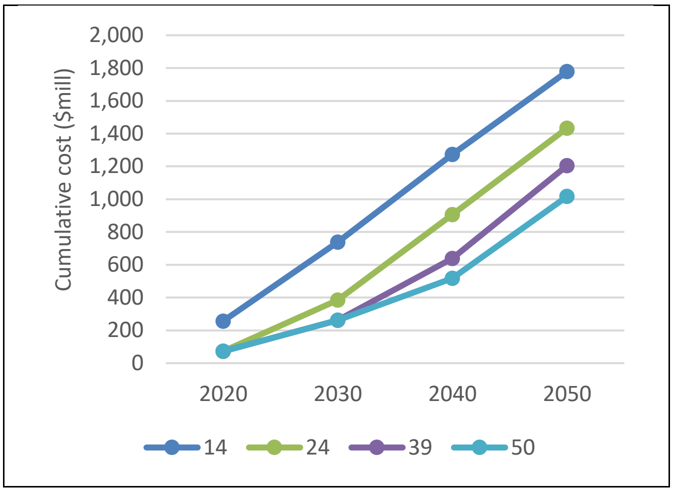

Figure 3.1: Total cumulative cost of repair and replacement for four break targets over three decades (see Appendix 2 for model details).

The model outputs suggest that if a target of 39 rather than the current industry average of 24 breaks/100 km were adopted, financial savings from avoiding early replacement could be significant. However, this assumes that repair services are capable of keeping up with the escalating breaks while maintaining a low cost of repair per break and that customers and regulators accept a higher rate of breaks. Moreover, the model omits the full economic costs because it ignores secondary costs such as customer interruptions, disruption of business or political or reputational damage to a service provider. These impacts can be difficult or impossible to value but must be considered when determining the appropriate investment profile for Queensland's networks (see Section 5) and require a more proactive and evidence-drive approach to repair and replacement.

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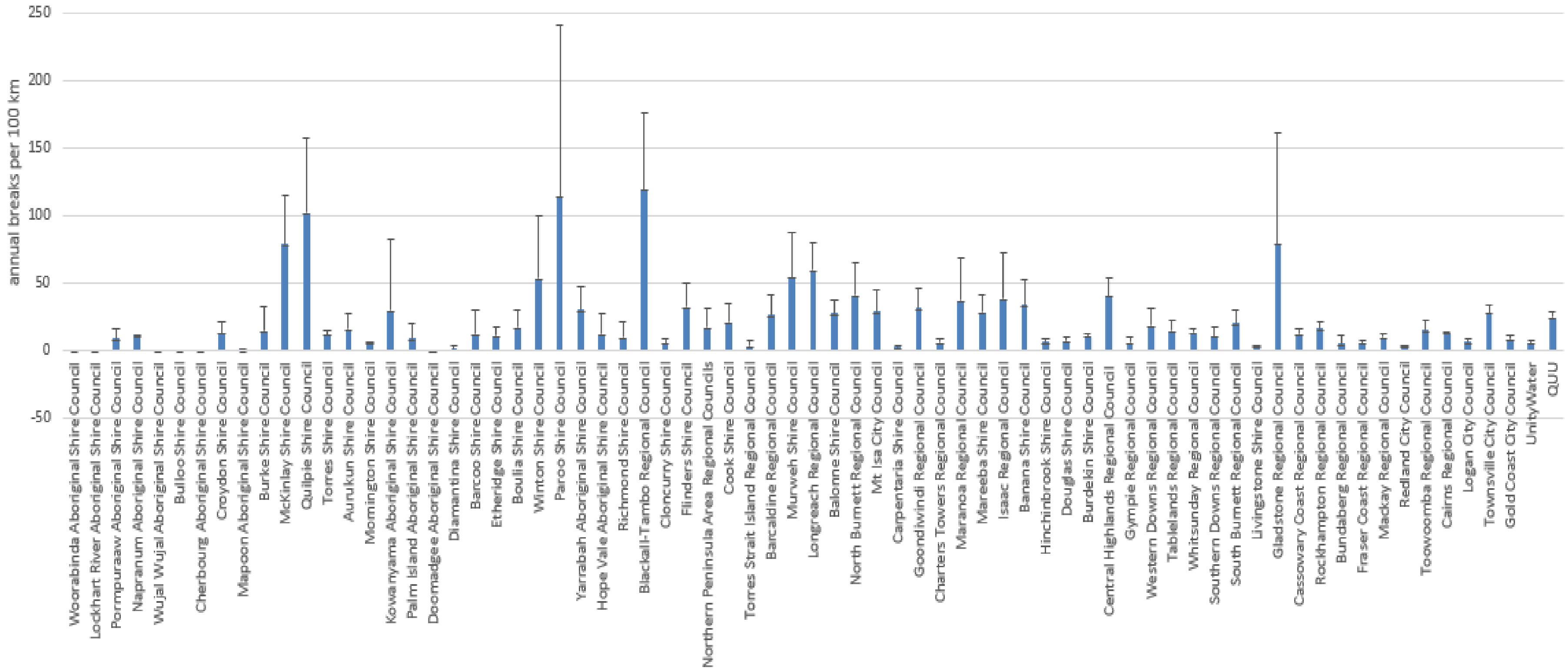


Figure 3.2: Average number of annual water main breaks per 100 m for all Queensland utilities that reported this indicator between 2010/11 to 2016/17. Data are ordered by total length of water mains managed by each utility and error bars indicate the standard deviation of the mean (Source: SWIM, 2018).

3.2 Best practice repair and replacement

"Ideally, pipe replacement occurs at the end of a pipe's 'useful life'; that is, the point in time when replacement or rehabilitation becomes less expensive going forward than the costs of numerous unscheduled breaks and associated emergency repairs" WSAA (2013, p. 8). This is a nuanced trade-off which must consider the full economic costs of breaks, repairs and replacement (such as secondary costs such as service interruption, economic disruption and traffic impacts). It varies from town-to-town (and perhaps from pipe-to-pipe) and must be informed by appropriate data.

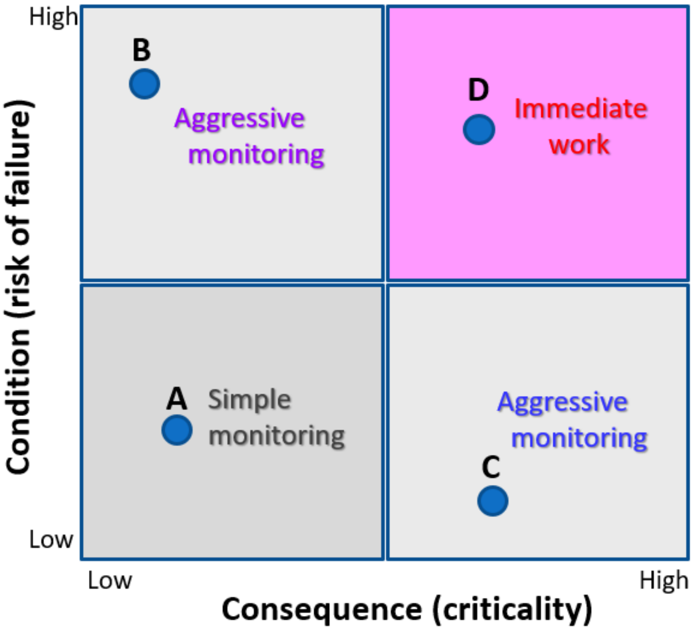


Figure 3.3: Investment risk matrix based on condition and criticality. Source: USEPA (2015).

The best-practice approach for determining investment in repair versus replacement is to base the decision on a risk assessment of pipes based on their likelihood of failure (condition) and the consequence of the pipe failing (criticality). Investment in management of pipes is determined by their position the matrix of criticality versus condition (see e.g. Figure 3.2.1). "For example, if the consequences of failure are perceived to be relatively low, the decision to intervene may be delayed until an upper limit (or optimistic) estimate of lifetime is reached. Alternatively, if the consequences of failure are perceived to be high, the decision to intervene will be at a lower limit (or pessimistic) estimate of lifetime before the expected time to failure" (Punurai *et al*., 2014, p. 6). Even if the risk associated with a highly degraded low-criticality pipe is assessed to be similar to that of a less degraded, high-criticality pipe, it may still be preferable to invest preferentially in the critical pipes first. This is because of the multiple secondary costs associated with critical pipes so the approach to scoring the renewal needs of pipes must be based on risk and must take into account more than simply financial costs of repair.

This approach depends heavily on appropriate condition assessment. Service providers commonly use visual inspections, often using CCTV cameras to inspect the inner surfaces pipes. Increasingly, new technologies are being employed to more closely monitor pipe condition (e.g. automated analysis of CCTV footage, statistical analysis of breaks, pressure and complaints, sensors for detecting leaks and different forms of scanning for pre-leak failures). Increasing the information available on the condition of in-ground assets is an important mechanism to inform decision making and allocate limited funding optimally for ageing infrastructure (USEPA, 2015). However, condition assessment and adoption of emerging technologies is routinely hampered by cost and limited capacity in small service providers so condition and criticality data are not universally captured. Greater investment in condition assessment will be needed to avoid cost increases as Queensland's networks begin to fail at an increasing rate.

4 Secondary costs of network repairs

The analyses undertaken in Section 3 did not consider the full impacts of rehabilitation of ageing assets such as costs of interruption to supply, disruption to other stakeholders, leaks, public health risks and environmental harm. A comprehensive prioritisation process must include all secondary economic, ecological and social costs of managing ageing assets but these are not readily quantifiable in financial terms.

The secondary economic impacts of ageing mains are often more expensive than the direct costs of repair or replacement. Impacts can be exacerbated if deterioration is ignored or allowed to proceed unchecked resulting in larger unplanned failures. Extreme pipe failures, spills, leaks or bursts can cause collateral damage (e.g. flooding, pressure damage and sinkholes) and impact water security by increasing water loss. They can also have negative impacts on flow, pressure, and water quality elsewhere in the network. Failures impact other essential services such as firefighting or healthcare and can cause reputational and political damage to a utility or the government that owns them. This is the primary reason why "postponing the investment steepens the slope of the investment curve that must ultimately be met…[and]… increases the odds of facing the high costs associated with water main breaks and other infrastructure failures." (AWWA, 2013, p. 13).

Some of the principal secondary impacts are considered below along with a high-level assessment of potential costs so that they can be appropriately compared with financial costs in Section 6.

4.1 Business and traffic disruption

Traffic and business disruptions through interrupted supply and the physical impost of major works are the most visible economic costs associated with ageing pipes. VWC (2017) reviewed the costs of business disruptions across the US and Canada finding that as well as manufacturing, activities such as schools, universities, hotels, motels and restaurants were highly impacted by disruption. For example, "for every $1,000 in sales to the hotel industry, water utilities must deliver 4,700 gallons [17.8 kl] of water" meaning that disruptions have significant impacts on the local economy. Indeed, education and tourism sectors were among the most affected by disruption. These classes of stakeholders along with the resources sector would also be strongly affected in the Queensland economy particularly in areas with seasonal or itinerant populations. In the US, the impacts of temporary service disruptions were measured at $230 per employee for every day of water disruption to a standard business and were even higher for industries more reliant on supply (FEMA, 2011).

Loss of supply was a key impact on businesses but many impacts are related to traffic disruption. Although basic 'traffic control' is included within some unit rates, there are frequently multipliers of up to two times standard rates for high traffic volumes in city areas. Many service providers reported that traffic management is one of their largest costs anecdotally during data collection. This is a direct cost of repair and renewal and this does not include secondary impacts on businesses and individuals from delays and disruptions which could be higher still depending on the location and timing of the work being undertaken.

4.2 Social and reputational impact

As well as economic impacts to businesses, disruptions to water supply and to sewerage services have social impacts. Maintenance and repairs to networks can temporarily interrupt services to households and other premises and are most keenly felt by socially disadvantaged communities that lack access to alternative supplies. Services to critical customers (such as hospitals and dialysis patients) cannot be interrupted, thus magnifying the costs as alternative supplies must be available during maintenance and repairs.

All disruptions must be well managed to avoid reputational damage to the owner of the services particularly where service agreements specify a maximum number of interruptions that can occur each year. Exceeding an agreed (either contractually or tacitly) rate of breaks is a significant reputational and political risk for water and sewerage utilities. These risks are amplified where damage to private property results from high pressure water leaks or from sewage overflows.

4.3 Public health risks

Risks can also be created by water quality hazards that can lead to disease incidents. The most important services provided by networks are safe drinking water supply and protection of public health through appropriate sanitation. The need to protect public health is paramount but also carries a financial cost: Corso (2003) estimated that medical costs can exceed $100 million to deal with a single disease outbreak associated with inadequately treated drinking water. Even a ‘near miss’ or water quality incident in a utility from a different jurisdiction presents additional costs to service providers as they must keep their own customers informed and deal with media and social concern about the local relevance of such issues. Asbestos cement pipes add another layer of complexity as they do not pose a threat while in operation but may cause public or workplace hazards when exposed for repair or replacement. Public and customer perceptions about potential for health risks can have similar or even higher impacts than avoiding the hazards themselves.

4.4 Environmental risks

Water and sewerage service providers have responsibility for protecting ecosystem goods and services that may be impacted by their activities. Repairs and rehabilitation must be undertaken so as to avoid or mitigate direct impacts on the natural environment and costs can be substantial for networks near protected or iconic environments. Further complexity (and cost) arises when leaks, breaks and overflows have the potential to impact the local environment. For example, arguably the greatest cost caused by breaks in sewer mains results not from leaks but from infiltration of groundwater water into the network. Along with inflow (from incorrectly and illegally connected stormwater pipes), infiltration raises the hydraulic loading of sewers and can cause overflows downstream or overload the capacity of sewage treatment plants. Excess surges, particularly in tropical Queensland or during floods, can disrupt treatment processes and must bypass treatment plants to some extent. Unplanned discharge of untreated sewage has the potential to damage aquatic habitats which can also have secondary impacts on recreation and commercial fishing. Design and construction of STPs and sewerage infrastructure to protect these values in the face of wet weather surges is extremely expensive.

4.5 Quantifying secondary costs

The secondary costs of breaks (and subsequent rehabilitation) can be difficult or impossible to quantify financially but can greatly exceed the cost of repairs by impacting economic productivity, the environment and community well-being. Placing a specific value on different secondary impacts risks raising arguments over the importance and values of social, environmental and economic factors and related externalities. As the costs are difficult to detail with any accuracy, attempting to value them could also run the risk of a utility overspending to “save” secondary costs with the result that rates increase with no tangible benefit. Instead of deriving specific costs, the approach taken here is to estimate the magnitude of such impacts and adopt a coarse multiplier to compare renewal, repair and associated secondary costs.

Secondary costs are not captured within the service provider’s planned financial costs (i.e. unit rates) and the majority are felt and absorbed by customers or the broader community. They vary in magnitude and importance on a case-by-case basis. Piratla *et al*. (2015) reviewed 11 of the USA’s recent breaks of very large mains and modelled the cost of the following impacts:

1. Traffic congestion (delays, longer trips)
2. Lost water (particularly in drought-prone areas)
3. Rehabilitation costs for third-part infrastructure
4. Business costs of loss of service
5. Health risks
6. Property damage

The study determined the total cost of the breaks in a range of $US 3.5 million through to $US 85.4 million and suggested these were conservative estimates. For these very large breaks, the secondary costs were on average around three times larger than the direct costs of repairing the break.

Another way to visualise the magnitude of secondary costs is to consider the proportion of a network that may be impacted by a service interruption and the density of connections for that network. For example, if it is assumed a break in a critical length of pipe impacts 1% of a large network while other breaks impact only 1 km of surrounding connections then a large regional service provider with a rate of 10.5 breaks /100 km could theoretically be impacting 6% of their connection base or roughly 16,000 residents per year. Costs could be calculated by determining the impacts of increasing breaks on Gross Regional Product (GRP). These figures are available for a subset of regional Queensland towns and average at $18.50 per hour per connection. This figure incorporates current break rates but costs will be higher if increasing breaks result in increased disruption periods.

Secondary costs can also be considered in terms of the time service providers take to affect a repair. Many utilities include a timeframe for break repairs in their service standards which is typically between 2 and 6 hours. As an example, a leading service provider with an annual rate of 10.5 breaks /100 km across a 700 km network that repairs all breaks within 3 hours still creates an interruption of service of 220 hours for the year, or 9.2 days. The secondary costs associated with this (likely conservative) estimated outage would be difficult to determine for any particular break as it would depend on local wages, business revenue and social costs, but would be significant.

None of the above approaches consider the cost of potential or actual environmental harm or the impact of lost reputation with customers or the community. These externalities are possibly more difficult to value although there is no doubt that they would increase the cost of breaks and repairs.

An important element in representing secondary costs is the criticality of the infrastructure. Breaks in large mains have greater potential for causing damage to other infrastructure or the environment and could cause economically significant water losses. Small pipes that service critical customers or elements of the network, or those that are in high-traffic or difficult-to-access parts of the network will also increase secondary costs more than typical reticulation mains. These factors increase the criticality of a pipe and its associated cost of failure.

As it is difficult or impossible to estimate accurate secondary costs associated with each break and repair, for the purposes of the case study analysis, costs were represented by a multiplier on the unit cost of repair. This approach allows comparison of the impact of financial costs of repair and replacement along with costs of potential economic impacts. A higher multiplier was used for high criticality than for low criticality pipes to represent the greater economic impact that such breaks and repairs create and to represent the large expenditure of utilities to avoid such situations. Different multipliers were trialled as discussed in the assumptions of the modelling approach described in the next section.

5 Comparing full costs of repair and renewal of networks in regional Queensland

This Section describes a comparison of costs of renewal and repair adding a multiplier to allow for secondary costs in order to graphically represent the effect of different renewal investment strategies. This modelling cannot provide a specific assessment of actual costs for individual councils but accurately compares relative merits of different investment strategies for representative ‘case study utilities’.

5.1 Model assumptions

To determine the impact on councils of different sizes, case studies were developed using three groupings of regional Queensland councils. The size classes were selected using Figure 5.1.1 which compares cost impacts per customer for replacing AC water pipes across 29 service providers outside SEQ. The smallest councils in the dataset (many of which are indigenous councils) were excluded from the graph as most had relatively small and new water and sewer networks. The total cost per connection is higher in medium sized utilities due to their high proportion of aged pipes (see Section 2.4) and their greater length of pipes per customer.

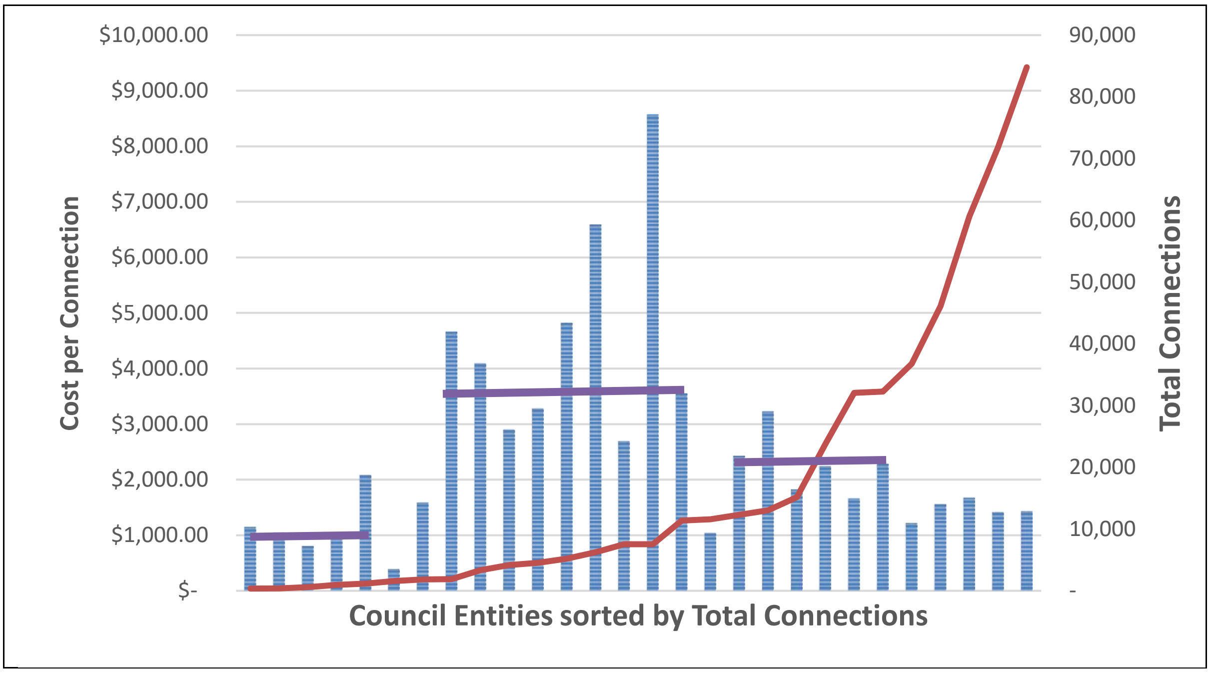


Figure 5.1.1: Total replacement cost per connection in blue (left axis) and number of connections in red (right axis) for the 29 regional councils in the dataset showing the relative impacts of ageing infrastructure are greatest for customers in medium sized councils. Purple lines indicate the groupings for three of five size classes used in further analysis.

The data from all of the councils in the three groupings was averaged to develop three representative case study 'utilities' as summarised in Table 5.1.1. The detailed data structures for each case study included average age profiles for pipes across five different size classes and the percentage of each size class deemed to be critical pipes (see Appendix 4 for full details).

Table 5.1.1: Summary Details of Case Studies (see Appendix 4 for detail).

Case Study	Connections	Length water pipes (m)		Breaks/ 100 km/ year	Secondary cost multiplier	
		Total	> 70 in 2020		LC	HC
Large	21,433	655,727	30,689	12	x2	x10
Medium	4,695	196,952	11,102	19	x1.5	x7.5
Small	524	37,931	150	28	N/A	N/A

For each case study the model allows the input of an annual renewal budget over 20 years along with the percentage of the budget to be applied to:

- high criticality versus low criticality pipes and
- old (i.e. assumed poor condition) versus young (good condition) pipes, and

outputs the predicted number of breaks and combined annual expenditure on repairs and renewals.

Simple multipliers of repair costs were used to represent secondary costs (e.g. multiplier of 2 for low criticality and 10 for high criticality pipes for the large case study). The assumptions of the model (see Appendix 4 for full details) mean that the actual costs predicted can be used as a consistent basis for comparison of different investment strategies rather than predicting actual costs for any specific council. In effect, model scenarios compare decisions about directing renewals across the four quadrants of the investment risk matrix shown in Figure 3.3.

5.2 Large case study – fixed investment strategy

A fixed annual renewal budget of $500,000 (which is equivalent to a replacement rate of around 0.3% per year for this size entity) each year for the 20-year period considered was modelled for the large case study. Five scenarios were run (Table 5.2.1) varying the proportion of the annual budget directed to high criticality (HC) and low criticality (LC) pipes but each scenario assumed investment was directed only to the oldest (assumed worst condition) pipes. As an example, the third scenario (i.e. 150 HC/350 LC) is equivalent to the investment structure represented in Figure 5.2.1.

Table 5.2.1: Scenarios for the large case study with a regular annual replacement of $500,000.

Scenario (HC/LC)	Annual investment in HC pipes	Annual investment in LC. pipes
250/250	$250,000	$250,000
0/500	$0	$500,000
150/350	$150,000	$350,000
500/0	$500,000	$0
350/150	$350,000	$150,000

An excerpt of the model outputs for a single scenario (150 HC/350 LC) are shown in Table 5.2.2 showing estimated breaks, and predicted costs of replacement, repair, and secondary costs (based on the assumed multipliers of 2 for LC and 10 for HC pipes). The total cumulative cost is also provided and Figure 5.2.2 and compares total cumulative costs over time for each scenario. The predicted level of breaks for all scenarios commences at 13.98 breaks per 100 km (Figure 5.2.3) which aligns well with those reported by councils of a similar size to the large case study (see Appendix 4).

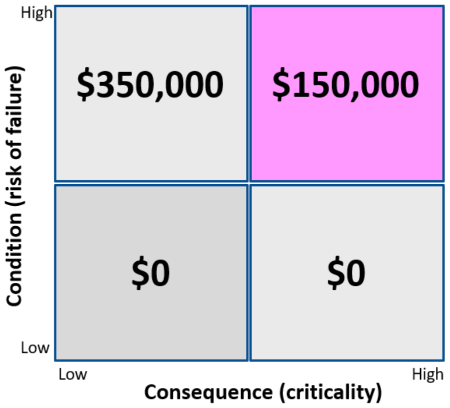


Figure 5.2.1: Renewal investment structure of third scenario (150 HC/350 LC).

The outputs show that investing $500,000 solely in HC or solely in LC pipes results in greatest cumulative costs over time. This is because this approach allows breaks in one of the criticality categories to mount unchecked making total repair and secondary costs more extreme. Investment solely in HC pipes had the added disadvantage of resulting in the greatest number of breaks per 100 km (Figure 5.2.3). This is because break rates in (prevalent) LC pipes increase in an exponential manner if not addressed. Although such breaks have relatively low secondary costs (represented here by x 2 multiplier), costs accumulate rapidly because small diameter, low criticality pipes form the bulk of most networks and small pipes deteriorate more rapidly than large ones.

Table 5.2.2: Example model outputs for large case study with scenario of $150,000 and $350,000 invested annually in renewal of high-criticality and low-criticality pipes respectively (only selected years are shown in this excerpt).

		2020	2024	2028	2032	2036	2040
H-C Replace Budget ($)		**$150,000**	**$150,000**	**$150,000**	**$150,000**	**$150,000**	**$150,000**
L-C Replace Budget ($)		**$350,000**	**$350,000**	**$350,000**	**$350,000**	**$350,000**	**$350,000**
Estimated Breaks/100 km		13.98	14.52	16.17	18.64	21.79	25.84
Modelled Expenditure	**Replace ($)**	$499,515	$500,000	$500,000	$500,000	$500,000	$500,000
	Repair ($)	$110,006	$114,268	$127,261	$146,635	$171,492	$203,329
	Secondary ($)	$324,189	$333,548	$370,445	$428,353	$507,183	$607,421
	Tot. Cumulative	$933,710	$4,682,406	$8,592,643	$12,770,778	$17,318,154	$22,361,245

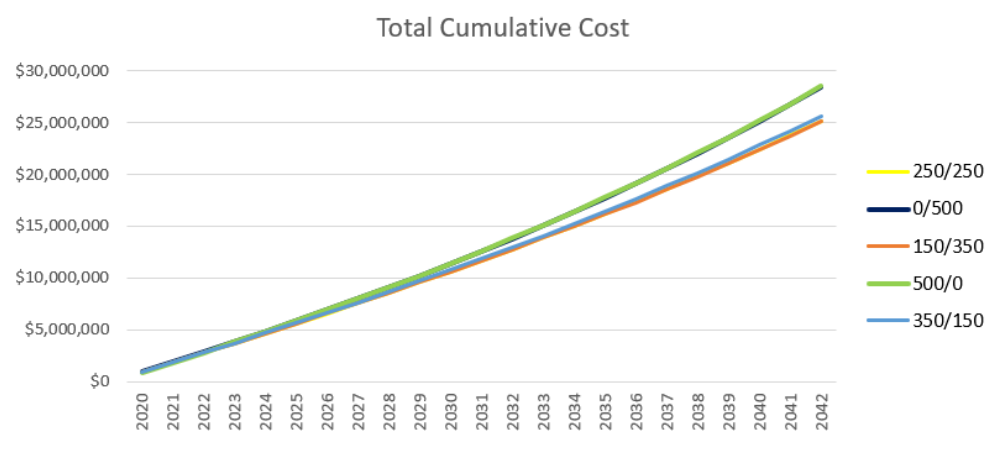


Figure 5.2.2: Total cumulative cost of renewals, repair and secondary costs over 20 years for the five scenarios listed in Table 6.2.1.

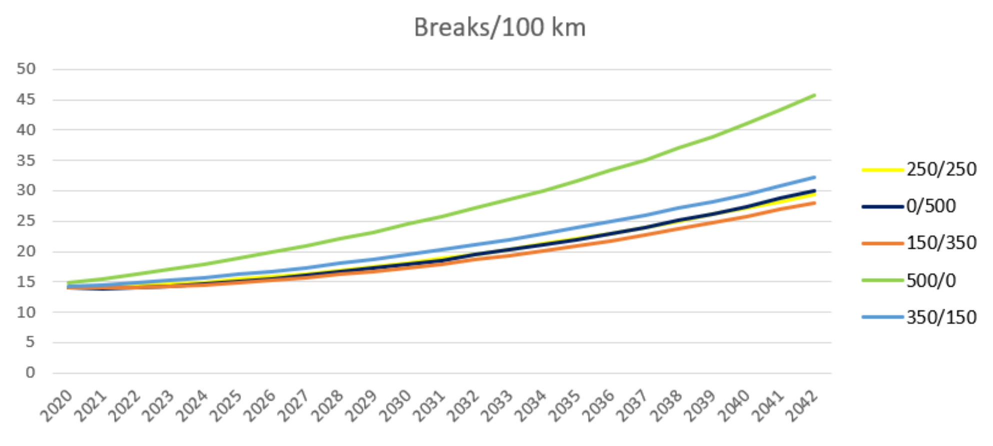


Figure 5.2.3: Annual breaks per 100 km over 20 years for the same scenarios as Figure 6.2.2.

When all renewal investment is directed towards HC pipes, breaks increase to exceed the current state average (24 breaks/ 100 km) by the late 2020s. In all other scenarios, breaks remain below this figure until the mid to late 2030s and there is little difference among the different investment approaches. This indicates that while HC pipes need to be addressed with urgency, it is unwise to focus solely on them and ignore breaks in the (small) LC pipes. This is a well-known rule in the industry: utilities that focus solely on a single element of their network can suffer reputational risks as breaks across the remainder of the network mount to impact numerous customers. A balance is desirable (see for example the balanced investment strategy currently being pursued by Sydney Water (2017) described in Appendix 1).

Although there is not wide variation in the costs of the scenarios in this example, the results clearly demonstrate that a regular annual investment of $500,000 (equivalent to 0.3% for the large case study), regardless of how it is directed, cannot keep breaks at current levels over the next 20 years. Such an approach results in repair and secondary costs rising significantly in this period. Even the scenario with the lowest total cumulative cost (namely 150 HC/350 LC) had repair costs increasing by 25% by 2030 and 85% by 2040 (at which point the rate of breaks reaches the current state average of 24 breaks/ 100 km). This means that the model indicates ‘large’ service providers must invest more than the assumed 0.3% rate annually or repair costs will dramatically increase over the next two decades. Any secondary costs, regardless of their exact magnitude, are borne by customers and the wider community and are in addition to the OPEX associated with repair.

5.3 Large case study – targeted investment

The model uses age as a surrogate for condition and thus assumes that pipes in the poorest condition can be replaced preferentially. In practice, this is not possible because it would require ‘perfect knowledge’ of condition and likely failure rate across the network. Many Queensland Service Providers have moderate to severe data gaps in condition assessment data meaning that investment scenarios that assume that the poorest condition pipes are replaced first do not reflect what is possible in practice. Many utilities are building their condition assessment data with some using an increasing range of new technologies to provide asset information to prioritise rehabilitation.

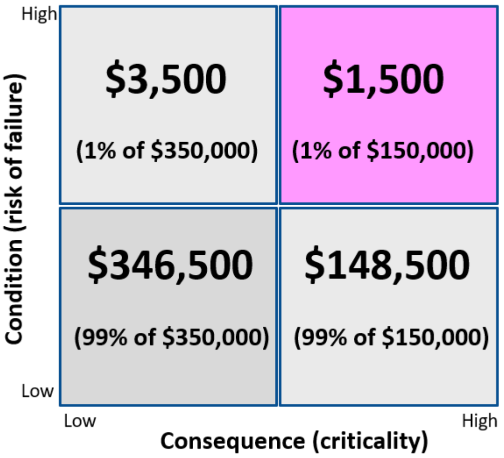
However, even utilities with advanced assessment methodologies cannot replace all pipes in strict order of need. This is because factors other than pipe condition influence selection for network replacement. These factors can include:

- need for upgrades or expansion of capacity,
- proximity to other work (e.g. if a road is already being excavated),
- rationalising setup costs (e.g. if a certain area is being targeted and there are economies in replacing the entire network rather than re-establishing at a later date, particularly if replacement is foreseeable in the near future).

Moreover, for publicly-owned utilities, “a water system is often one of many responsibilities of a community or municipality. Other factors can influence which water system projects are funded and when they are completed” (USEPA, 2003, p. 14). These factors combined with gaps in quality condition assessment data mean that a proportion of any replacement program will not target the most deteriorated (most likely to break) parts of a network.

To account for scenarios where investment doesn’t target only the most vulnerable parts of the network, the proportion of the annual renewals to be directed towards the oldest (assumed poorest condition) pipes was altered (with the remainder being spread equally over the remaining network).

Scenarios using the two least-cost budgets from Section 5.2 (namely 350 HC/150 LC and 150 HC/350 LC) were modelled under two different conditions. First, the scenarios were modelled exactly as shown in the previous analysis, then these runs were replicated with the unlikely investment strategy of 'untargeted investment'. These scenarios directed only 1% of the renewals budget to the oldest (assumed most deteriorated) pipes while the remainder was spread evenly over the rest of the network (see e.g. Figure 5.3.1). These scenarios provide a comparison with previous set of scenarios but with either 1% or 100% of the investment targeted at the most deteriorated pipes.



$3,500 (1% of $350,000)	$1,500 (1% of $150,000)
$346,500 (99% of $350,000)	$148,500 (99% of $150,000)

Figure 5.3.1: Renewal investment structure of first (yellow) scenario in Figure 5.3.2 (1% 150 HC/350 LC).

Figure 5.3.2 shows that the cost of untargeted investment is similar to the initial scenarios at first but increase over time due to the failure to address the pipes that are most likely to break. This allows repair (and secondary costs) to increase rapidly (see Figure 5.3.3). This analysis indicates that untargeted investment increases repair costs by 50% of their current levels by 2026 despite the same investment in renewal. In contrast, if all investment was directed to the most deteriorated pipes the increase was only 9%. By 2030, untargeted investment resulted in 82% higher OPEX costs compared with a 24% increase if funds are targeted at the most deteriorated pipes. It is important to note again that the secondary costs are in addition to these increases in OPEX and would increase the total cost to the community significantly.

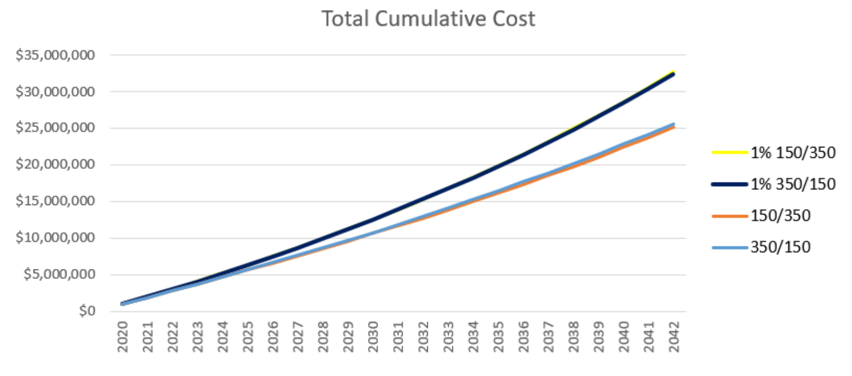


Figure 5.3.2: Total cost including replacement, repair and risk costs over 20 years for scenarios of regular annual investments in HC/LC pipe with either 1% or 100% of funds targeting the most deteriorated pipes.

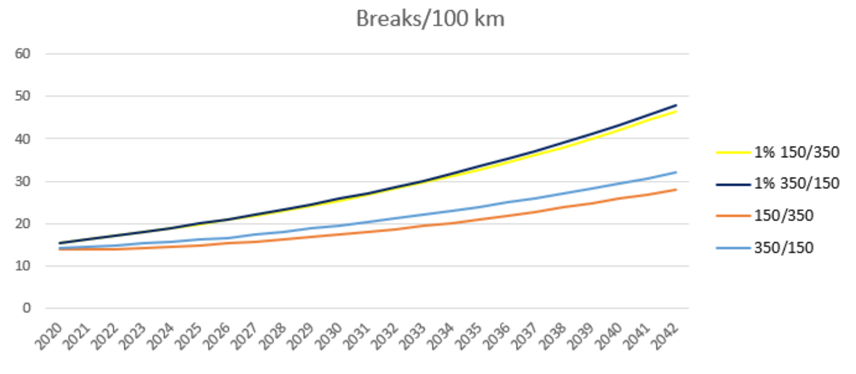


Figure 5.3.3: Annual breaks per 100 km over 20 years for the same scenarios in Figure 5.3.2.

The scenarios of 1% or 100% of investment directed into poorest condition pipes are equally unrealistic and the actual value will fall somewhere between these two extremes. This would be determined by the quality of condition data used by each service provider and their asset management prioritisation process.

The impact of different proportions of targeted investment was explored in further scenarios (see Appendix 5). This analysis showed that while poorly targeted investment greatly increased total costs, a perfect knowledge of condition is not necessary to achieve savings. Any improvement in targeting pipe condition will result in savings, with greater savings and fewer breaks achieved as targeting improves (because the impacts of poor initial investment are magnified over time). However, returns diminish so that full knowledge of network condition is not required to achieve significantly lower rates of breaks at a reasonable cost (Appendix 5).

The scenarios presented so far confirm the well-known principles (see e.g. USEPA, 2015) that network renewal is most effective when it is:

- targeted at poorest condition assets (as much as possible),
- directed to both high-criticality and low-criticality assets, and
- commenced as early as possible.

Unstructured investment in network renewal has the potential to incur further costs which for service providers similar to the large case study could be in the order of tens of millions of dollars over time. Such an approach would be financially crippling if applied across the twelve large providers across the state, not to mention the costs from other size classes. These results highlight the need for improving the capacity for targeting funding for network renewal in general.

This is not a new finding, but the impacts of not following this asset management axiom may be more complex than expected. An initial increase in investment in poorly targeted renewals is not large and, if the cost is poorly understood by asset owners, could appear to be an appropriate response to ageing assets. That is, a large immediate investment in an ageing network might be interpreted as necessary expenditure, even if it is not directed carefully at the most deteriorated pipes. Additional costs incurred by this approach increase slowly over time and may not provide sufficient feedback at first to signal the need to improve the investment strategy. Costs for individual service providers eventually increase rapidly and at a regional or state scale these increases would not only be unaffordable but could threaten the sustainability of the sector.

This means that any investment in network renewal must balance not only repair and replacement but also have a strong focus on the quality and extent of condition assessment and prioritisation processes based on criticality. As these later processes are considered routine operational expenses, they can be easily overlooked when capital investment in ageing infrastructure is being considered.

5.4 Large case study – investment varied over time

The inputs used in analyses so far have included a fixed and consistent total annual renewal rate of $500,000. This figure assumes a background replacement of around 0.3% of pipes for a 'large' service provider (which amounts to only one to two km of pipe replaced each year) but yet, may be optimistic for some service providers. At this level of investment, the rate of breaks increases above current levels and exceeds acceptable targets within two decades. To examine the impact of strategies of varied annual investment (including injections of additional funds), five scenarios were tested with variable investment strategies.

*'Best Practice' s*cenario
Initially, a current industry 'Best Practice' scenario was selected to represent a baseline of what a well-positioned large service provider might achieve with the fixed annual renewal rate of $500,0000 (i.e. the assumed typical rate for national utilities by WSAA, 2013). This scenario uses the least-cost approach to criticality identified in previous analyses (i.e. 150 HC/350 LC) assuming that a large service provider would have optimised the proportion of their investment across pipes of different criticality. It is assumed that 75% of investment is directed to the most deteriorated pipes (based on the analyses in Appendix 5). That is, only one quarter of pipes replaced each year are not in need of immediate replacement and the majority of the investment is targeted at the oldest (assumed poorest condition) pipes. In effect, this scenario assumes that a 'Best Practice' service provider had directed sufficient funding to monitoring and prioritisation to allow condition and criticality to be accurately assessed and prioritised.

'Worst-case' scenario
To create a contrasting baseline, the 'Worst Case' scenario has a similar annual expenditure as the Best Practice scenario, but all investment is focussed on HC pipes (500 HC/ 0 LC) and it is untargeted and spread across the entire network (i.e. 1% targeting at oldest/poorest pipes). This scenario could represent a large service provider that is only replacing critical pipes reactively based on poor or non-existent condition data. This may not be fully realistic but provides a reasonable baseline given that some service providers may have renewals even less than the assumed rate of 0.3% per annum.

'*Realistic'* Scenario
A third scenario approximates a '***Realistic'*** large service provider by assuming that 30% of investment is targeted at the poorest condition pipes. The assumption that only a third of investment is targeted is unfair for some large service providers but could be optimistic for others given the lack of condition data indicated from some anecdotal reports. The funding

is distributed to the HC and LC pipes in a ratio of 300 HC/ 200 LC to reflect the imperative for repair of high-profile services in many communities. This scenario aims to approximate the situation average utilities may be in, falling somewhere between assumed ‘Best Practice’ and ‘Worst Case’.

‘$10 M Injection’ Scenario
This scenario reiterates the ‘Realistic Scenario’ but with an additional initial investment of $5 million for HC and $5 million for LC pipes in 2020 (i.e. a ‘$10 M injection’ balanced across HC and LC pipes). The aim is to compare the impact of an immediate additional investment into assets (e.g. from a grant or loan to address ageing assets), but without changing operational activities for prioritising investment.

Staged Investment Scenario
The final, ‘Staged Scenario’ assumes the investment mix is altered from year to year while maintaining total replacement expenditure over 20 years at an average of $500,000 per year. However, 85% of funds are targeted at the most degraded pipes on the assumption that operational activities have been optimised to accurately identify the poorest condition assets. The investment structure and outputs of this scenario are tabulated in Table 5.4.1 to show how renewal costs are varied from year to year.

This scenario has the same infrastructure expenditure over 20 years as previous scenarios but assumes (unspecified) investment has been directed also to improving condition assessment and mechanisms for prioritising renewals allowing better targeting of replacement. It also assumes the service provider can bring some future funding ‘forward’ to allow a staged renewals program that addresses the emergent needs of the local network. Early investment is targeted at the backlog of aged or poor condition pipes that could raise future costs significantly if not addressed as a priority.

Figures 5.4.1 and 5.4.2 show outputs of these five scenarios showing that ‘Best Practice’, ‘Worst Case’ and ‘Realistic’ scenarios have the same initial conditions and do not vary markedly in total cumulative cost until five years have elapsed. After this period the total cost increases most rapidly for the ‘Worst Case’ with the ‘Realistic’ costs somewhere between this and the ‘Best Practice’ scenario. The number of breaks predicted under each of these scenarios varies markedly but with a similar pattern between the three scenarios. These outputs reiterate the benefits of targeted investment on both break rates and total costs although the increase in costs may not become apparent for some years.

Table 5.4.1: Model Output '*Staged Scenario*'. *Assumed age - 70 years, HC multiplier - 10, LC multiplier - 2, % oldest pipes to replace – 85%*

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Inputs: Annual Renewal Budgets											
High Criticality	**$1,500,000**	**$800,000**	**$350,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**	**$80,000**
Low Criticality	**$2,300,000**	**$1,950,000**	**$450,000**	**$220,000**	**$220,000**	**$220,000**	**$220,000**	**$220,000**	**$220,000**	**$220,000**	**$220,000**
Outputs											
Breaks/100 km	11.3	10. 7	10.9	11. 5	12.0	12.6	13.1	13.81	14.4	15. 1	15.8
Costs											
Replacement	$3,800,000	$2,750,000	$800,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000
Repair	$89,189	$83,927	$86,418	$90,382	$94,556	$98,917	$103,512	$108,301	$113,306	$118,535	$123,997
Secondary	$250,450	$235,894	$242,872	$254,828	$267,488	$280,771	$294,785	$309,467	$324,873	$341,037	$357,997
Tot Cumulative	$4,139,639	$7,209,460	$8,338,750	$8,983,959	$9,646,002	$10,325,690	$11,023,987	$11,741,755	$12,479,934	$13,239,506	$14,021,500

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Inputs: Annual Renewal Budgets												
Renewals (HC)	**$80,000**	**$80,000**	**$50,000**	**$50,000**	**$50,000**	**$50,000**	**$50,000**	**$30,000**	**$30,000**	**$30,000**	**$30,000**	**$30,000**
Renewals (LC)	**$220,000**	**$220,000**	**$100,000**	**$100,000**	**$100,000**	**$100,000**	**$100,000**	**$50,000**	**$50,000**	**$50,000**	**$50,000**	**$50,000**
Outputs												
Breaks/100 km	16. 5	17.3	18.3	19.2	20.3	21.3	22.5	23.7	25.0	26.4	27.8	29.3
Costs												
Replacement	$300,000	$300,000	$150,000	$150,000	$150,000	$150,000	$150,000	$80,000	$80,000	$80,000	$80,000	$80,000
Repair	$129,823	$136,359	$143,641	$151,333	$159,437	$167,973	$176,964	$186,632	$196,842	$207,612	$218,972	$230,805
Secondary	$376,031	$395,851	$417,813	$441,055	$465,593	$491,499	$518,850	$548,369	$579,619	$612,666	$647,614	$684,273
Tot Cumulative	$14,827,354	$15,659,565	$16,371,018	$17,113,406	$17,888,436	$18,697,908	$19,543,723	$20,358,723	$21,215,184	$22,115,462	$23,062,048	$24,057,126

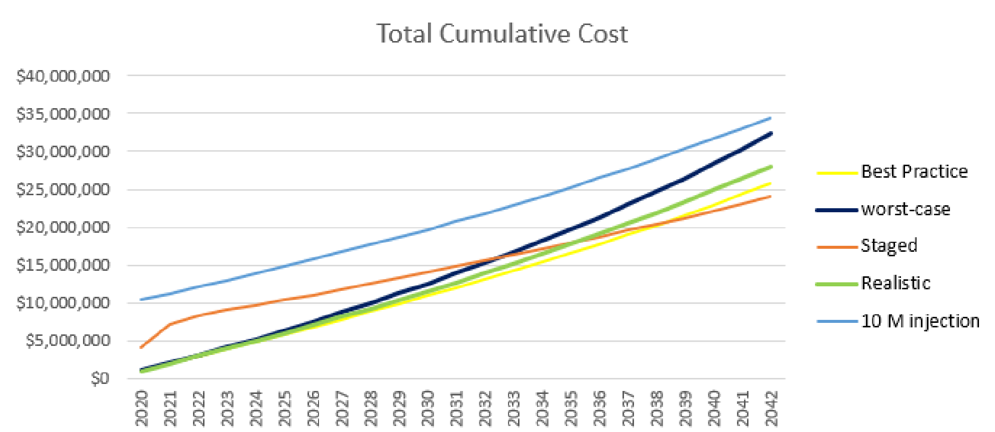


Figure 5.4.1: Total cumulative renewals, repair and secondary costs over 20 years for five with different investment structures.

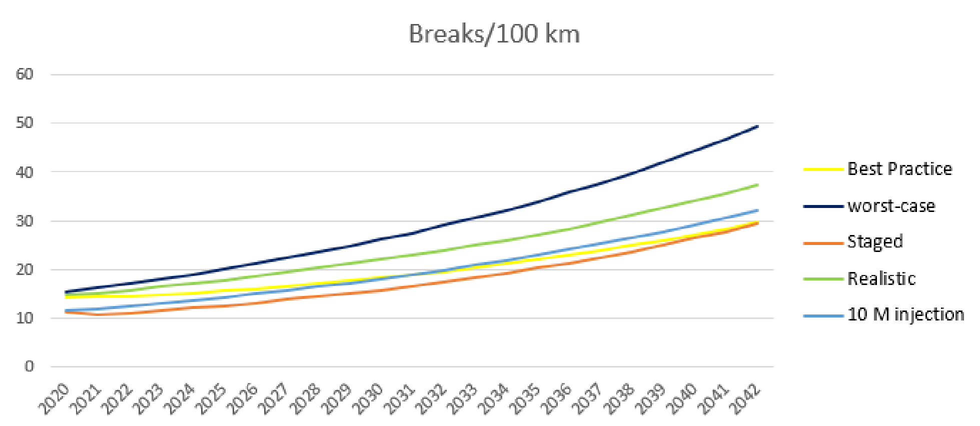


Figure 5.4.2: Annual breaks per 100 km over 20 years for the same scenarios in Figure 5.4.1.

The ‘$10M injection’ scenario immediately increases the total expenditure and the benefit of this early investment is reflected in an immediate reduction in breaks which remain lower than the ‘Realistic’ scenario for the duration of the 20-year period. Initially, breaks fall below those predicted for the ‘Best Practice’ scenario but only for the first 10 years after which they exceed the breaks in this scenario. The benefit of the early capital investment is also reflected in the slightly lower slope of cost curve. This means that after the initial capital injection, the regular annual investment by the service provider is better able to keep pace with increasing breaks (because a large initial backlog has been cleared). The costs of the initial investment are slowly being recovered but this process is so gradual that the cost curve is almost parallel with that of the ‘Best Practice’ scenario. Consequently, the cost over 40 years is the highest of all scenarios (and similar to the ‘Worst Case’ by 2040). These disbenefits could be expected to be greater still if the analysis included the net present value of the investments. This shows that early investment, if not properly targeted, results in higher costs immediately but also in the long term.

The early investment, though more expensive, decreases break rates and although it is not as successful as the ‘Best Practice’ approach at reducing breaks in the long term, may still reflect a politically favourable option. It provides immediate benefits by improving outcomes for the community in terms of reduced breaks (at least for the first decade) in terms of reduced breaks and secondary costs. It could be seen to indicate bold and decisive investment, potentially making use of external funding without requiring (often difficult) operational improvements (or OPEX). Some councils may be willing to pay (or seek funding) equivalent to half their planned 20-year investment profile in order to achieve these early, short-term benefits. However, on a state-wide scale, such expenditure would not be tenable.

An alternative approach focussed on improved targeting of investment is reflected in the 'Staged' investment. In this scenario, expenditure is brought forward to address the backlog of aged/poor condition pipes, but the 10-year and 20-year cumulative costs are still lower than the 'Best Practice' scenario as is the break rate each year. As with the '$10M injection', this scenario highlights the importance of immediate investment to address the compounding costs of backlog repairs and their associated secondary costs. However, the scenario also assumes that expenditure (not shown) on operational processes improve ability to target future funding and build intelligence about local networks. The scenario consequently performs better than all other scenarios in terms of capital cost and total rates of breaks. However, improving asset prioritisation and bringing capital expenditure forward, though the most effective solution is likely beyond the means of many individual service providers and may present more difficult management problems beyond merely seeking an upfront cash injection.

5.5 Medium case study – investment varied over time

The same five scenarios tested for the large case study in Section 5.4 were run using data for the medium case study utility. A 0.3% annual investment for this size of service provider amounts to around $130,000 per year budget for renewals, so scenarios were replicated using low but proportionally equivalent investment strategies as shown in Section 5.4. Multipliers for secondary costs were also adjusted for the medium case study on the grounds that impacts of each break and repair would be lower because of the smaller size communities involved. A multiplier of 1.5 was used for LC and 7.5 for HC pipes. The scenarios were as follows.

'Worst Case' scenario
The total budget from the best practice Scenario ($130,000) is focussed on HC pipes (130 HC/ 0 LC). The funding is spread across the entire network with only 1% targeted at the oldest (most degraded) pipes.

'*Best Practice' s*cenario
This scenario assumes a fixed annual investment of $40,000 in critical pipes and the remainder in non-critical (i.e. 40 HC/90 LC) and that 75% of the funding is targeted at the oldest (most deteriorated) pipes.

'*Realistic'* Scenario
The '*Realistic'* scenario assumes 30% of investment is targeted at the oldest (poorest condition) pipes with $80,000 spent on critical and the rest directed to non-critical pipes (i.e. 80 HC/ 50 LC).

'$1.25 M Injection' Scenario

This scenario reiterates the early funding injection of Section 5.4 but with a proportionately lower immediate investment of $1.25 mill in HC and $1.25 mill in 2020. Otherwise the investment approach is equivalent to the 'Realistic' scenario.

Staged Investment Scenario

The 'Staged Scenario' assumes variable annual investment reflecting the pattern in Table 5.4.1 but at proportionately reduced values.

Figures 5.5.1 and 5.5.2 show that the pattern for the medium case study is equivalent to that for the large case study but at reduced levels of expenditure and slightly higher background rates of breaks.

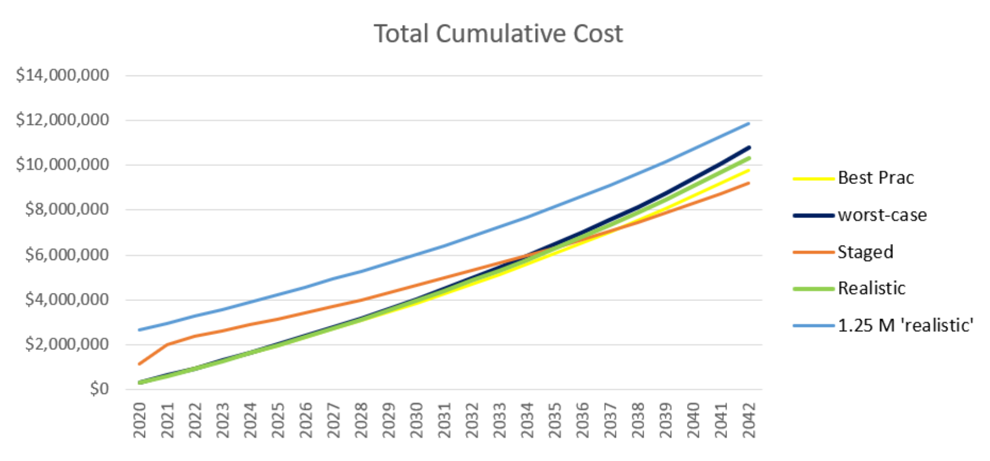


Figure 5.5.1: Total cumulative renewals, repair and secondary costs over 20 years for five with different investment structures.

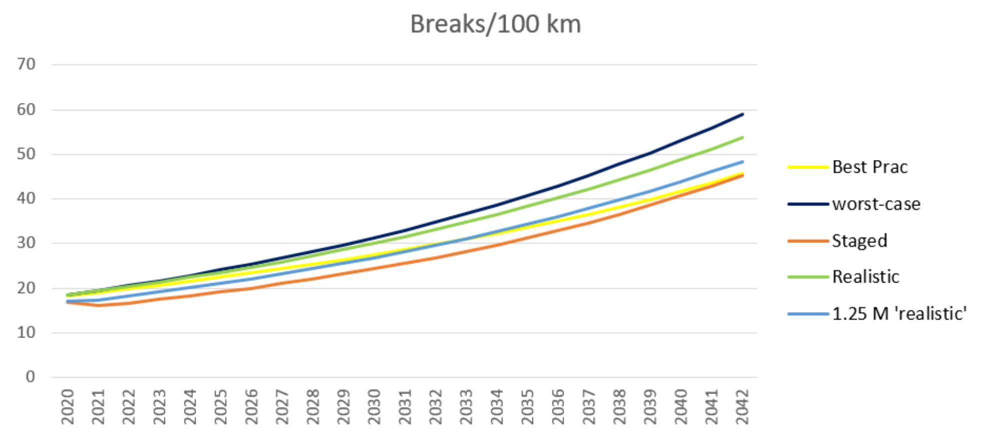


Figure 5.5.2: Annual breaks per 100 km over 20 years for the same scenarios in Figure 5.5.1.

5.6 Small case study

The small case study data was trialled in the model but it was not possible to recreate initial conditions matching those reported by councils of this size. In particular, the model tended to under-estimate the rate of breaks for this case study which are reported to be around 28 breaks per 100 km (see Appendix 4). At the assumed replacement rate of 0.3%, the annual renewal rate of these councils would be negligible and the cost of broad-scale replacement of aged mains would be negligible on a state scale because of the small size of the aged networks. While these, often remote, councils would benefit from improved asset condition and criticality assessment for prioritisation, the establishment costs for companies undertaking renewals or relining could well exceed any benefits of staged replacement. The benefits of full replacement of networks in very small towns must therefore be assessed on a case-by-case basis depending on the expected costs, population growth estimates and predicted risks from water loss or sewage leaks. I some cases it may well be preferred to undertake replacement or relining as a concerted program of works but in other replacement could well be deferred in favour of increased investment in employment in local assessment and repair skills.

5.7 Very large service providers

Very large service providers were not considered in the modelling scenarios because they are assumed to have their own asset modelling and renewals approaches to reflect the local complexity of their networks. The total mains length of these ten entities is 30 times that of all small and very small service providers combined and even the five ‘very large’ regional councils have nearly 10 times the mains of the small and very small service providers combined. Despite having, on average, relatively younger networks, these utilities have many kilometres of aged mains. Dealing with these assets would overwhelm any uncoordinated state response, including dominating limited rehabilitation service providers. This means that the approach of these utilities must also be considered in any coordinated or collaborative program of investment in Queensland’s networks.

6 Discussion and Recommendations

It is clear that the cost to maintain Queensland’s ageing water supply and sewerage networks is going to increase in coming years. The diversity of Queensland’s networks and the different mechanisms that can be used to address deterioration mean that there is no single solution. However, the modelling in Section 5 confirms standard asset management principles that optimising investment requires better understanding of condition and criticality, local factors, types of failure, as well as the impacts of remoteness and the scale of impacts cause by ageing pipes.

There is a lack of local data to prioritise renewals and repairs and it is difficult or impossible to calculate the full economic impact of secondary costs borne by the community from increasing breaks and repairs. They are likely to be substantial. Using assumed multipliers for such impacts showed that least cost investment occurs through a balance of replacement of low and high criticality networks targeting the poorest condition pipes as a priority. While this finding simply reiterates good asset management principles, it also indicates a need for additional investment in technologies for condition assessment, criticality and prioritisation of renewals.

This investment may not naturally be prioritised and may be significant for many Queensland councils for which management of in-ground assets has not yet become an issue. When investment is made there could be perverse incentives to invest rapidly without strong understanding of the needs of networks that have long been out of site and out of mind.

The analyses presented in this paper confirm that “a proactive approach to pipe asset management is crucial in determining the optimal time to replace a pipe” (Punurai and Davis, 2017, p. 7). The key to this decision-making process is availability of accurate information and this currently varies markedly across Queensland. When the research dataset was compiled, a range of information on existing networks including pipe condition assessments and failure histories was requested but the information was seldom supplied, sometimes because it was difficult to access and often because it was unavailable. While a number of Queensland service providers have advanced processes for assessing condition and criticality and prioritising repair and replacement, for the majority this data has not been consistently recorded over time.

USEPA (2015, p.11) summarise the need for better data: “the compelling reason to perform condition assessment on the sewer collection system is to preserve the existing structure, reduce O&M costs, and avoid emergencies and the costs (social, economic, environmental) and political repercussions they entail”. In a survey of large utilities across Australia in 2013, the majority reported that they inspected pipe materials following failure events and used this information in condition assessments (WSSA, 2013). However, the survey also found that “assessment of pipe coupons from under pressure cut-ins is utilised by around 25% of water agencies and 70% of water agencies record the type of failures, and this information is available” (p. 31). In the US and Canada, a survey of numerous utilities found only “45% of the respondents reported that they do use some kind of condition assessment process but normally limited this effort to larger diameter transmission system pipes” (Folkman 2018, p. 37). Rates of data collection and availability across Queensland utilities are unknown but likely need to be improved.

The types of information that need to be recorded and regularly maintained include not only standard asset management indicators such as condition, age, service history and adjusted useful life, but also each asset’s criticality (i.e. the importance, redundancy, vulnerability and risks of failure including potential impact on public health, safety and the environment). Asset condition can be assessed using non-destructive methods in addition to visual and CCTV inspections including electromagnetic and acoustic methods identifying wall thickness, internal and external corrosion, flaws, leaks and 3D internal and external condition mapping (see e.g. USEPA, 2015; Quail and Zhao, 2018). Samples such as tapping coupons (Folkman, 2018), and pressure testing of used pipes (A. Hughes, 2017, pers comm) are also useful methods but can be prohibitively expensive. Collection of this data may be difficult for individual service providers so opportunities for facilitation and economies of scale through regional approaches should be explored to increase focus and expertise in these areas.

The information collected can be used to prioritise asset repair and replacement as part of a standard asset management approach. However, given the potential consequences of ageing network assets and the constraints of some local government asset management systems, additional processes should also be explored. This could include modelling approaches such as the WSAA Pipeline Asset Risk Management System (PARMS) model developed by CSIRO and similar commercially available products from commercial vendors. Network modelling and statistical approaches using machine learning algorithms often linked with 'smart metering' are increasingly being used by large agencies (see e.g. WaterRF, 2014, ***qldwater,*** 2017). These methods can expand on, and link with, traditional asset management systems to better resolve the timing of investments in repair and replacement. While some larger Queensland utilities are exploring these new approaches and technologies, they are less available and sometime unaffordable for small service providers. Access might be improved through a regional collaboration.

Optimisation of planned investment in repair and replacement must be complemented with appropriate procurement and selection processes. Given the continual and increasing cost of in-ground pipe repair and rehabilitation, significant savings can be realised over time through any improvement in this area. Although Queensland service providers have well-developed procurement processes for all manner of assets, a focussed approach for water and sewerage networks may provide additional advantages. As an example, joint procurement for sewer relining has led to savings for a number of regions under QWRAP because of critical mass, economies of scale and improvement in process through knowledge sharing across councils. Similar savings may be possible for other aspects of network repair and rehabilitation but have not yet been explored.

A holistic approach to procurement of pipeline rehabilitation techniques could help individual service providers make better decisions on more than just the timing and investment of rehabilitation. Additional benefits would be possible through focussed analysis of optimal materials, pipe sizes and installation methods based on 'life-cycle costing' that considers both performance and affordability rather than merely the initial design and installation cost (see e.g. Sinha, 2018). In a review of replacement approaches across the US and Canada (Folkman, 2018, p. 43) found that:

> *… existing practices tended to ignore the effect of environmental conditions on different pipe materials. Yet, every engineer understands how the complexity of underground infrastructure has increased along with the array of choices. The ability to change old habits and consider new materials requires additional analysis, and improved design and installation practices. This enhanced analysis of pipe design, selection and installation sets forth the longevity and life-cycle costs critically influencing water service affordability and sustainability for the next 100-200 years.*

Such analyses require sufficient availability of quantitative information on the durability, performance and longevity of different pipe materials under local conditions and similar conditions elsewhere. This requires not only greater collection of information but also the capacity to share it at regional, state and national scales. A full life cycle assessment that assesses the broad environmental impacts of the replacement material and methodology would provide additional value to regional communities in the future (Folkman, 2018).

As network assets age, increasing capacity to deal with repairs efficiently will be needed. The analysis in Section 6 shows that the cost of increased repairs, if carefully managed to avoid secondary costs, is lower than premature replacement of ageing networks. However, this assumes that appropriate resources have been put in place to deal with a growing repair load. If ignored, the increasing need for repair will exacerbate the secondary costs discussed above, and increase overtime hours for service personnel or outsourcing of maintenance contracts. The need for a planned and proactive approach for future repairs in both water and sewerage networks will be felt throughout the state to different degrees but will more strongly impact small service providers or those with difficulties attracting and retaining staff. Many large utilities outsource network maintenance but even this approach requires good asset management systems and a sophisticated approach to contract management. It often not financially feasible or politically palatable for small councils, particularly those at a distance from major centres. These issues too might be mitigated through regional collaboration and sharing skills (e.g. civil maintenance experience) across a region.

To overcome these various challenges inherent in managing Queensland's in-ground water and sewerage infrastructure, four recommendations are provided:
Firstly, avoiding excessive increases in costs from ageing networks requires a much greater focus on network data than has previously been the case for many regional Queensland service providers. The necessary data ranges from standard asset management information such as relative condition and age to include estimates of criticality, redundancy and vulnerability driven by more accurate, higher resolution data on pipe condition using emerging technologies. The extent of (particularly small-diameter) networks means that sampling must be statistically stratified and statistically robust. The costs of appropriate collection and analysis of the data will be much lower than those of premature replacement or poorly managed repairs but may still be beyond the capabilities of some (particularly small and remote) service providers. Regional collaboration could allow an informed and prioritised approach to data collection using optimal technologies and would combine economies of scale with local knowledge as well as enabling better sharing of data state-wide and national datasets.

The regional approach could extend to the second recommendation:
To apply increasingly sophisticated mechanisms for to prioritising repair and replacement of existing networks. Network modelling and 'smart network' approaches would be more affordable for regional service providers through economies of scale and may facilitate improved prioritisation of repair and replacement plans. While it is unlikely that these approaches could be feasibly extended to every network in Queensland it may be applicable to critical pipes, which typically "necessitate a higher-resolution pipeline assessment tool to yield better data and more information to establish the extent of degradation, imminence of failure, and remaining life expectancy" (Quail and Zhao, 2018). While Queensland councils have extensive experience in asset management, systems are often geared for non-water and sewerage assets and even large utilities are being encouraged to reform asset management for in-ground assets in recognition of the need for special treatment of networks as they age (e.g. USEPA, 2016; Folkman, 2018). There can also be a constrained focus on like-for-like replacement that disregards opportunities for strategic down-sizing of pipe sizes, decentralised alternatives and emerging technologies that may reduce dependency on expensive network infrastructure. Fit-for-purpose asset management processes could be developed across different sized service providers more readily if it was undertaken at a regional scale that provides critical mass, but builds local knowledge and re-inserts appropriate actions back into the preferred asset management systems of individual councils.

The third recommendation is to adopt a more holistic approach to procurement to replace or rehabilitate existing networks based on total-life-cycle costs and better understanding of the performance of different pipes under locally relevant conditions. Careful procurement of pipe laying services could avoid future costs of deterioration caused by poor installation, a commonly reported cause of failure in current networks (see WSAA, 2013; Folkman, 2018). Failure to properly install pipes or to select appropriate sizes and materials was also an issue that was common in anecdotal reports in the first stage of this research (Cosgrove and Fearon, 2017). While individual service providers have the means to improve procurement processes, the advantages of regional approaches in improving efficiency and effectiveness of procurement of relining services have already been demonstrated for sewer relining in QWRAP regions. This regional approach could be extended to other forms of network rehabilitation and would also facilitate the sharing of data, within and between regions as well as with other utilities nationally.

The final recommendation is to review how repair programs are rolled out in regional Queensland. An increased focus on network repairs to reflect changing public expectations, increased regulation and increased rates of breaks in ageing networks will require an evolution in how regional councils respond to breaks and undertake preventative maintenance (e.g. pipe cleaning and pressure management). Reactive repair programs will not suffice and will need to be augmented with predictive maintenance programs and increased communications with customers and with regulators. Once again, this process will be more difficult for individual service providers but a regional approach would allow greater sharing of information and skills and a stronger foundation for negotiation with regulators. It could also allow an increase in locally-relevant analysis of customer expectations and behaviour including opinions on how long-term risks should be managed leading to more proactive and predictive maintenance that marries with renegotiated levels of service.

These four recommendations take account of some of the existing barriers to asset management for network infrastructure in regional councils by promoting a collaborative approach. This is not to suggest that individual service providers would be unable to deal with many of the issues, but recognises the barriers and capacity issues may overwhelm the need for positive action in time to address an infrastructure cliff. Even large utilities accustomed to a predictable, low background rate of asset degradation with up-front investment followed by decades of low-cost maintenance may need incentives to direct greater focus to in-ground assets in coming years because “budgetary constraints and urgency commonly dictate the viability of a pipeline assessment” (Quail and Zhao, 2018). Moreover, coordinated responses will be needed to avoid overwhelming available services for repairs, renewal and relining as break rates begin to increase across the State (and nationally). The suggested centrally-driven, regional approach to overcome inertia in financial-challenges are illustrated in Figure 5.1.

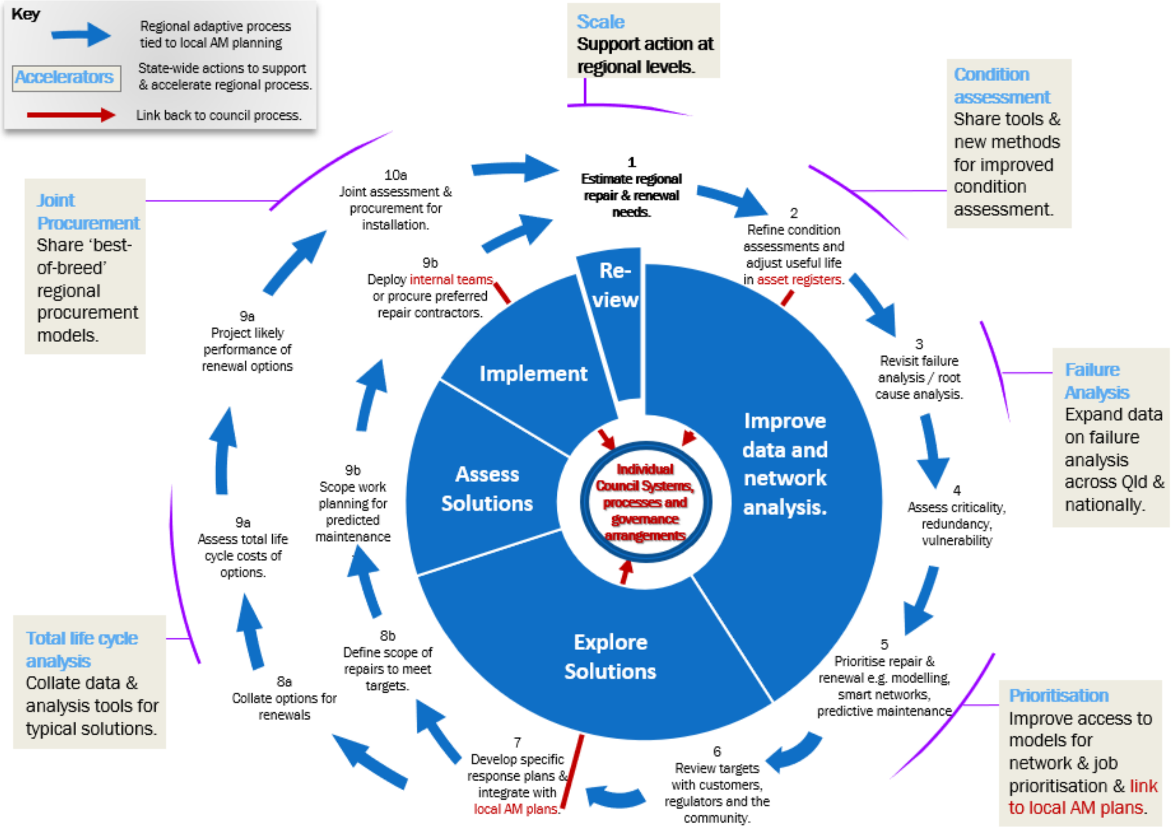


Figure 5.1: Recommended actions at a regional (blue arrows) and accelerators at state scale with links back to individual council processes (red arrows).

7 Glossary

AC: asbestos cement
CAPEX: Capital Expenditure
CI: cast iron (CICL – cast iron cement lined)
DI: ductile iron (DICL – ductile iron cement lined)
LGAQ: Local Government Association of Queensland
NPR: National Performance Report
OPEX: Operational Expenditure
PE: polyethylene (HDPE – high density polyethylene)
PVC: polyvinyl chloride
SWIM: State-wide Water Information Management system
TOTEX: Total expenditure incorporating OPEX and CAPEX across an asset's entire life cycle.
uPVC: unplasticised polyvinyl chloride
VC: vitreous cement
WSAA: Water Services Association of Australia

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Appendix 1: Cost of Repair and Rehabilitation

To estimate costs of repair and rehabilitation in Queensland (Section 2.2), costs reported from across Queensland and other Australian jurisdictions were used to establish current rates. Two methods were used:

1. a review of Australian utility websites, recent reports and news articles to collate reported rates for repair and rehabilitation and
2. ‘Unit Rates’ for renewals reported by Queensland and national utilities.

1. Recently Reported Costs

At the lower end of reported costs was a report from Barwon Water which replaced around 20 km of pipe annually for approximately $4 million or $200/m (Barwon Water, 2018). In addition to this annual replacement program, other projects were undertaken by the utility to improve water supply security including 11 km of water main for $19 million or $1,700/m. In a similar program, South East Water (Utility, 2013) in Victoria upgraded 6 km of water mains at a cost of $1.4 million ($233/m). Cairns Regional Council (2017) recently announced works to install 1.45 km of water mains to replace existing mains at a cost of $1.46 million ($1006/m). Longreach Regional Council along with the Queensland Government invested $1 million in laying 2 km of 300 mm ($500/m) water mains in recent years to replace the old smaller mains and improve services (Queensland State Development, 2018).

Some utilities have taken a large-scale approach to water mains. An example is the WA Water Corporation’s ‘Pipes for Perth’ program which saw $100 million invested to replace 150 km ($667/m) of water mains across Perth (Utility, 2017). SA Water recently increased their replacement program to 2020 to $137 million to replace 375 km of water mains (ABC, 2017). Sydney Water has detailed a significant investigation into their assets and the expected costs associated with rehabilitating their network to continue current levels of service (Sydney Water, 2017). Under the price regulation framework, Sydney Water has assets valued at around $13 billion but the calculated replacement cost is over $45 billion meaning price rises are inevitable as assets age (Sydney Water, 2017). A comparison is often drawn with Queensland’s total water and sewerage assets total replacement cost (conservatively estimated at $37 billion) but it can be misleading to compare replacement costs across entities using different valuation methodologies.

Sydney Water categorised their water mains into ‘critical’ and ‘reticulation’ mains with both groups receiving significant investment in recent years. Critical mains received $140 million for 2012 to 2016 with the replacement of 40 km of network. An additional $110 million has been set aside for 2016 to 2020 to replace another 40 km (Sydney Water, 2017). The replacement of these mains and the $250 million allocated over 8 years is only an initial investment with predicted increases over 20 years to reach a yearly replacement rate of 15 km by 2036. The reticulation mains of Sydney Water are currently being replaced under similar time frames as the critical mains. In the 2012 to 2016 period $150 million was spent replacing 140 km of mains with a similar $110 million for 120 km being invested for the

2016 to 2020 period. Beyond 2020, Sydney Water has determined to increase their current replacement rates by 2% each year until 2040.

Sewers are generally less costly to rehabilitate than water mains because of the greater ability to use sewer relining technologies. In cases where sewer relining cannot occur the costs can be significant. For example, in the Melbourne CBD, a project to cope with increased volumes and aged pipes replaced 700 m of sewer with a new 1.4 m diameter main cost of $24 million or $34,300/m. The project was completed through tunnelling over the course of 3 months, with the total project expected to take 12 months (City West Water, 2018). The sewerage example is not representative of many places in Queensland but does provide evidence of the extremes of cost for replacing sewer mains.

Table A1.1: Summary of actual replacement rates from recent news releases.

Location and size of mains	Period	Total Cost (mill)	Length replaced	Cost ($/m)
Barwon Water (mixed sizes)	2018	$4.0	20 km/yr	$200
	2018	$19.0	11 km	$1727
South East Water (mixed sizes)	2018	$1.4	6 km	$233
Cairns Council (mixed sizes)	2018	$1.46	1.45 km	$1,006
Longreach Council (300 mm)	2018	$1.0	2 km	$500
Water Corp - Perth (water mains)	2018	$100	150 km	$667
South Australia (metro and regional mains)	2017	$137	375 km	$365
Sydney Water (critical mains)	2012-16	$140	40 km	$3,500
Sydney Water (reticulation mains)	2012-16	$150	140 km	$1,071
Sydney Water (critical mains)	2016-20	$110	40 km	$2,750
Sydney Water (reticulation mains)	2016-20	$110	120 km	$917
City West Water (tunnelled CBD sewer)	2018	$24	700 m	$34,300

This snapshot (summarised in Table A1.1) shows the significant range of costs associated with repair or replacement of mains of different sizes and the diversity of methods used with a median cost of $836 per metre replaced. The examples also illustrate that an emphasis on ageing networks assets is high in some large utilities nationally.

2. Recently Reported Unit Rates

Network ‘unit rates’ are commonly used with in the water and sewerage sector to describe the average cost per meter to renew a given type of pipe. Unit rates for specific sized pipes collected from the Queensland industry are compared with those reported from a national survey in 2013 (WSAA, 2013) in Table A1.3. There was high variability among these figures reflecting different time periods, renewal approaches and localities. It is clear from the national data that each example may have included different elements in their reported costs and hence it is difficult to compare values directly across utilities. However, the distribution of cost allows a typical rate to be estimated. Following the approach adopted by WSAA (2013) the unit rates and the reported rates collated in the section above were used to derive a set of ‘adopted unit rates’ for five size classes of water and sewerage pipes (see Table A1.2).

Table A1.2 Examples of specific rehabilitation and relining rates for different sized water and sewer pipes.

Location	Year	Mechanism	50	100	150	200	225	250	300	375	450	525	600
Water Mains													
WSAA (2013) - A	2013	general replacement		533	584	980	980		1,150				
Victoria	2013	bursting or splitting	147	159	206		349		465				
Metropolitan area	2013	new alignment/ lift & re-lay	275	308	521								
WSAA (2013) - E1	2013	general replacement		400									
Metropolitan	2013	bursting or splitting	172	172	224	374							
WSAA (2013) - G	2013	directional boring		138	172	225		249	295				
WSAA (2013) - L	2013	unit rates	400	500	600	800	1100	1500	1800	2000	2500	3000	
Metropolitan area	2013	general replacement	198	251	272	311	334		388	455	672		787
Rural area	2013	general replacement	90	142	163	201			271	334	552		667
Longreach (rural)[2]	2018	general replacement							500				
Regional Qld[2]	2017	PVC or steel (for >375 mm)		187	232	280	313	345	414	1,056	1,202	1,441	1,660
WSAA, 2013	2013	adopted unit rates[1]	150	200	225	250	300	300	400	450	550	600	700
***qldwater* Adopted**	**2018**	**water unit rates**		**200**	**230**	**275**			**410**		**650**		
Sewer Mains													
Regional Qld[2]	2014	urban relining including CCTV and establishment costs (does not include junctions)			131				174				
Regional Qld[2]	2016				142		169		193				
Regional Qld[2]	2016				134		152		181				
Regional Qld[2]	2016				115		144						
Regional Qld[2]	2017			102	153	204	230	255	306		459		612
Regional Qld[2]	2017	urban installation, Gravity Sewer 1.5-3m Depth, uPVC or DICL for >400 mm		260	306	396	430	410	472	869	955		1,316
***qldwater* Adopted**	**2018**	**relining unit rates**		**100**	**140**	**190**			**240**		**400**		**500**
***qldwater* Adopted**	**2018**	**replacement unit rates**		**200**	**280**	**320**			**400**		**600**		

1. less than average "to reflect that an efficient rehabilitation method". 2. Data sourced from confidential local reports.

Table A1.3 shows another common method for reporting network costs by using average rates for water or sewer relining and renewals encompassing more than one size of pipe. Again, there is significant variation among the reports indicating that different aspects of the work may have been measured in each case. For comparison, the average for Queensland pipes was calculated using the adopted unit rates for each size class (see Table 2.3.1) divided by the total length of the pipes in each class across the dataset. The averages are comparable to those listed in other reports. These are conservative estimates and do not capture the additional costs that many councils may face (e.g. remoteness, density, workforce availability) which are sometimes calculated using multipliers of up to two time the given unit rates.

Table A1.3: Examples of reported 'average' rehabilitation and relining rates for all pipes in a specific network.

Source	Year	Description	Average $/m
Water Mains			
Barwon Water	2018	replacement	$200
South East Water	2018	replacement	$233
Water Corp (CBD)	2018	replacement	$667
Sydney Water	2016	reticulation mains	$1,071
Sydney Water	2020	reticulation mains	$917
Sydney Water	2016	critical mains	$3,500
Sydney Water	2020	critical mains	$2,750
WSAA (2013)	2013	avg replacement	$219
qldwater* adopted	**2018**	**replacement**	**$275**
Sewer Mains			
Reg Qld	2014	relining	$253
WSAA (2013)	2013	relining	$205
qldwater* adopted	**2018**	**relining**	**$175**
qldwater* adopted	**2018**	**replacement**	**$310**

* average rate when '***qldwater*** adopted unit rates' (Table 2.3.1) are applied to the entire dataset of Queensland water or sewerage networks.

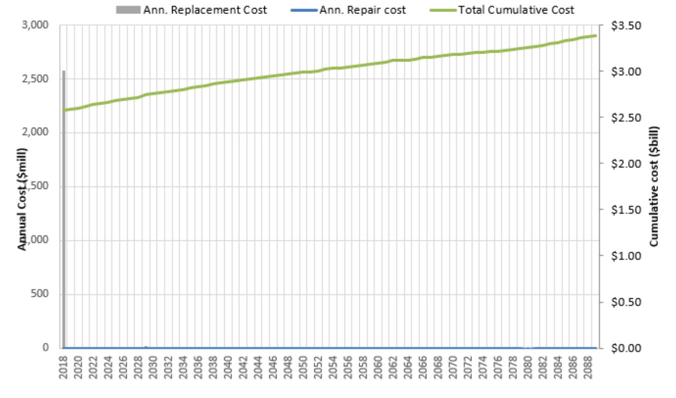
Appendix 2: Financial costs of repair versus renewal

One way to explore the potential impact of ageing networks is to compare the financial costs of continual repair versus replacement. An analysis was undertaken using a modification of the 'breaks model' used in Report 5.1 (Cosgrove and Fearon, 2017) which predicts breaks over time in asbestos cement (AC) pipes (see Fig. 1.1). AC pipes were modelled in the first report (Cosgrove and Fearon, 2017) because they represent a large proportion of the oldest networks in Queensland and have been well studied in terms of multiple modes of failure. The following analysis also focuses solely on the AC component (or 36.8% of the research dataset) to explore the interactions between repair and replacement costs. However, the general patterns are relevant for all pipes although specific timings and costs may differ because of different failure modes and expected lifetimes.

The analysis assumes that renewals can be deferred if repair efforts are increased. At one extreme, repairing pipe breaks could be continued (without significant renewal) in spite of rising break rates as pipes age. The opposite extreme would be to replace all aged pipes immediately to reduce future repair costs. The trade-off between these two extremes can be examined by assuming a specified number of breaks (per 100 km) can be tolerated.

The model compares the cost to repair and the cost to replace mains at a specified rate of breaks. It is assumed that oldest mains are first to break and are replaced first (representing an artificially accurate best-practice approach where poorest condition pipes are the first to be replaced). Criticality of pipes is not considered in the model. Replacement and repair costs are calculated using the adopted unit rates and for simplicity, calculations are not adjusted for the future cost of cash. This model of therefore conservative: model runs that accounted for net present value tend to further accentuate the differences described below (because deferring investment provides financial savings).

The modelling approach assumes that oldest pipes are the most likely to break and thus breaks can be avoided by replacing the oldest pipes first. In reality, age is only an approximate surrogate for probability of failure as a range of other factors also play a role (see WSAA, 2013; Cosgrove and Fearon, 2018; Folkman, 2018). Breaks are actually distributed stochastically over the entire network with greater probability of failure in oldest pipes and those of small diameter confounded by the distribution and criticality of different types of pipe.



(a) Early renewal (<1 brk/ 100 km). An extreme scenario of full and immediate replacement results in few ongoing repair and rehabilitation costs for the lifetime of the new pipes. For the suite of AC pipes in the model the upfront replacement cost is $2.6 bill. and the total cumulative cost over 70 years was around $3.4 billion due to

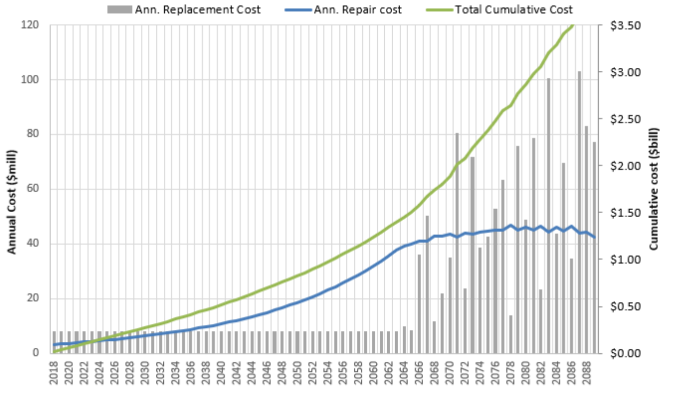
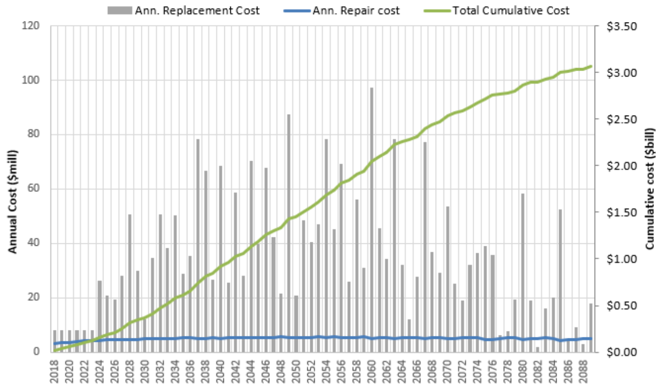
minor ongoing repairs and replacements.	
(b) Defer renewal (200 brk/100 km) At the opposite extreme, background replacement at 0.3% per annum is assumed until 200 breaks/100 km is reached. The result is a gradual increase in repair costs until 2066. However, total costs then increase rapidly and the 70-year cost is much greater than scenario (a).	
(c) Business as Usual (24 brk/100 km) Deferring renewal until 24 breaks /100 km (the current Qld average) maintains renewals at 0.3% until 2022 when greater replacement is needed to mitigate increasing breaks. The total cost of this moderate approach over 70 years is lower than either of the first two scenarios.	

Figure A2.1: Three scenarios comparing repair, replacement and total cumulative costs for different annual targets for breaks per 100 km.

The number of breaks tolerated clearly impacts the total cost with early, full replacement having the highest initial and long-term cost (Fig. A2.1a). This impact would be magnified if the net present value (NPV) of the expenditure was included. The remaining scenarios have the same initial cost as they assume current rates of expenditure on repair and replacement but deferring replacement has the highest total cost. Allowing up to 24 breaks per 100 km had the lowest financial costs in the long term. Figure A2.1b illustrates the outcome if the financial savings were to be the sole decision tool. Even without considering the NPV of future savings, the scenario results in low initial costs due to rolling deferral of renewals until an extreme value of breaks is reached and the area becomes unserviceable (in 2066). This provides the highest total long-term costs, compresses renewal expenditure in time and results in an unreasonable level of breaks (and their associated secondary costs). However, this approach may not be entirely unrealistic illustrating business as usual with growing but (initially) barely perceptible increases in breaks rising to a high agreed target.

The effect of the targeted level of breaks was compared by running the model at a range of break targets. The total cumulative cost for repairs and renewals over the next three decades is compared in for targets of 0.01, 1, 14, 24, 39, 50 and 100 breaks per 100 km Figure A2.2. This clearly shows the extreme costs of avoiding breaks entirely (i.e. permitting only 0.01 breaks per 100 km). There was no difference in costs with targets of 1 or 14 breaks per 100 km because in both cases the backlog of aged pipes would need to be replaced immediately to achieve these low break rates meaning the total costs till 2050 are dominated by a similar amount of renewals. In contrast, there was little difference between targets of 50 and 100 breaks per 100 km because significant renewal is deferred beyond the first three decades and thus not captured in the period depicted.

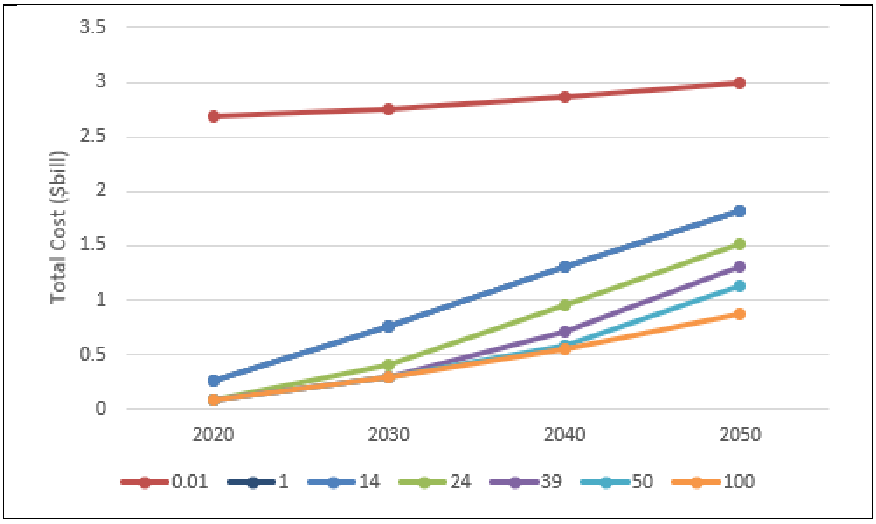


Figure A2.2: Cost of repair and replacement over three decades for annual break targets from 0.01 to 100 breaks per 100 km.

To explore sensitivity of these analyses to different unit rates a range of cost combinations was modelled (see Appendix 3). Total cumulative cost was most sensitive to changes in replacement while increasing repair costs by almost 33% resulted in only a 4% increase in total cumulative costs (when replacement costs were held constant). At the maximum cost modelled for repair and replacement, the difference in total cumulative costs in 2040 increased by almost 20%. Regardless of adopted unit costs and the allowed number of breaks, it was financially beneficial to defer replacement in favour of repair programs, a benefit that would be more pronounced if the net present value of future expenditure was taken in to account. Although this analysis was undertaken using data on AC water pipes similar results would result for other materials and similar patterns would be expected for sewers (although the lower cost of relining might make the difference less dramatic despite shorter expected lifetimes).

Appendix 3: Sensitivity analysis of different unit rates for repair and replacement

To explore sensitivity of the analyses of repair and replacement trade-off in section 3, different unit rates cost combinations were modelled at a set number of target breaks. Repair costs were adjusted up and down in in steps of $20 per metre relative to baseline rates for 100 mm pipes (providing a range of $160 to $240 per metre for 100 mm pipes and a relative range of rates for each of the other size categories). Repair costs were adjusted by plus or minus $200 per repair in two steps (yielding a range of between $800 and $1600 per break).

The example provided in Figure A2.1 shows the total cost in 2040 if 39 breaks per 100 km was adopted as a target. The cumulative break and repair costs for the adopted unit rates is depicted in the central column. Other columns show the relative total cost (in 2040) for other combinations of repair and replacement costs. These figures are tabulated in Figure 3.2.4b.

The difference in total cumulative cost is most marked for changes in replacement cost. A 20% increase on the adopted unit rates resulting in a 0.15 increase in total cumulative costs when repair costs were held constant. In contrast, increasing repair costs by almost 33% resulted in only a 4% increase in total cumulative costs (when replacement costs were held constant). At the maximum cost modelled for repair and replacement, the difference in total cumulative costs in 2040 varied by almost 20%.

Sensitivity to price was not markedly different when modelled at targets of 14 or 24 breaks per 100 km suggesting that even if the adopted rates used in the analyses above are altered, the pattern shown in the analysis will not alter significantly. However, the total cost for repair or replacement could vary by up to 20% if extreme average costs for repair and replacement were assumed for all of Queensland's networks.

Figure A2.1: Relative total costs by 2040 at different combinations of repair and rehabilitation unit rates. Cumulative costs at 2040 are shown as ratios of the central column which represents the adopted unit rates.

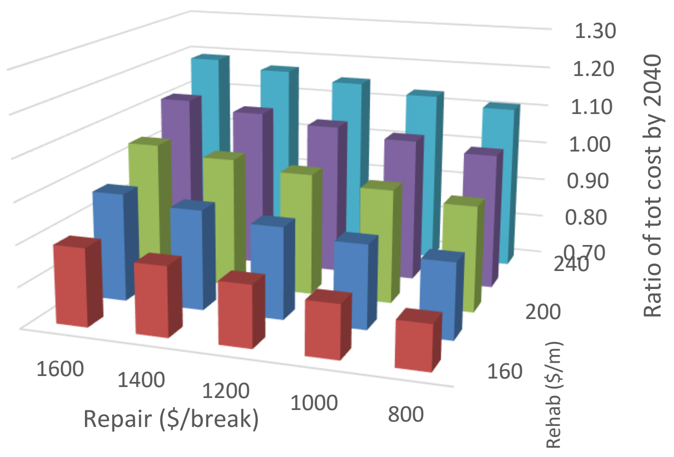


Figure A2.1: Tabulated ratios highlighting the greater impact of changes

Repair Cost ($/break)	Tot. cost at 2040 as ratio of the median costs				
	Initial replacement Cost ($/m)				
	$160	$180	$200	$220	$240

in rehabilitation cost than repair costs.		$800	0.81	0.88	0.96	1.03	1.11	
		$1000	0.83	0.90	0.98	1.06	1.13	
		$1200	0.85	0.92	1.00	1.08	1.15	
		$1400	0.87	0.94	1.02	1.10	1.17	
		$1600	0.89	0.97	1.04	1.12	1.19	

This simple analysis shows that regardless of adopted unit costs and the exact degradation rate of pipes, it is financially beneficial at least initially to defer replacement in favour of repair programs, even if the rate of breaks increases as networks age. The difference would be even greater if the net present value of future expenditure was taken in to account.

Appendix 4: Case Studies and Model Assumptions

The sizes of service providers in Queensland ranges from QUU with over 9000 km of water main to councils with less than 10 km of mains. The impact of ageing assets varies across the state based on the age and condition of pipes in each community, the total length to be managed and the number of customers paying for the services. However, in general, councils of similar size have comparable distributions of aged network allowing size classes to be adopted to represent similar groupings of service providers (Table A4.1). The size classes are arbitrary divisions based on the groupings evident in Figure 5.1.1 based on the cost per connection to replace aged (AC) pipes. The table also shows the median breaks per 100 km reported for each size class over the past five years.

Table A4.1: Length of water mains and median breaks of Queensland Service Providers in 2017. Size classes are arbitrary groupings determined as described in Section 5.1.

Service Provider	Water Mains (km)	Breaks/ 100 km[1]	Size
Lockhart River Aboriginal Shire	5	-	Very Small
Pormpuraaw Aboriginal Shire	8	13	
Napranum Aboriginal Shire	9	12	
Woorabinda Aboriginal Shire	9	-	
Wujal Wujal Aboriginal Shire	10	-	
Bulloo Shire	11	9	
Cherbourg Aboriginal Shire	11	-	
Croydon Shire	14	20	Small (case study 3)
Mapoon Aboriginal Shire	15	1	
Burke Shire	15	20	
McKinlay Shire	16	49	
Quilpie Shire	17	94	
Torres Shire	18	13	
Mornington Shire	18	6	
Kowanyama Aboriginal Shire	19	32	
Palm Island Aboriginal Shire	19	21	
Doomadgee Aboriginal Shire	19	-	
Diamantina Shire	21	-	
Aurukun Shire	21	10	
Barcoo Shire	21	16	
Etheridge Shire	23	7	
Boulia Shire	27	11	
Winton Shire	32	51	
Yarrabah Aboriginal Shire	33	36	
Paroo Shire	34	-	
Hope Vale Aboriginal Shire	37	16	
Richmond Shire	46	15	
Blackall-Tambo Regional	47	136	
Cloncurry Shire	56	8	
Flinders Shire	66	34	
Northern Peninsula Area Regional	76	13	
Longreach Regional	99	56	Medium (case study 2)
Torres Strait Island Regional	105	6	
Balonne Shire	107	24	
North Burnett Regional	131	45	
Mt Isa City	157	37	
Carpentaria Shire	163	3	
Goondiwindi Regional	164	27	
Charters Towers Regional	223	6	
Banana Shire	247	23	
Maranoa Regional	255	50	
Mareeba Shire	256	37	
Isaac Regional	261	41	
Douglas Shire	266	9	
Hinchinbrook Shire	267	6	
Burdekin Shire	299	11	
Central Highlands Regional	416	45	Large (case study 1)
Gympie Regional	450	8	
Western Downs Regional	457	23	
Tablelands Regional	470	7	
Whitsunday Regional	531	14	
Southern Downs Regional	546	4	
South Burnett Regional	603	12	
Livingstone Shire	686	3	
Gladstone Regional	705	11	
Cassowary Coast Regional	814	12	
Rockhampton Regional	864	16	
Bundaberg Regional	924	4	
Fraser Coast Regional	1,175	4	Very Large
Mackay Regional	1,232	10	
Redland City	1,308	3	
Toowoomba Regional	1,789	17	
Cairns Regional	2,200	13	
Logan City	2,201	6	

Cook Shire	83	22	
Barcaldine Regional	89	27	
Murweh Shire	92	43	

Townsville City	2,629	27	
Gold Coast City	3,469	7	
UnityWater	6,122	4	
Queensland Urban Utilities	9,391	26	

1 - median of reported values over past 5 years.
– means no data was available.

Three case studies were created representing the ‘large’, ‘medium’ and ‘small’ size classes (i.e. excluding ‘very small’ and ‘very large’ service providers). An overview of the number of councils (including connections and reported main breaks) used to generate the case studies is provided in Table A4.2. Data structures for each case study were built by averaging available data within each size class as summarised in Table A4.3

Table A4.2: Summary of service providers whose network data was used to form the three case studies.

Case Study	No.s	Average Connections	Median Breaks/100 km			Five-year median
			15/16	16/17	17/18	
Large	6	21,433	11.3	9.6	11.5	12
Medium	7	4,695	12.9	21.4	17.6	19
Small	7	524	34.2	30.2	24.2	28

For each size class a percentage of critical pipes was calculated based on data provided by a small number of service providers in the research dataset. High criticality pipes are those with a high consequence for any break (e.g. mains servicing reservoirs or hospitals or large portions of the network). Most high-criticality pipes are of large diameter but proportions of smaller size classes are also considered critical (see Table 4.2.2). Most small pipes in the large case study are rated as low-criticality likely due to larger networks being able to re-route water around a main break. These pipes also serve a smaller number of customers, meaning interruptions are not wide-spread when a repair is made. A larger number of small pipes are rated as critical in small networks where trunk mains are smaller and some small mains service large proportions of the network with little redundancy.

Table A4.3: Number of connections and lengths of pipes in large, medium and small case studies.

Case Study	Measure	Size Class (mm)					Total
		100	150	200	300	400	
Large	**Total Pipe Length (m)**	344,153	140,415	46,996	78,210	45,953	655,727
	Length >70 yr in 2020 (m)	17,748	5,736	2,234	4,467	504	30,689
	% deemed critical	5	5	20	75	98	
Medium	**Total Pipe Length (m)**	117,422	41,447	11,055	18,941	8,086	196,952
	Length >70 yr in 2020 (m)	6,481	1,727	414	1,443	1,037	11,102
	% deemed critical	10	20	85	90	98	
Small	**Total Pipe Length (m)**	21,911	7,141	3,188	5,691		37,931
	Length >70 yr in 2020 (m)	15	74	61	0		150
	% deemed critical	20	30	85	98		

Model Assumptions

The breaks model used to compare repair and replacement timing for AC mains was extended and applied to all pipe materials using case study data. This approach yields only approximate break rates and costs (because the AC pipe deterioration functions used are not accurate for all pipe materials) but provides a consistent basis for relative comparison of investment structures. The model assumes the unit rates developed in Section 2 for repairs and renewals.

An average expected pipe life of 70 years was assumed and in the absence of condition data for each pipe, age was used as a surrogate. This means the analyses assume oldest pipes will deteriorate most rapidly and that replacing these pipes will avoid future breaks. In reality, age is only an approximate surrogate for condition and it is impossible to have full knowledge of condition (and thus which pipes should be replaced most urgently). To allow for this uncertainty, the model included an input of the percentage of investment targeted at old (i.e. assumed poor condition) versus young pipes.

Model scenarios compared costs of repairs and renewal over 20 years based on the annual renewal budget for each of the years. The renewal budget was divided across high and low criticality pipes to allow comparison of investment in these two asset classes. The predicted expenditure on renewal differs slightly from the budgeted amount in some years because of the model distributes available funding across different sizes of pipe. All breaks were assumed to be repaired within the year that they occurred at a given unit rate. For the purposes of comparison, the highly conservative rate of $1200 per repair was assumed for all breaks.

To represent secondary costs, multipliers were applied to repair costs of low and high criticality pipes. As it is not possible to determine these multipliers from first principles, a range of inputs was trialled and a multiplier of 2 for low criticality and 10 for high criticality pipes adopted for consistency (for the large case study). This means that low criticality pipes are assumed to cause additional economic costs equal to twice the financial cost of repair while for high criticality the economic impact would be 10 times as high. In trials using a default replacement rate of 0.3% these multipliers yielded initial conditions where replacement costs marginally exceeded combined repair and secondary costs. It should be noted that the multipliers are applied only to repair costs in order to represent the secondary costs of breaks and the repairs undertaken to remedy them. Some secondary costs would also be associated with replacement activities and could have higher multipliers for some impacts (e.g. traffic interruptions). These impacts were not included assuming that renewals were much less common than repairs.

Appendix 5: Additional Model scenarios

Figure A2.1 and A2.2 show outputs from the model comparing different investment scenarios for renewals. The scenarios tested here share regular annual investment (150 HC/ 350 LC) but vary the percentage of renewal directed at old (most deteriorated) pipes. Scenarios include 1%, 10%, 30%, 60% and 100% of funds targeted at the most deteriorated parts of the network.

As would be expected, the more targeted the investment, the lower the increase in annual breaks and in the total cumulative cost. However, savings in total cumulative cost become less pronounced as the targeted percentage increases. This is because the disadvantages of poorly targeted investments are magnified over time by their impact on repair and secondary costs. This suggests that perfect knowledge of pipe condition is not as important as making sure that the majority of investment is well directed. This would be good news for asset managers given the limitations on targeting solely the most deteriorated pipes. However, this relationship may be an artefact of the assumptions of the model and deserves further research.

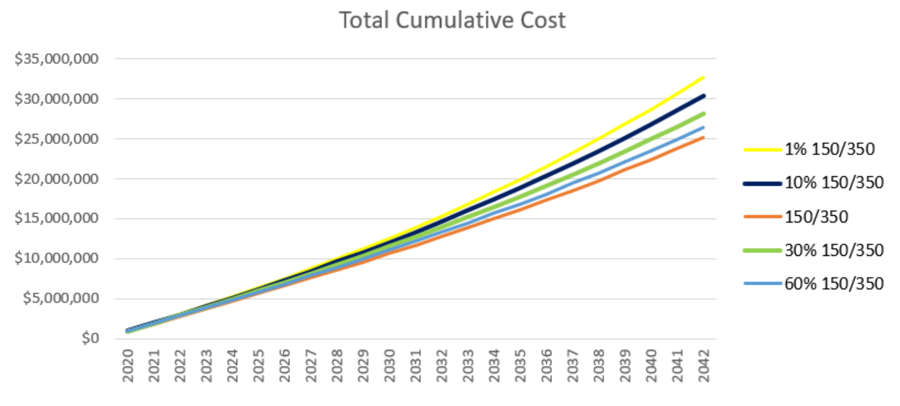


Figure A2.1: Total cost including replacement, repair and risk costs over 20 years for scenarios of regular annual investments in HC/LC pipe with different percentages of funding targeted at the oldest pipes.

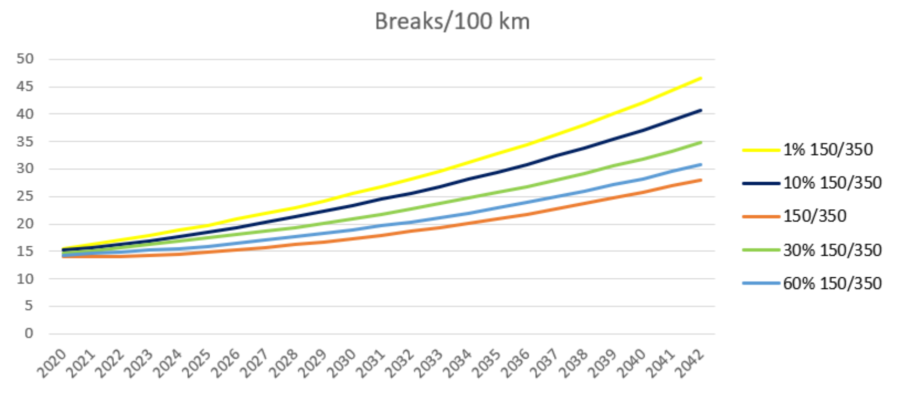


Figure A2.2: Annual breaks per 100 km over 20 years for the same scenarios in Figure A2.1.