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PAPERS

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WEF advocates private sector participation in infrastructure funding

A new report from the World Economic Forum advocates private sector participation as a way to help close the global investment shortfall in infrastructure.

The report, 'Infrastructure Investment Policy Blueprint', notes that a significant number of economically viable infrastructure investments are not moving forward. The global investment shortfall in infrastructure is estimated to be at least $1 trillion a year. Enhanced participation from the private sector, while not a complete panacea, could do much to close this gap, the report adds.

Major recommendations include the need to structure projects with appropriate risk allocation and clear investment propositions for the private sector. Projects should be developed with the understanding that investors are 'global shoppers' for infrastructure and will rank opportunities based on their risk-adjusted returns, the report says.

Governments need to proactively address political risk, which has emerged as a pressing concern for infrastructure investors in both emerging and developed markets.

The report also suggests developing an ongoing pipeline of investment opportunities that will give private sector players the confidence to build internal capabilities and local expertise.

Capital recycling – leasing or selling brownfield assets to fund greenfield projects – is advocated as a strategy to attract private capital, and the report also recommends addressing the tremendous costs and time delays often incurred in infrastructure procurement processes.

The report was overseen by the World Economic Forum's Global Agenda Council on Long-Term Investing, which consists of thought leaders from institutional investors and academia.

The chair of the council, Danny Truell, who is also chief investment officer of the Wellcome Trust, said: 'Within this report, we have set out a series of practical steps that can be taken by governments to increase the flow of long-term capital into infrastructure projects. Improving collaboration between the public and private sectors, including national and regional governments, corporates and investors, is a key part of this.' ●

Maynilad announces water and wastewater expansion

Maynilad Water Services has announced that it will spend some P7.2 billion ($2.2 billion) to improve and expand its water and wastewater services in parts of southern Metro Manila, particularly Parañaque, Muntinlupa, Las Piñas and parts of Cavite.

P4.7 billion ($1.4 billion) of this will be allocated to constructing a wastewater treatment plant in Muntinlupa, and over 50km of wastewater pipelines in Parañaque and Muntinlupa.

The remaining funding will extend primary lines in various areas and construct additional booster stations and reservoirs, as well as rehabilitating network facilities in the south. P36 million ($11 million) has been set aside for other operational support projects. ●

Moody's warns of credit impact on highly-geared companies from AMP 6

Moody's Investors Service has warned that recent guidance from the economic regulator Ofwat indicates a significant reduction in allowed returns for UK water companies. The regulator's guidelines indicate that the return companies will be allowed to earn on their assets over the AMP 6 investment period will fall to 3.85% from the 5.1% set in 2009.

Moody's notes that highly geared companies, including Anglian Water Services, Thames Water Utilities, Yorkshire Water Services and Southern Water Services are most exposed to a reduction in returns because of their low interest cover ratios.

Depending on the final outcome of the review, Moody's says it expects negative credit pressure for these companies, unless management and shareholders can implement balance-sheet strengthening measures.

Moody's views Ofwat's stance on the cost of capital as 'particularly credit negative' for the holding companies of highly leveraged companies, including Anglian Water (Osprey) Financing and Thames Water (Kemble) Finance.

Some companies are well-positioned to accommodate lower returns, Moody's added, citing United Utilities Water, with fairly low gearing and strong interest coverage, adding that it will be able to accommodate the lower returns with limited credit quality pressure.

Other companies, including Severn Trent Water, also enter the price review with financial headroom, Moody's said, but may face challenges in downside scenarios and will likely have to adjust their dividend policy to maintain credit quality. ●

water asset management INTERNATIONAL

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ADB provides extra funding for Kathmandu water project

The Asian Development Bank (ADB) is to provide an extra $25 million to the government of Nepal to enable it to complete the Melamchi tunnel, alleviating a severe water shortage in the Kathmandu valley.

ADB approved a restructured $137 million loan in February 2008 for the then $317 million Melamchi water supply project, but the completion was delayed by political and economic uncertainties in Nepal, changes to the project design, and, later, the need to find a new contractor to complete the tunnel construction.

The extra funds, along with an extra $13.1 million from the government of Nepal, means the overall cost is now estimated at $355.4 million. Under the project, Italian construction company Cooperativa Muratori e Cementisti di Ravenna will complete the 27.5km Melamchi tunnel by the end of September 2016.

The tunnel will take 170MLD of water from the Melamchi river to Kathmandu. A Japan International Cooperation Agency-financed water treatment plant is being constructed in Sundarijal on the outskirts of the city, which will treat the water brought through the Melamchi tunnel.

Improvements to the Kathmandu Valley water transmission and distribution network are also under way, with the help of an $80 million ADB loan, to take water from the treatment plant to households and reduce leakage.

The ADB approved another $80 million loan in April 2013 to expand and rehabilitate the sewerage network and build wastewater treatment plants to treat more than 90MLD of wastewater in the Kathmandu Valley. ●

NRDC poll finds Californian voters favour local supply strategies

The Natural Resources Defense Council (NRDC) has revealed that a new poll conducted on its behalf reveals Californian voters are more concerned about the drought than any other major issue, and an 'overwhelming' majority favour strategies to make local supplies go further, including recycling, rainwater harvesting and efficiency measures.

Ann Notthoff, NRDC California advocacy director, said: 'Californians are united in their desire for concrete long-term solutions to our water needs. It's time to embrace and implement water-smart strategies that ensure we make the most of every drop.'

By a margin of 74% to 17%, Californians think the best way to deal with the drought is to develop local supplies of water rather than expand water imports. In addition, 77% of voters would be willing to pay more on their water bill in order to increase sustainable local water supplies.

The poll also found that a very strong majority of Californians support, and are willing to pay for, a range of local water resiliency efforts including cleaning up locally-contaminated groundwater, investing in new water efficiency technologies, and capturing rainwater.

In addition, the California Department of Water Resources is working with NASA to access the agency's satellite data and other technologies to measure the state's snowpack and groundwater levels more accurately.

NASA is also starting projects that use satellite images to measure the number of fields left fallow by farmers, and to detect where ground levels are sinking due to excessive groundwater abstraction. NASA projects also aim to provide better prediction of global storm systems further in advance, allowing rain to be captured more efficiently. ●

Funding awarded for modernisation of Moldovan capital's water network

The The European Investment Bank (EIB), European Bank for Reconstruction and Development (EBRD) and the EU, through the Neighbourhood Investment Facility, are joining to support the modernisation of water and wastewater infrastructure in Moldova's capital, Chisinau.

EBRD and EIB will each provide loans of €24 million ($32.6 million) to the city's water and waste-water utility SA Apa Canal Chisinau, while the EU will contribute an €11 million ($14.9 million) grant.

The funds will be used to finance extending, rehabilitating and modernising the water and wastewater infrastructure. The upgrade programme will improve the efficiency of the city's water network, save energy and contribute towards future compliance with relevant EU directives, the group said in a statement.

The existing water network in Chisinau, which has 800,000 inhabitants, is no longer adequate to meet its demands, the statement adds. Due to a lack of investment key parts of the network are in urgent need of refurbishment. Investment planned under the new upgrade programme will reduce water loss, improve water quality and reduce health risks.

The programme will enable Apa Canal Chisinau to enhance operating efficiencies, quality of customer services and reduce environmental impacts in its service area in Chisinau. The EU supported the preparatory phase of the programme by providing €3 million ($4.1 million) for a feasibility study and continues supporting the implementation of construction and rehabilitation works through its latest grant. ●

Implementation of an optimised decision support tool for advanced asset management of the 3 Waters reticulation network

In a drive to achieve advanced asset management and improve efficiencies, New Zealand's Dunedin City Council is upgrading its asset management information systems to improve the way that data is stored and analysed. Philip McFarlane, Theuns Henning, and Tom Dyer look at the work undertaken by the Dunedin City Council's Water and Waste Services Business Unit, together with Opus International Consultants, IDS and Deighton Associates, to develop and test an optimised decision making software tool.

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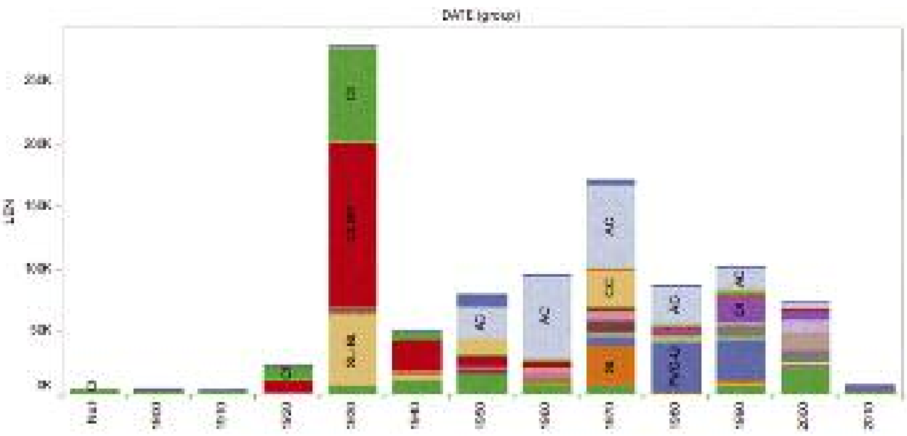


Figure 1 Age / material profile of Dunedin's water network

Dunedin city is located on New Zealand's South Island. It was originally established in the mid-19th Century, and currently has a population of 125,000. A large portion of the pipes in the city's three water networks were installed in the 1930s, with another, smaller peak in the 1970s. The systems have been constructed from a variety of different materials (see Figure 1).

Dunedin City Council has a good understanding of the capital and operational requirements to meet present and future hydraulic conditions, having completed its 3 Waters Strategy project. However, it has less understanding of how pipe deterioration will affect future expenditure.

Planned renewals for deterioration are currently forecast based on age. On this basis, renewals expenditure is forecast to increase to three times the current rate over the next 15 years. This has highlighted a requirement for optimised renewals planning and the need for a decision support tool that can:

- Perform advanced asset management processes that include forecasting capabilities and optimisation of investment levels
- Provide robust estimation of remaining useful life of pipe assets
- Undertake 'what if' optimisation models to enable consideration of different treatment strategies, performance standards and budgets

Dunedin City Council's situation is not unique. A review of the current status of the water industry undertaken in 2009 to determine whether there was a need to develop a decision support tool (IDS, 2010) concluded that most asset managers were keeping records of key asset data, such as age, condition and historical maintenance. However, many users were not satisfied with existing asset management systems, particularly with respect to predictive modelling capabilities.

A high level of knowledge is required to predict how the performance of the three water networks will change over time and how this will influence levels of service, risk and budgets. However, very few local authorities in New Zealand have this level of understanding for the pipes in their water networks. This appears to be because pipe networks are:

- Long life assets – accurate prediction of future performance is difficult and there are normally shorter life assets that need more immediate attention
- Buried assets – it is difficult to accurately determine condition and gain the data required to predict future condition. The assets are out of sight and out of mind until there is a problem
- There is no common funder or strong regulator to drive improved asset management practices

Table 1: Outputs from decision support tool

Outcome area	Parameter
Cost	Annual cost
	Net present value
Reliability	Breaks
	Accelerated failure
	Shutdowns
Characteristics	Age
	Diameter
	Material
Hydraulic performance	Capacity
Risk	Risk profile

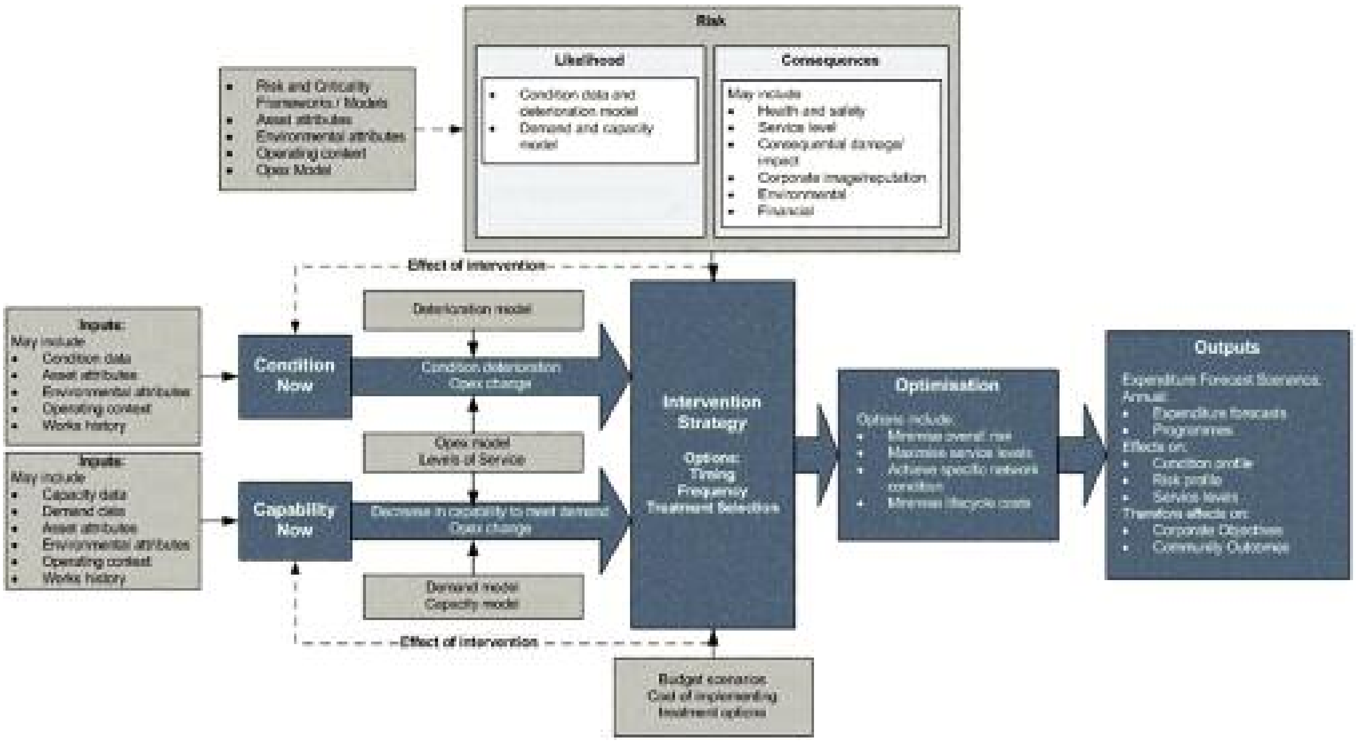


Figure 2
The components of the systems (IDS, 2010)

The Auditor General (2010) has noted that 'until local authorities have robust underlying information and appropriate financial strategies, the potential inherent in local authorities to think long-term will not be fully realised'. This statement is certainly true for the three water networks.

Development process

Development of a decision support tool to aid long-term, sustainable planning of maintenance, replacement and renewals for the three waters infrastructure began in 2009. Prototype development for Dunedin City Council started in 2012, using its potable water, wastewater and stormwater networks as real life examples to refine the required functionality and test the tool.

A series of workshops were held with Dunedin City Council to determine required outputs and outcomes, interfaces with other business processes, performance measures, interventions and data requirements.

The outputs that the decision support tool produces are listed in Table 1. During the development workshops it identified that the initial version of the decision support tool should predict the timing and cost of renewals required due to deterioration and the effect that deterioration has on levels of service. The decision support tool should be able to prioritise renewal of pipes with capacity issues and higher criticality pipes. Changes in the characteristics of the network over time should also be reported. It was decided that leakage and blockage predictions would not be included in the initial version of the model, but should be included in subsequent versions.

The decision support process

The overall concept of the Decision Support Tool is illustrated in Figure 2. The decision support tool uses the input data to develop intervention strategies for all pipes in the network. It considers two high level strategies:

- Maintenance – repair breaks as they occur
- Replacement – proactively replace pipes

The optimal time for replacement is calculated. Figure 3 shows the time for replacement if cost alone is considered, though in most cases level of service or risk considerations will force earlier replacement. These components are discussed further in the subsequent sections.

Data requirements and confidence

It was decided that the decision support tool would draw on data stored in Dunedin City Council's Hansen asset management system. The decision support tool is seen as a tool supplementing, not replacing the existing asset management system.

The decision support tool, however, has been developed with the flexibility to interface with most of the asset management databases commonly being used in New Zealand or alternatively it can house the data directly in the system itself.

Dunedin City Council had already prepared, as part of earlier asset management measures, a number of inputs that would form the basis of the decision support tool. These included information on:

- Capacity
- Asset attributes
- Works history
- Levels of service

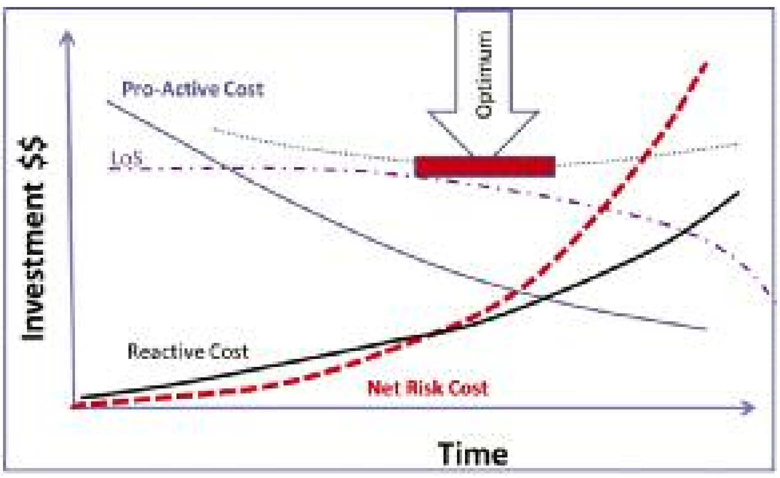


Figure 3
Finding the optimum replacement timing

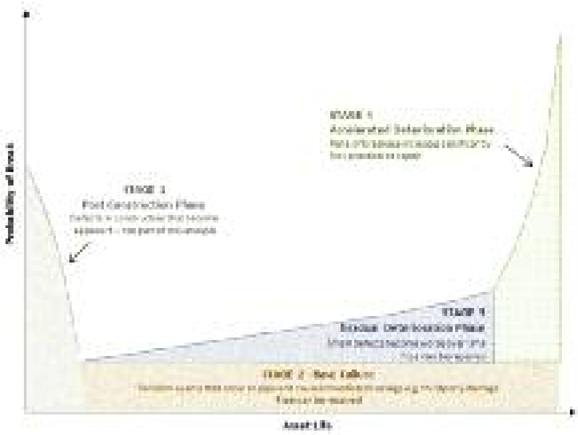


Figure 4
Pipe deterioration stages

- Criticality
- Cost of repair / replacements

These records were fairly comprehensive, but there were gaps. One of Dunedin City Council's desires was to understand where it should concentrate its efforts to close the information gaps. Therefore, confidence ratings have been assigned to all input data as follows:

- Accurate – input variable has been measured or determined from as-built information
- Confident – there is reasonable confidence that the input data is accurate, but it has not been confirmed by measurement or as-built data
- Assumed – input data is unknown, it is an assumption

This approach enables the system to be implemented with minimum data and developed from there. Over time, users will improve the confidence ratings of the data, concentrating on the data that has the greatest impact on the decision support tool's predictions. It is expected that the decision support tool will give a 'purpose' to the data users collect and show the value of the data.

Conceptual model of pipe deterioration

Figure 4 shows the conceptual model for pipe deterioration that has been incorporated into the decision support system. There are four stages:

- Post construction phase – construction defects that become apparent early in the life of the pipe. These defects will normally be identified during the defect liability period for the construction contract and be repaired by the construction contractor at their cost, so these defects do not need to be included in the decision support system.
- Base failure phase – random events that affect pipes, causing immediate damage, such as third party damage. The frequency of these events is constant over time. For the initial version of the decision support tool it has been assumed that all pipes in the network have similar base failure rates. In later versions, variations to the base failure rate, based on location and other factors, may be incorporated.
- Gradual deterioration phase – small defects in the pipe become worse over time, causing the pipe to break. These defects result in isolated breaks that can be repaired. The frequency of breaks will increase over time, and the future break rate can be estimated from break history. This process might occur through either: small defects from events that happen to the pipe, resulting in deterioration, such as damage to pipe coating during installation, resulting in corrosion at that point; or two events occurring at the same location, for instance a pipe being cracked during installation, with tree roots at that location, causing collapse / blockage.
- Accelerated failure phase – the frequency of breaks increases significantly to a point where it is not practical to continue to repair the pipe. Collapse of large sections of pipe may occur. An example of this is the failure of asbestos cement pipes due to deterioration of the pipe material. Break history cannot be used to determine the possibility of the pipe reaching this stage, as in most systems pipe deterioration will not have yet reached a stage where it is causing pipe failure. Instead it needs to be estimated through other factors, such as testing to estimate the rate of pipe wall deterioration.

Each one of the above stages is independent, for example undertaking proactive repairs on an asbestos cement wastewater main will reduce the likelihood of stage 3 breaks occurring, but will have no effect on the rate of stage 2 or 4 breaks. The length of time for each stage can vary significantly between pipes depending on material types and other factors.

Treatment of Stage 3 breaks

The decision support tool predicts the frequency of breaks occurring, considering pipe type, size, material and age, as shown in Figure 5. Two threshold levels are set. When the lower threshold is reached, the decision support tool starts to consider intervention strategies, choosing them if they are optimum. When the upper threshold is reached, the pipe must be replaced. Thresholds are set based on criticality, which typically generate a 'run to failure'

Figure 5
Stage 3 intervention levels

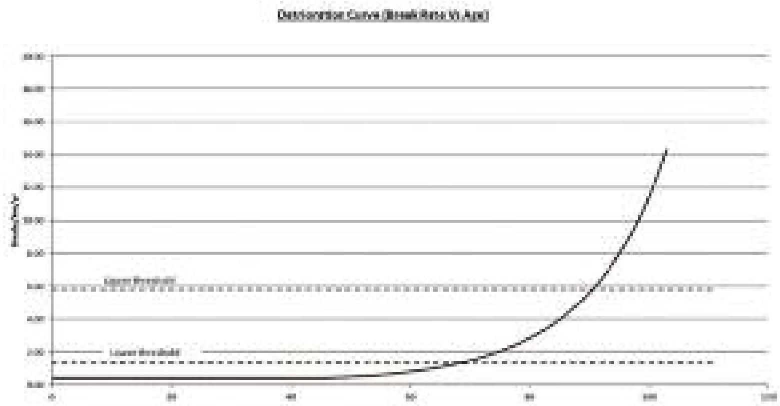
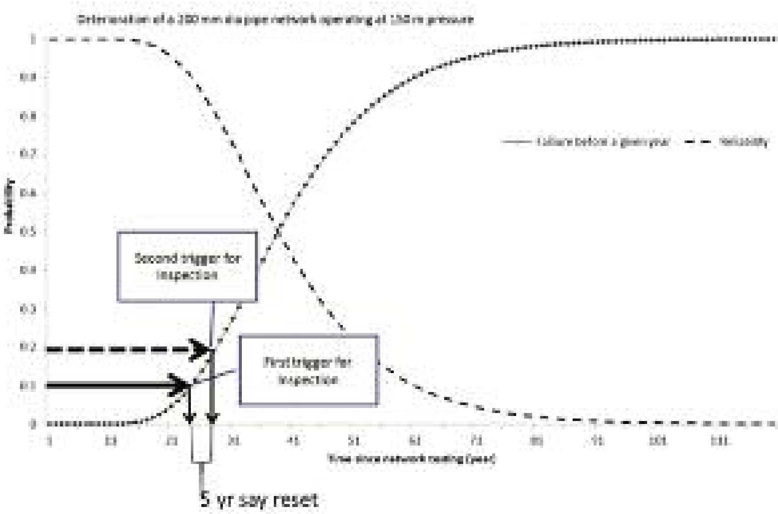


Figure 6
Stage 4 interventions



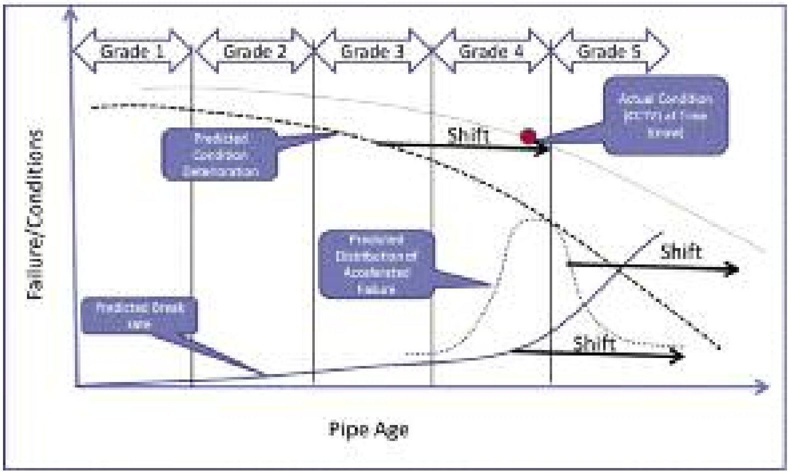


Figure 7
Effective curve shifting to predicted condition at age_corrected

approach for low criticality pipes and an 'intervene before failure' approach for highly critical pipes.

Treatment of Stage 4 replacements
The likelihood of a pipe going into accelerated failure is predicted, based on the pipe size, type, material, pressure and age. Intervention triggers are set based on the maximum likelihood of the pipe going into accelerated failure, as shown in Figure 6. For highly critical pipes this trigger is low, for instance 10%. For pipes that are not critical the trigger might be set at 100%, that is, run to failure. When the trigger is reached, the decision support tool generates a triggering sequence as follows:

- An inspection is triggered at given intervention level (for criticality) – say 10% as an example
- The inspection could result in two instances – a 90% chance the pipe is still OK and a 10% chance it is weak and must be replaced: Cost for inspection only = 100% time inspection – benefit = reduced life (equals the time it takes for another inspection threshold to be reached – in this example, 20%, which is another five years away; cost to replace = 100% of inspection plus 10% of replacement – the benefit of this would be a full regain of the pipe life (that is, age back to '0').
- The next cycle will again trigger an inspection (in this example five years later) with the same ratio outcome as above

All of these cycles and outcomes become potential strategies that the systems uses when optimising to a given budget or level of service.

Capacity
The decision support tool draws on information on the hydraulic capacity of pipes from the hydraulic model. Four types of capacity needs are identified in the model:

- Pipe is under capacity and needs to be upsized immediately
- Pipe is under capacity and needs to be upsized when replacement is triggered because of breaks
- Pipe has no capacity issues
- Unknown

Condition assessment
Undertaking condition assessment influences the decision support tool process in the following ways:

Network level

- Enables deterioration curves to be refined
- Improves confidence levels

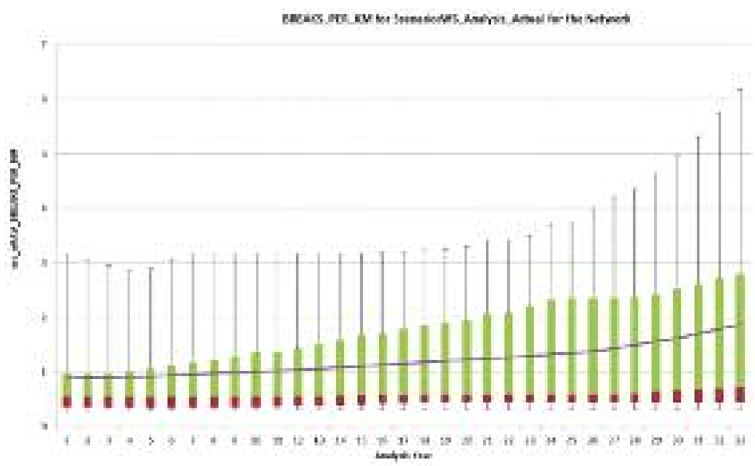


Figure 8
Network deterioration – breaks

Asset level

- Enables the deterioration state of individual assets to be refined
- Enables proactive repairs to be undertaken

The concept at an asset level is shown in Figure 7. It involves:

- The decision support tool predicts the likelihood of failure. When this level exceeds the maximum threshold or an optimised level, then the decision support tool will propose an intervention strategy. The condition of the pipe will be assessed prior to implementing this intervention. The condition will either be: at or worse than the condition expected for the predicted risk of failure, in which case the intervention should be implemented; or better than the condition predicted, in which case the age of the pipe will be reset to reflect the assessed condition of the pipe.
- Condition assessment is undertaken prior to the optimised level or maximum trigger level, for instance as part of a proactive programme, or pipe condition is assessed when a break occurs. In such a case the age of the pipe is reset to reflect the assessed condition of the pipe.

This concept is incorporated by introducing new variables for 'Corrected_Age'. These parameters are used rather than 'Age' to predict breaks and accelerated failure. This on-going process of condition assessment improves the accuracy of the deterioration predictions and calibrates the deterioration models to actual conditions. It also means that the importance of getting the initial deterioration predictions accurate is less critical.

Results / findings

Development of the decision support system has been completed, and it is currently being calibrated to Dunedin City Council's data and the outputs tested.

Condition assessment
An early outcome has been the identification of pipes where further condition assessment is required. The tool has firstly identified a series of highly-critical pipes that are at risk of failure. These will be investigated further to determine their actual condition. The tool has also highlighted the need to assess the condition of the cast iron pipes in the network, as these have a large bearing on the accuracy of the model outputs.

Figure 9
a) left - network condition now;
b) right - network condition in 25 years

Model outputs

Sample outputs from the model for varying budget and optimisation scenarios are currently being assessed. Figure 8 shows a sample of how the condition profile of the network would change over time from a break perspective. For this illustration a minimum cost budget was used, which would be less than that required to maintain the current level of service. A key point to note is that although the mean break rate is predicted to deteriorate from under one break/km/yr to two breaks/km/yr over 33 years, the break profile is predicted to expand, with the worst pipes in the network getting far worse. It is these pipes that will drive renewals expenditure.

Figure 9 shows how deterioration is predicted to change spatially over time. These presentations enable hotspots to be identified. This helps in calibration of the model, with maintenance crews being able to comment on whether the model predictions match what they are observing in the field. The presentations also assist in allocating condition assessment, and enable discussions to be taken with the community and elected officials about changes in levels of service.

Figure 10 shows the mix of expenditure. Different investment scenarios will alter the mix from reactive to proactive expenditure.

Figure 11 shows how hydraulic capacity of the network changes over time for a particular investment scenario. In this example, capacity improvements have not been prioritised, but it can be seen that capacity (red and blue bars) improve as a consequential benefit of renewals. A greater improvement could be expected if capacity improvements were prioritised during the optimisation.

Figure 12 compares the effect on level of service, in this case breaks, for different investment scenarios. The green bars show the minimum cost scenario, where it is predicated that the number of breaks will double over the next 30 years. The question is whether this deterioration in level of service is acceptable to the community.

Figure 10
Mix of expenditure

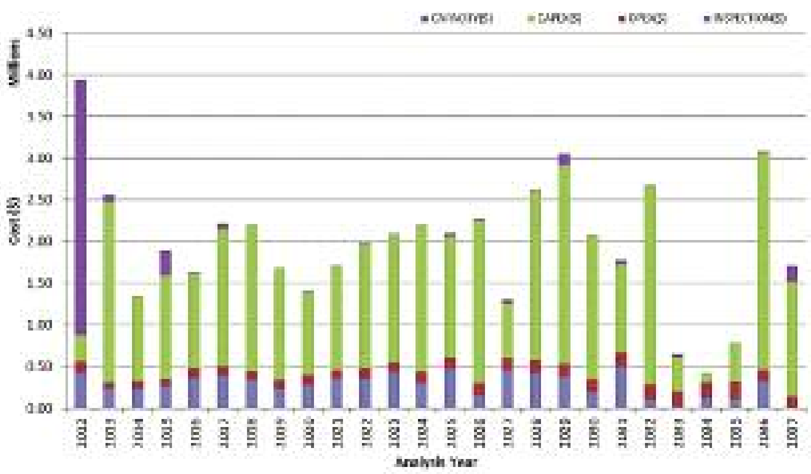


Figure 11
Change in hydraulic capacity

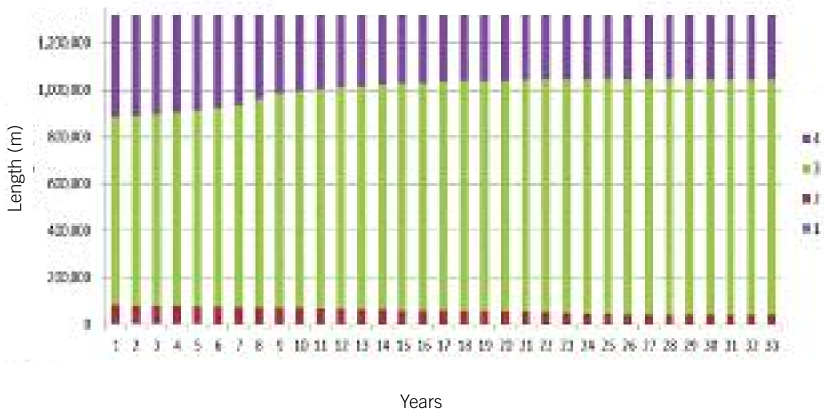
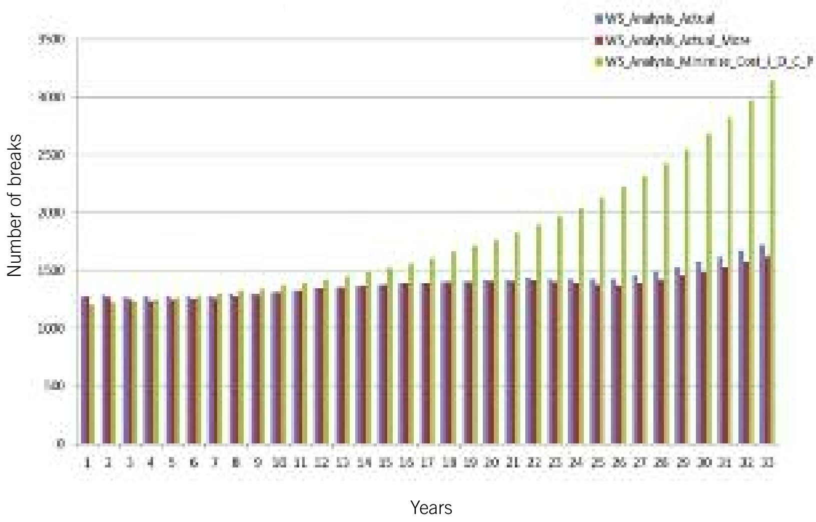


Figure 12
LOS for different investments



The blue bars show an investment profile designed to maintain the level of service at the current nominal level. The brown bars represent a 30% increase in expenditure. The analysis indicates that the increase in expenditure will have little effect on the number of breaks.

Conclusion

The decision support tool that is being trialled at Dunedin City Council helps organisations develop long-term strategies for the operation, maintenance and renewal of potable water, wastewater and stormwater pipeline assets. It:

- Identifies intervention strategies, determines the timing, frequency and treatment type to be implemented
- Optimises intervention strategies based on minimising lifecycle costs, minimising risks or maximising service levels. Interventions can be optimised for either one factor or a combination of these factors.
- Produces expenditure forecasts, works programmes and predictions of future condition, risk and service level profiles for various scenarios

By linking strategic long-term infrastructure investment scenarios to level of service outcomes, the decision support tool helps organisations implement advanced asset management practices. It allows network owners to better predict cashflow by using realistic renewal and replacement profiles that are not based on age alone. ●

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Management challenges facing dual water systems

Despite the large amount of research addressing technical issues of water reclamation, little has been published about management of infrastructure systems for water reclamation. Peter Rogers and Neil Grigg report on the outcomes of a recent Water Research Foundation study of systems that distribute non-potable water supplies and how utilities are confronting management challenges.

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Water providers are facing formidable challenges in providing customers with reliable, high quality, and affordable water supplies. Issues with ageing infrastructure, water scarcity, vulnerability of water supplies to climate change, and wastewater discharge standards are forcing utilities to re-examine their systems and look for new strategies to improve water management. One such strategy involves the use of reclaimed water through a dual distribution system in which the piping is separated into two independent networks. As shown in Figure 1, one network is used to convey potable water while the other conveys lesser-quality non-potable water. While the non-potable water can be raw or reclaimed (treated wastewater), most dual water systems distribute reclaimed water (Grigg, Rogers, and Edmiston, 2013).

In order for a system to be considered a dual system, the non-potable distribution network transporting the raw or reclaimed must exist alongside a potable network. If raw or reclaimed water is distributed directly to a user it is referred to as 'direct use of raw or reclaimed water' and is not considered to be a dual system (Grigg et al., 2013). Over time, if the direct use system is extended to service multiple users and the non-potable distribution line increases in coverage, then it is classified as an emerging system. An example of an emerging system is a system that was initiated to provide reclaimed water through a dedicated line to a recreational facility for landscape irrigation, but evolves into providing reclaimed water for other users and applications.

While the distinction between a direct use and emerging system may seem like a fine point, the distinction is significant in terms of the management scheme and issues associated with each. With direct use systems, because they were initiated for a specific purpose, the utility responsible is managing a limited scope project that was planned for. As such, it is better prepared to handle the public relations, regulatory, financial and infrastructure management issues. For emerging systems that evolved in response to evolving needs, the utility finds itself managing a complex dual system that was inherited. Under the scenario, all of the aforementioned issues become major obstacles to the successful operation of the system.

Trends in dual water systems

The use of dual systems to distribute treated sewage effluent (TSE) for non-potable applications such as landscape irrigation is not a new concept. In the US, the practice of dual water distribution has been evolving since the 1960s with the first publication on dual

The recycled water system at Santa Clara Valley Water District, California, US, where it is used for non-potable purposes such as irrigation. The purple colour denotes that the pipe is carrying recycled water. Credit: Santa Clara Valley Water District.

systems by Haney and Hamann in 1965. While there are hundreds of systems throughout the country, it was not until the recent Water Research Foundation study by Grigg et al. (2013), the results of which form the basis of this paper, that a retrospective assessment of the performance of dual water systems was performed.

The study included the development of a database of cases where dual systems have been implemented; the formulation of a protocol to identify claimed benefits, costs and risks; and the collection of quantitative and anecdotal data to assess performance. The criteria used for the performance assessment were derived from an extensive literature review, the development of 37 case studies, site visits, feedback from participants attending regional workshops, and the creation of a classification framework enabling comparisons of similar systems. The outcomes of the study (see box) included both the identification of the primary motivators behind the use of dual water systems and several emerging issues affecting their operation and management, including:

Motivators
- Dual systems are primarily used to extend water supplies and for wastewater management. They are not used to improve water quality.
- The non-potable portion of a dual system is used primarily for landscape and agricultural irrigation. There are some systems that provide water for other applications such as toilet flushing, industrial process water, power plant cooling, wetland nourishment, and groundwater recharge.

Emerging issues
- Dual system operation is largely influenced by regulatory barriers, which vary by state. Dual systems are also subject to local regulations such as city ordinances.
- Public understanding and acceptance are key factors in the success of a dual system. Utilities that actively engage the community in educational and informational campaigns often have successful systems.
- Dual systems are expensive both in terms of added infrastructure and operational costs. This explains why dual system coverage for residential customers is less common than coverage for commercial and industrial customers.
- Financing dual systems is challenging since many of the factors, such as extending water supplies, reducing wastewater discharges, deferring capital, and loss in potable system revenue relating to the true cost, are not fully understood or accounted for.
- Limitations in cost accounting lead to inadequate rate-setting systems for dual systems.

Whereas the conclusions regarding the motivators behind the uses of dual systems help explain the reasoning behind the implementation of dual systems, the emerging issues highlight the challenges facing water providers in managing these systems. Each of these management issues are discussed in the following section. In doing so, the authors provide examples from the case studies complied through the WaterRF and US EPA-sponsored study as well as offer solutions to each management issue.

Management challenges

Regulatory barriers

With no regulations regarding the use of water reuse at the federal level, water reuse providers must look to their state for guidance. At the state level, the creation of a reclaimed water policy is a work in progress for some states and non-existent in others. To date, 27 states have regulations regarding the use of reclaimed water, 17 states had some form of guidelines and design standards, and the remaining six have no specific regulations or guidelines (WateReuse, 2013). For states with no regulations, or as a technical reference for other states, the US EPA developed a publication entitled 'Guidelines for Water Reuse', which provides information regarding best practices for the use of reclaimed water. The first version was published in 1980, then updated and expanded in scope in 1992, 2004, and most recently in 2012. In addition to state regulations, water providers must also be aware of additional local regulations such as requirements from local environmental health agencies, which were reported in Grigg et al. (2013).

For the states with some level of reclaimed water policy, there is a lot of variance with regards to water quality standards and classifications, treatment type requirements, distribution system requirements, mandatory reclaimed water use requirements, governmental responsibilities, and state-wide reclaimed water use goals. Table 1 provides an example of the extent of variance among states with regard to water quality and treatment requirements for parks, playgrounds, and schoolyards among five states. These

Figure 1
Schematic of a dual water system (Grigg et al., 2013)

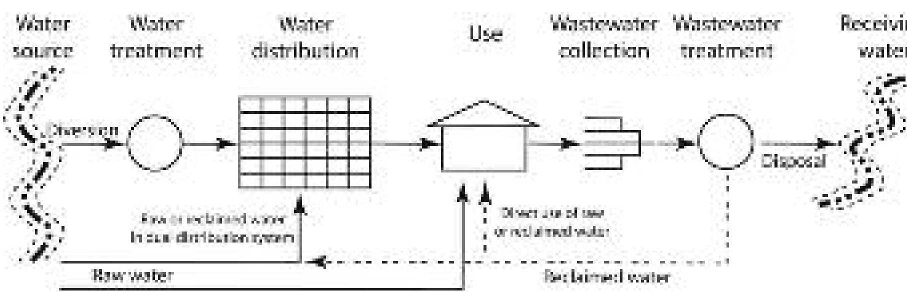

Table 1: Comparison of state reclaimed water requirements for landscape irrigation (Crook, 2007)

State	Water quality limits	Treatment requirements
California	1 total coli / 100ml 2 NTU turbidity	Secondary Filtration Disinfection
Colorado	126 *E. coli* / 100ml 3 NTU turbidity	Secondary Filtration Disinfection
Florida	No detectable faecal coli / 100ml	Secondary Filtration Disinfection
Nevada	2.2 faecal coli / 100ml	Secondary Disinfection
Texas	20 faecal coli / 100ml 2 NTU turbidity 5mg/l BOD	Not specified

states represent the top five in terms of volume of water reuse as reported in Edmiston, 2011.

The largest factor influencing the coverage and specificity of each state's regulation programme is how reclaimed water is viewed and the degree to which it is needed. In states in which reclaimed water is not viewed as a viable water source, water reuse regulations have often evolved with it being a disposal alternative to surface water discharge (WateReuse, 2013). Conversely, in states in which reclaimed water is regarded as a viable and needed water source, there are specific water quality standards, treatment type requirements, often some form of mandatory water reuse requirements, and possibly state-wide water reuse goals. For example, in California where reclaimed water is managed and regulated by the State Water Resources Control Board (SWRCB) and the Department of Health Services (DHS), the SWRCB has specific water reuse targets including an increase to 200,000 acre-foot per year (AFY) (246.7M.m^3 per year) by 2020 and an additional 300,000 AFY (370M.m^3 per year) by 2030 (Grigg et al., 2013).

As an example of the differences in reclaimed water classifications, in Arizona title 18 of the Arizona Administrative Code has provisions for five classifications of reclaimed water as a function of quality and permitted uses: A+, A, B+, B and C. The water quality measure of these classes is based on turbidity, type of disinfection and treatment, concentration of faecal coliform, nitrogen concentration, alternate treatment permitted, and other characteristics. Class A+ water is the highest quality and Class C the lowest. In the state of Texas, the Texas Administrative Code (Chapters 210, 217.39, and 321) designates two classes of reclaimed water, Type I and Type II, of which Type I is of higher quality since contact between this class of reclaimed water type and humans is more likely (TCEQ, 2013).

Water providers contemplating the use of dual water system as a tool for either extending water supplies or for wastewater management must determine whether the state- or local-level rules and regulations will encourage or impede the system. For example, in Arizona the use of a dual system for fire protection and toilet flushing requires using a minimum Class A reclaimed water, which is a very stringent classification (Edmiston, 2011). This is the reason why water providers often choose not to provide reclaimed water for indoor uses (commercial or residential). In the case of Livermore, CA, in spite of the state health department's rigid inspection and testing requirements, the City decided to continue using reclaimed water for indoor fire protection (Grigg et al., 2013).

As part of their recent study, Grigg et al. (2013) observed that several of the systems investigated in California reported that the state's current reclaimed water policy as complex and 'an impediment to increasing the use of recycled water' (BACWA, 2010). The Bay Area Clean Water Agencies (BACWA) Recycled Water Committee (2010) reported that 'the complexity of California's reclaimed policy is most likely the result of a policy which was developed through several iterations of a collaborative process involving representatives from public interest groups, water and wastewater agencies, state organizations, and industry associations' (BACWA, 2010). Despite issues with the state's policy, Grigg et al, (2013) observed that California is encouraging utilities to initialize or expand reclaimed water systems through state mandates. For example, the community of Santa Rosa is under a zero discharge requirement, which necessitates reuse and Redwood City uses reclaimed water for urinal flushing, internal cooling, towers, and other applications to meet the state's Reclaimed Water Use Ordinance. Similar mandates were reported in Florida, including the system in Eustis in which the city initiated a dual water system project with reclaimed water in order to meet the 'alternative water incentive' mandated by the local water management district (Edmiston, 2011). In another community in Florida, Winter Springs, the utility began expanding their reclaimed water system due to the St. Johns River Water Management District mandating a reduction in groundwater withdrawal (Edmiston, 2011).

This section highlighted several of the key differences in regulatory requirements among several states including water quality standards and classifications, governmental responsibilities, and state level reclaimed water use incentives. For communities considering the use of a secondary system to distribute wastewater, unfortunately there is not an easy solution since water reuse is certainly not a 'one size fits all' endeavour. Nonetheless, a thorough investigation of the management implications of their state and local government's rules and regulations will go a long way in helping the utility decide if the proposed benefits outweigh the regulatory barriers.

...public resistance to any project involving reclaimed water is largely related to fears about health and safety

Public understanding and acceptance

Public acceptance of reclaimed water has an enormous impact on the performance of a dual distribution system and its ability to meet the community's needs. In general terms, Grigg et al. (2013) observed that public resistance to any project involving reclaimed water is largely related to fears about health and safety. This observation coincides with a study by Po et al. (2003), which identified several factors that influence public perceptions of water reuse projects in the United States and other countries. These factors include the disgust or 'yuck' factor, perceptions of risk associated with using recycled water, the specific uses of recycled water, the sources of water to be recycled, the issue of choice, trust and knowledge, attitudes toward the environment, environmental justice issues, and the received cost of recycled water. For example, customers in New Haven, Australia rejected the use of recycled water for toilet flushing due to odour, colour, and even sediment (Po et al., 2003). In a separate study by Crook (2007) in which the author examined the degree of public support for using reclaimed water for various landscape irrigation applications, the author determined that public support for park irrigation ranged from 86-90% compared with 70 to 86% for playground or schoolyard irrigation. Grigg et al. (2103) identified several cases of public opposition to the use of reclaimed water. While several of the cases of public opposition were related to aforementioned 'yuck' factor, the authors identified other concerns such as concern over potential cross connections (flawed plumbing connections in which the reclaimed water supply is inadvertently connected to potable water supply), the spread of viruses, and the potential damage to plants. Regarding cross connections, in several of the 37 case studies developed by Grigg et al. (2013) the authors did identify cases in which cross connections had occurred. For example in Cary, NC the utility discovered four cross connections occurring at residences in 2007, and in San Antonio, TX there was a single case reported in 2002. Despite finding isolated cases of cross connections, Grigg et a. (2013) were unable to find (in either the literature review or case study investigations) any reports of related illnesses associated with the distribution of reclaimed water in the US. Aside from cases involving cross connections, other cases of public opposition included St. Petersburg, FL, which has the honour of being the first large urban reclaimed water system in the United States in 1977, in which public opposition stemmed primarily from concern about the spread of viruses and damage to plants. Concern over the spread of viruses was also a concern for the citizens of Redwood City, CA who objected to the use of recycled water in public areas where children play (Grigg et al., 2013).

Grigg et al. (2013) identified that a practical solution for a utility to gain public acceptance of a reclaimed water project is through public outreach and education campaigns. They observed that in communities in which the water provider educated the public about the safety record of reclaimed water and addressed the community-specific issues that merit its use, dual system projects have proven to be successful. For example, in Tampa, FL where residents were initially opposed to using reclaimed water, media reports highlighting the role of reclaimed water due to recent droughts helped stem the public resistance (Grigg et al., 2013). While the study identified several public outreach programmes with a limited educational scope, it also identified numerous utilities with robust public outreach efforts that went as far as to require prospective customers to complete training prior to connecting to the reclaimed water system. In the case of the Denver Water system, the utility is required by state law to offer reclaimed water customers with annual training to prevent drinking water contamination due to cross connections. The dual system in Cary, NC takes it a step further by requiring property owners to complete 'reclaimed water awareness training' as well as designate a site supervisor to oversee reclaimed water operations.

Findings of the dual water systems study

The outcomes of the study by Griggs et al (2013) revealed surprising results regarding management issues and motivations associated with implementing dual systems. It also pointed to the importance of emerging issues such as potable water safety, wastewater standards, water scarcity, and the economic incentives to provide water for designated urban uses. The study concluded that:

Governance and regulation
- Although dual systems are managed at the local level, they are subject to both local (such as city ordinances) and state regulations
- State and local government opinions on reclaimed water vary depending on how it is viewed and the degree to which it is needed. State laws can either promote or discourage its use.
- There is considerable variance among state governments regarding reclaimed water quality standards and classifications, governmental responsibilities, and use incentives. Communities considering the use of a secondary system to distribute wastewater must assess the management implications of their state's rules and regulations in deciding if benefits outweigh the regulatory barriers.

Public acceptance and culture
- Public outreach and education campaigns are critical in gaining public acceptance and participation in reclaimed water projects.
- Projects which empower its citizens to learn about the safety record of reclaimed water and the community-specific issues that a secondary system will address are more successful.

Finance, cost accounting, and rate setting
- Dual distribution systems require additional infrastructure, operation, and maintenance costs that rarely are financed by user charges alone.
- Cost accounting and rate-setting systems for reclaimed water distribution need additional development. Benefits from reducing wastewater discharges, deferring capital investments in developing treatment facilities and / or with developing new supplies, or in procuring dependable supplies need to be quantified in order to better understanding the true costs of dual systems.
- Reclaimed water rate structures and incentives vary greatly among utilities. Utilities with limited supplies tend to use increasing rate structures to limit the over-use of reclaimed water; others with ample supplies tend to use decreasing rate structures and incentives such as waiving fees and free hook-up kits to encourage its use.

Risk and sustainability
- Despite identifying associated cases in which reclaimed wastewater was inadvertently consumed through cross-connections, Grigg et al. (2013) was unable to identify any documented cases in the US of public health problems from the distribution of reclaimed water.
- The risk of reclaimed wastewater consumption has been minimized by a combination of governmental regulatory scrutiny and utility-led efforts in cross-connection and backflow testing programmes, reporting, and public outreach and education programmes.
- Dual systems can play a vital role in minimizing system risk to drought by providing a drought resistant and continuously available source.
- The long-term sustainability of a dual system is directly impacted by how well utility management plans for the inevitable drop in potable water revenues.
- The diversity and number of reclaimed water users can directly impact the risk and sustainability of dual systems.

Financing

Utilities seeking the benefits of reclaiming wastewater through dual distribution systems discover a variety of additional infrastructure, operation, and maintenance costs that make the investment of a second system very formidable. In Grigg et al. (2013), the authors observed that for systems located in highly urbanized areas, the high cost associated with installing a secondary pipeline often limited the utilities' ability to distribute reclaimed water. For example, in the case of the Marin Municipal Water District (MMWD), which provides water and wastewater service for 195,000 customers in south and central Marin County, CA, the highly urbanized surroundings limits the coverage of their dual system to 24 miles (38.4km). The utility has responded to this

Reclaimed water sign. Credit: Straight 8 Photography / Shutterstock.com.

limitation by looking for opportunities such as building renovations and new construction to connect more users to the existing system.

Another infrastructure-related expense associated with dual systems relates to providing additional seasonal storage for reclaimed water. Whereas demand for reclaimed water for landscape irrigation is high during the summer months, this demand lessens considerably during the winter months. Utilities looking to minimize wastewater discharges year round or perhaps store unwanted reclaimed water in the winter for use during the high peak summer months often invest in additional storage infrastructure. Grigg et al. (2013) found that storage was a major issue for several dual systems throughout the country, including the LOTT Alliance project in Washington State where there is significant reclaimed water available for reuse but the member utilities lack the necessary storage to utilize it. In the case of the dual system in Largo, FL the utility increased the system's combined storage capacity to 18MG (68.4ML) in order to minimize discharge to Tampa Bay.

In addition to the infrastructure-related costs, reclaimed water systems have unique maintenance and operation challenges that can also be expensive. Many of the 37 utilities selected as case studies reported significant expenditures with cross connection and backflow testing, added reporting, and public outreach and education programmes. For example, Cape Coral, FL reported that the reclaimed system requires more maintenance due to cross connection control, reporting leaks and spills, and field quality testing. In Dunedin, FL the utility's testing and outreach programme consists of annual testing and inspection of backflow prevention devices, inspection of the drinking and reclaimed water plumbing for each customer, and an educational programme which includes videos and brochures delivered door-to-door (Grigg et al., 2013). Redwood City, CA also has a very extensive public outreach and educational programme that provides free training sessions twice a year on the safe and proper use of recycled water as well as complementary one-on-one residential conservation consultations and site water use analysis.

The study concluded that the added capital, operating and maintenance costs associated with operating dual water systems can be very significant and difficult to finance from user charges alone. While the literature review and case studies performed by Grigg et al. (2013) did identify dual systems in communities such as Fukuoka City, Japan and Orlando, FL, which are financed solely through commodity charges, the majority of the utilities in the study reported that the reclaimed water portion of their dual systems were not profitable and required some form of subsidy. While the reported losses of non-potable systems were based on comparisons of direct cost to revenue charges, the study found that utilities often had not prepared rigorous accounts for their systems. Researchers observed that financial information was frequently obscured by data limitations and accounting inconsistencies. For example, while some utilities separate the potable, reclaimed water, and sewer systems costs, most grouped the sewer and reclaimed water costs as a single 'wastewater' cost. The study also identified several inconsistencies in how utilities report various types of costs such as operation and maintenance, debt from capital expenditures, and employee salaries. Grigg et al. (2013) also observed that most of the utilities used as case studies lacked a holistic view in assessing the true financial impacts of their dual system on their community's water portfolio. For example, benefits such as extending scarce water supplies, reducing wastewater discharges, and deferring or avoiding capital investments in treatment facilities should all be considered when assessing the financial impact of dual systems.

Cost accounting and rate setting

Accurate cost accounting requires utilities to look beyond the 'direct cost vs. commodity charge revenue' viewpoint when assessing the actual costs and savings associated with reclaiming wastewater through a dual water system. Savings associated with reducing wastewater discharges, deferring capital investments in developing treatment facilities, deferring costs associated with developing new supplies, and procuring dependable supplies in areas prone to drought need to be quantified and factor into the dual system cost accounting process (Grigg et al, 2013). For example, while the city of Olviedo, FL reports that the reclaimed system is costly, the cost accounting of the system does not attempt to quantify the benefit of providing the community with a much-needed additional water source required to meet demands without exceeding its cap on groundwater pumping. In the case of the East Bay Municipal Utility District (MUD) in northern California, increasing the use of reclaimed water has enabled the utility district to defer developing new supplies and the construction of an additional potable water reservoir. For the community of Yelm, WA, which is susceptible to drought due to its limited water supplies, the dual system has saved more than nine billion gallons (34.2 billion litres) of potable water per year by using reclaimed water primarily for irrigation. While both of these utilities have demonstrated benefits associated with dual systems, neither has attempted to quantify these benefits as part of their reclaimed water cost accounting.

The study by Grigg et al. (2013) identified a variety of rate structures for both the potable and reclaimed water components of the dual distribution systems. The most common rate structure for potable water is an increasing block rate, which encourages conservation by increasing unit price charges once consumption surpasses a specified threshold. For instance, Marin Municipal Water District (MMWD) uses an increasing rate block structure for both their potable and recycled water rates to encourage potable water conservation. MMWD's reclaimed water rates are set at a specified percentage (55%) of the potable water rate. This approach is very common for reclaimed water charges. However, some reclaimed water rates have the increasing block structure and may have fines from over-use of reclaimed water, such as in Dunedin, FL. In cases in which utilities want to encourage reclaimed water use, they can apply a decreasing block rate structure (decreasing unit price charges as use increases) while others use low reclaimed water rates. The dual system in Ocala, FL uses this approach by using reclaimed water rates that are only one-quarter the potable water rates. Other utilities offer services to customers to encourage use of reclaimed water. For example, the dual system in Largo, FL offers simplified processes for connecting to the reclaimed system, waiving fees, and free hook-up kits.

Risk and sustainability

Risk is a measure of exposure to threats and consequences. For any system distributing reclaimed water, the greatest risk is the potential public health consequences associated with inadvertent consumption through cross-connections. From a utility management perspective, there are two fundamental questions that must be addressed: what are the public health consequences associated with the consumption of reclaimed water, and what actions can be performed to minimize the potential threat? In addressing the potential health consequences, while the study by Grigg et al. (2013) did identify isolated cases of cross-connections, neither the literature review or case study investigations identified any major public health problems resulting from the consumption of reclaimed water in the US. Examples of cross-connection occurrences include the community of Cary, North Carolina, which reported that at least four cross-connections occurred in residences in 2007 and an incident at the Denver Zoo in 2006 during the construction of a dual system. In both cases, there were no reported illnesses for people or animals (Sanchez, 2006). In addressing the issue of how utility management can minimize the potential threat, Grigg et al. (2013) provided evidence showing that risk the US to cross-connections has been minimized by a combination of governmental regulatory scrutiny and utility-led efforts in cross-connection and backflow testing programmes, reporting, and public outreach and education programmes. For example, the City of Cary responded to the cross-connection incident in 2007 by upgrading their standard specifications and cross-connection details. Since then, Rick Jordan from the City reports that there have been no reported cross connections or associated illnesses in the community. In the case of Denver Water, the utility's proactive approach includes a backflow and cross connection programme, which includes annual inspections and testing as well as mandatory yearly training for all reclaimed water customers (Edmiston, 2011).

For communities susceptible to drought or with limited quantities of potable water, the use of reclaimed wastewater as an alternative supply can minimize system risk by providing a drought resistant and continuously available source. In the case of the state of Arizona, Clinton (2010) reports that the need for a drought proof water supply was the primary incentive for the state's push to utilize dual systems. Similarly, Parsons (2010) reported that public acceptance of reclaimed wastewater use in the state of Florida grew sharply following the droughts of 2000, 2001, and 2007. Grigg et al. (2013) identified numerous examples of communities which are utilizing reclaimed wastewater for drought protection, including seven communities in California alone (Burbank, Irvine Ranch, Livermore, San Diego, Redwood City, Santa Barbara, and Santa Rosa).

While the use of reclaimed wastewater as an alternative supply source might address the system-specific needs of the community, the study by Grigg et al. (2013) revealed that failing to consider the inevitable drop in potable water revenues can have a severe impact on the secondary system's sustainability. For communities in which the TSE portion of the system is operating at a profit, this may not be as much of a concern. However, as the study concluded, there are limited communities operating under this scenario. The potential drop in potable revenues can be especially challenging when water and wastewater are owned by different utilities. For example, in the case of the Central Contra Costa Sanitary District (CCCSD) which is a special district serving a 146 square mile (233.6km^2) area of central Contra Costa County California, over 77 percent of the district's reclaimed water customers get their potable water from local utilities. This situation required delicate negotiations between the CCCSD and the local water utility (Hermanowicz et al., 2000).

Another key factor acting the sustainability of dual system identified in the study by Grigg et al. (2013) relates to the type and diversity of the reclaimed water service. As an example, at the time of the investigation by Grigg et al. (2013), the community of Pittsburg, CA had a total of eight reclaimed water customers (two power plants, five city parks, and a golf course). In contrast to Pittsburg's limited customer base focusing on large-usage consumers, the community of Oviedo, FL has over 720 reclaimed water customers, most of which use reclaimed water for residential and commercial irrigation. Having a limited number of high usage customers makes the Pittsbug system riskier and less sustainable than the Oviedo system, which has a large user base. Another example of service diversity-based risk can be seen with the system in in Odessa, TX. Because Odessa's reclaimed system TX had a limited number of customers, when two industrial users decided to stop using reclaimed water, the total reclaimed water demand was cut by nearly 50% (Edmiston, 2011).

> *...benefits such as extending scarce water supplies, reducing wastewater discharges, and deferring or avoiding capital investments in treatment facilities should all be considered when assessing the financial impact of dual systems.*

Conclusions

For utilities facing the need to extend water supplies and / or improve the management of wastewater, the use of a secondary pipe network (dual system) to distribute reclaimed water can be an attractive solution. Like most things in life, these benefits come at a cost. So in assessing the feasibility of a dual system, each community must assess if the water supply and wastewater management benefits outweigh the regulatory, public acceptance, economic, sustainability and challenges.

Since no two water systems are alike, the specific management challenges and eventual solutions facing every water provider are unique. Nonetheless, the management challenges, case study examples, and solutions discussed in this paper provide a roadmap for navigating through the process. ●

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Lastly, we would like especially to thank Dr Daniel A Okun, who is now deceased but who inspired us to think more deeply about the possibilities of dual water systems.

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Condition assessment – what have we learnt? What can we still learn?

Breivoll Inspection Technologies has developed the inline tool PipeScanner for the inspection of the condition of medium diameter metallic pipes and has been used by several utilities in Scandinavia and the rest of Europe. Most notably, around 100 inspections have been carried out on the Oslo VAV network. Matthew Poulton, Arne Christian Vangdal, Lars Brenna, Martin Skjelvareid and Chetan Hathi summarise the most important findings from these inspections, what has been learnt and how the use of inspection data can be maximised.

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Many utilities are now adopting a pro-active – and even predictive – rather than reactive approach to water distribution pipeline rehabilitation, based on the statistical analysis of breaks and other risk-based or opportunistic decision criteria (Poulton et al. 2009a).

However, the majority of breaks are on small diameter pipes (<200mm) and for larger diameters, these techniques are generally less reliable. At the same time, the consequences of failure are generally larger for these pipes. Indeed, the direct and social costs associated with damage and disruption after a pipe break can be significant and it is highly desirable from an economic point-of-view to limit large main breaks to as few as possible. Therefore, other means of assessing pipe structural integrity need to be sought, even if they bring additional costs.

Condition assessment provides a useful tool for determining the actual condition of pipelines. There are a range of evasive and non-evasive techniques available on the market today (WRF 2013). Breivoll Inspection Technologies (BIT) has developed the PipeScanner for in-line inspection of drinking water pipelines using the patented Acoustic Resonance Technology (ART) (Vangdal et al. 2011). The technique can distinguish between sediments and rust nodules, and the remaining pipe wall thickness. The current version of the PipeScanner inspects metallic pipes between 250 and 400mm. Scanning is continuous for up to 750m in each direction from the point of insertion into the pipe and detailed thickness plots are produced as well as information on the size of rust nodules and degree of internal and external corrosion (Figure 1).

A detailed analysis of the results allows utilities to decide whether to replace or rehabilitate individual pipe segments, whole stretches of pipeline or whether such measures can be postponed if the pipeline is still in good condition. The proposed actions are based both on quantitative data (thickness measurements) and qualitative observations of anomalies and can be used to perform an economic analysis of rehabilitation needs. Deferring rehabilitation of a pipe in better-than-expected condition not only reduces the replacement costs, but results in lower social and environmental costs. It is important to consider the whole-life cost when making calculations in order to fully evaluate the benefit of inspection (Gaewski et al. 2007).

Oslo Water and Sewerage Works (VAV) supplies water to 680,000 people in the Oslo area through a 1550km long network of mainly metallic pipes. To counter network degradation, fulfil the European Union Drinking Water Directive and met new service levels, VAV has prepared a comprehensive Rehabilitation Plan for the period 2010-2020. The Plan comprises an investment of €200 million ($275 million) for the Plan period.

VAV has been using the Pipe Scanner since 2007 in order to develop a greater understanding of the condition and continuing deterioration of the water network and to make effective investments. About 25-26km (more than 7000 pipe segments of around 4m in length) have been inspected in approximately 100 separate inspections (Figure 2). The results from the PipeScanner are digitised in ArcGIS and stored in the geodatabase. They consist of information about residual pipe thickness, internal or external corrosion and the nature of the corrosion. VAV is by all accounts an advanced water utility with a comprehensive and state-of-the-art GIS and has been a key participant in many asset management-related research projects.

Although the length of inspected pipes is still below 2% of the network total, the large number of individual pipe segments and amount of data generated by each inspection means that a statistical analysis of inspections to-date can be performed. This paper will look at how the inspection data can be synthesised and what overall conclusions can be made. This is of use, both to prioritise further inspection planning, and also as a basis of developing corrosion models to more accurately estimate remaining life expectancy from a structural perspective. A simplified economic model based on the Oslo VAV example will also be presented to illustrate the cost / benefit of the inspection programme. The paper will conclude with a discussion on more recent developments involving the PipeScanner and subsequent treatment of condition data.

Method

The results from the PipeScanner can be analysed at the individual pipe segment level (each segment is generally 6m or less in length) or the overall pipe level (where a 'pipe' is the entity defined by the utility in its GIS or database and is generally between two manholes). For rehabilitation of small diameter pipes based on statistical analysis, it is more efficient to work at the 'series of connected pipes' level rather than replace individual pipes (Poulton et al. 2009b). However, for larger pipes where the condition is actually known from the inspection it may be more efficient to work at the pipe or even pipe segment level.

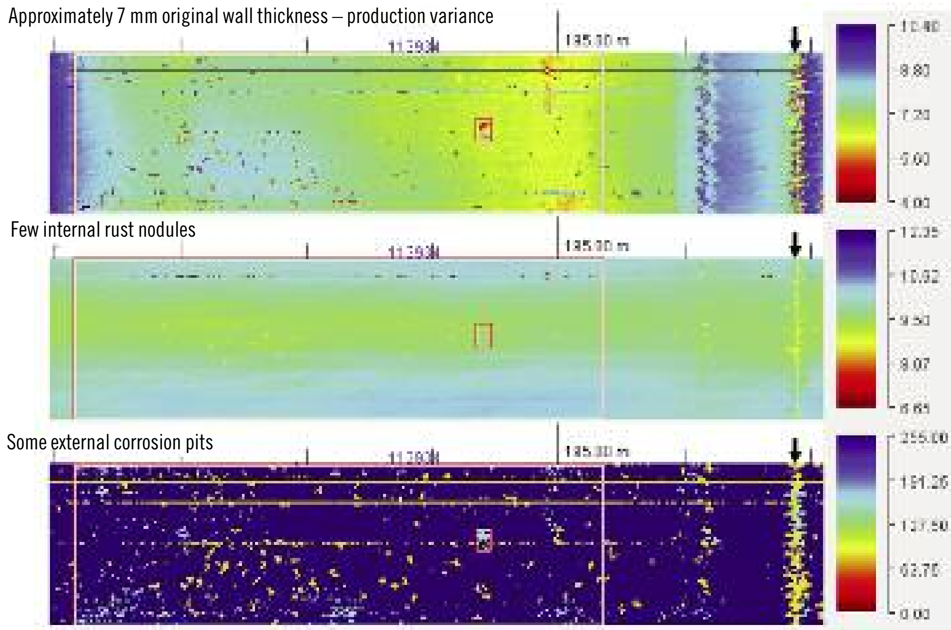


Figure 1
Examples of BIT PipeScanner plots. The plots represent thickness, distance (from centre of pipe) and pitting (light blue is external and yellow is internal)

Both quantitative and qualitative data are delivered from the PipeScanner via the state-of-the art PARS – Pipe Analysis Report System (Figure 3 and Tables 1 and 2).

Statistics can then be derived for each pipe, for example:

- Mean or X percentile median thickness value for all segments in pipe
- Minimum or mean minimum thickness value for all segments in pipe
- Total internal and external (when internal not also present) corrosion area for all segments in the pipe
- Number of each main anomaly type per km for all segments in the pipe

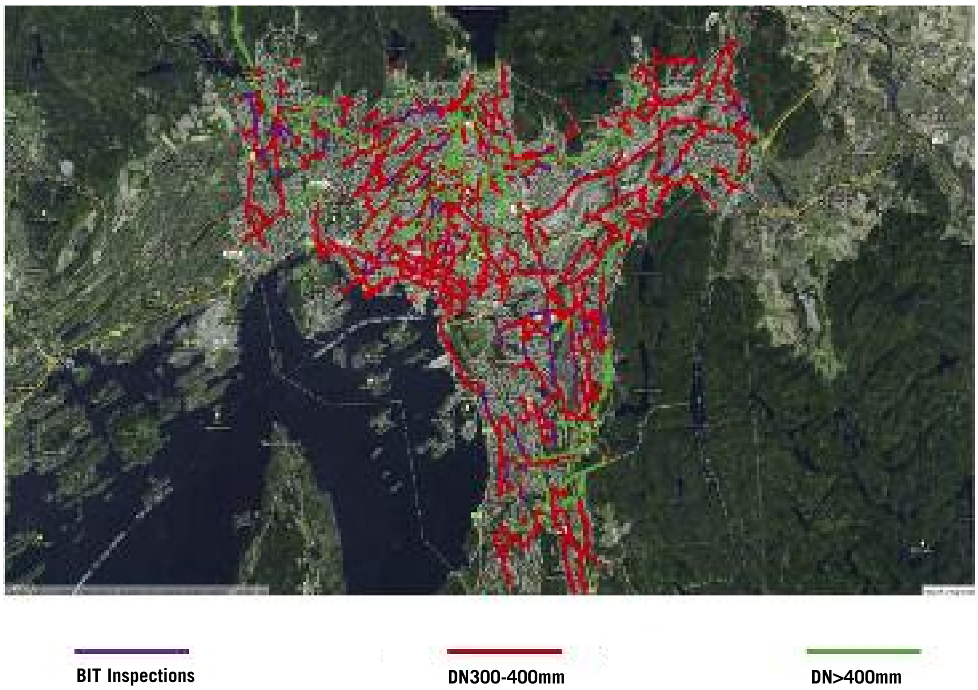
Once the data are summarised at pipe level, attempts can be made to correlate with other data from the GIS database, for example:

- Installation period
- Soil type
- Traffic type
- Other environmental or operational attributes

The economics of pipe inspection can be calculated by summarising the proposed actions from the various inspections. These include:

- Structural no-dig rehabilitation
- Point repair or rehabilitation
- Internal lining or coating
- 'Do nothing' (as the pipe is still in good condition)

Figure 2
The Oslo VAV network



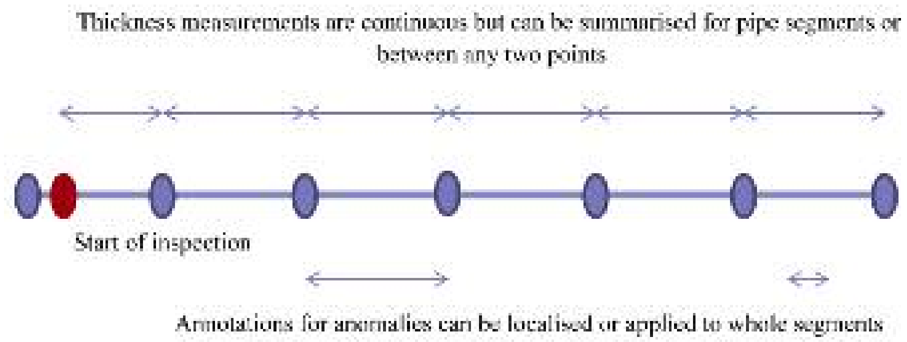


Figure 3
Inspection data

Clearly, the more pipes that fall under the last category, the greater the savings. Although the direct costs alone can result in savings, it is useful to consider the whole life cost and make allowances for social and environmental costs as well as the in-ground value.

General findings

There are a number of general findings from the data synthesis exercise.

The first is that there are often two or more different pipe types present in a single 'pipe' (the entity defined in the GIS database). This is evidenced by different pipe lengths (matching with different manufacturing standards) and / or clear differences in original thickness values, corrosion patterns and inner topography of the pipe. This simply means that several manufacturing companies supplied pipes at the time of installation. In some cases these segments might have been stored together and hence the distribution of pipe types is somewhat random. In other cases, the first part of a pipe might be all one type and a second type used when the first ran out.

Secondly, an inspection will often uncover information missing from maps or the GIS. This might include additional fittings and the discovery of undocumented repairs or misaligned pipes. The inspection might also point to incorrect asset information (e.g. a pipe believed to be cast iron is actually ductile iron or even plastic).

Thirdly, many pipe stretches demonstrate a high degree of heterogeneity with regards to condition – pipes in a generally poor condition will often have a number of segments in good condition and vice versa. Localised environmental conditions are likely to be crucial – for example external corrosion might be more prevalent on a section next to a leaky joint. Consequently, in some cases rehabilitation decisions might be made at the segment rather than pipe or stretch of pipes level.

Finally, for several pipe types, production variance (different original thickness values in the longitudinal or circumferential direction) is common. Allowances need to be made for this if attempts are made to model the corrosion.

Summary of anomaly observations

The data presented in this paper are from approximately 15km of the VAV inspections (corresponding to the data produced using PARS. The number of anomalies per km are presented for different installation periods (Table 3)). Whilst being far from a rigorous analysis, the results are interesting. An increase in internal corrosion with age is logical. Younger pipes exhibit more external corrosion though. This is probably linked to material (the most recent installation period is predominantly ductile iron rather than cast iron). Additionally, installation methods have changed (e.g. manual to machined backfill) and cheaper and poorer backfill material might have been used. This is also very apparent when looking at breaks in smaller pipes, with those installed after the Second World War generally breaking more than those laid before. Angular thickness variations decrease with installation period suggesting improved manufacturing techniques being introduced. Longitudinal thickness variations increase for newer generation pipes (ductile iron). Manufacturers confirm that even today they are not able to guarantee uniform thickness.

With further inspections it should be possible to break down the installation periods further, in line with the broad categories of pipe types defined by the utility. This information may be useful in prioritising pipes for inspection. Soil data is also available for Oslo VAV, but not at a resolution that can really be applied to individual pipe segments. Should more localised information ever be measured or collected then it would be worth analysing.

Synthesis of thickness measurements

Thickness statistics for 300mm cast iron pipes are presented for different installation periods (Table 4). The average thickness value is the mean value of all pipes inspected from each installation period. This value is in turn the mean value of all the median thickness values for each segment in the pipe. The minimum thickness value is the minimum value of all pipes inspected from each installation period. This value is in turn the minimum point from all segments in the pipe.

Very few pipes from the 19th

Table 1: Inspection data (quantitative) example

Pipe Id	Seg. Id	From Os.	To Pos.	Median Thickness	Minimum Thickness	Int. Corr. %	Ext. Corr. %
22522	3	11.1	14.8	14.3	12.9	9.1	0.1
22522	4	14.8	19.8	13.8	12.4	5.8	6.2
22522	5	19.8	24.7	13.7	12.3	3.8	1.3
22522	6	24.7	29.7	13.4	12.7	0.4	0
22522	7	29.7	34.7	13.4	12.6	1.4	0

Table 2: Inspection data (qualitative) example

Pipe Id	Seg. Id	From Os.	To Pos.	Anomaly	Class (1-4)*
22522	3	11.8	13.8	Internel corrosion area	2
22522	4	15.2	16.8	External corrosion	3
22522	5	19.8	21.1	Production variance	2
22522	6	19.8	24.7	Internel and external corrosion	2
22522	7	29.7	30.3	Angular shift at joint	1

***Class 4 = most severe – pipe should be replaced as a high priority**

century have been inspected but those that have tend to have a larger original thickness. This is consistent with the fact that many very old smaller diameter pipes are still in service and have yet to break. Nevertheless, the thinnest points of these pipes indicate a large percentage reduction in thickness. The youngest pipes have the lowest average thickness and the lowest average as a percentage of the assumed original thickness. This is consistent with break statistics for smaller diameter pipes. Loss in wall thickness because of poorer installation is a distinct possibility. Ductile iron pipes laid after 1964 are known to have an even lower wall thickness.

Again with further inspections, it should be possible to break down the installation periods further in line with the different generations of cast iron used by the utility. A more rigorous statistical analysis using, for example, the Linear Extension of the Yule Process (LEYP) (Renaud et al. 2012) is recommended. This would allow predictions of condition at the pipe level, though variations will occur at the pipe segment level variations. In effect, it would enable utilities to prioritise their inspection planning in a more effective manner. Condition data can be used as a covariate in a break prediction model (again using LEYP, for example). The problem is that attribute values are needed for each pipe and the number of inspected pipes (as opposed to pipe segments) is insufficient at the moment. If the condition covariate is derived from a corrosion model and not based on another covariate (e.g. installation period) then the problem can be overcome.

Table 3: Relationship between anomalies and installation periods

Installation period	Rust/Internal corrosion	External corrosion	Angular thickness variation	Longitudinal thickness variation	Inspection length (km)
1909-1938	208	117	66	10	6.9
1943-1959	129	92	51	4	3.9
1960-1979	98	160	4	63	3.9

Table 4: Relationship between thickness values and installation periods (300mm cast iron)

Installation period	Average thickness (mm)	Minimum thickness (mm)	Angular thickness % *	Minimum thickness % *	Inspection length (km)
1859-1888	14.8	9.7	97.2	63.8	0.3
1909-1938	12.8	9.0	96.6	76.1	4.2
1949-1964	12.4	9.4.8	98.0	73.3	3.7

*** As a percentage of the assumed original thickness (obtained from appropriate manufacturers' standards)**

Residual life expectancy

Improved estimation of the residual life expectancy, based on current condition and an improved corrosion model, is the next challenge. To complicate the task, corrosion rates are known to change over time. Generally, the rate decreases as corrosion products actually help prevent the pipe. Additionally, dynamic water quality and hydraulic conditions can affect the rate of corrosion.

Economic calculations

A cost model needs to be capable of quantifying the economic benefits of inspecting a pipe now, rather than either leaving it until it breaks or replacing it at a particular age or at a time determined in a more subjective manner. Economic calculations for Oslo VAV (direct costs only) are presented in Table 5. The rates apply to Oslo only, where costs tend to be higher than the rest of Norway (which in turn is more expensive than most other countries). Table 6 shows the savings from declaring pipes healthy after an inspection and from using point repair rather than replacing longer stretches. There are clear savings when inspection is performed prior to rehabilitation. The inspection costs are just 10% of the direct costs and the total cost of the recommendations is 33% of the cost of installing new pipes with open-trench technology.

For a more rigorous cost model, whole life costing needs to be adopted and both environmental and social (indirect) costs taken into consideration. Social costs include disruption to water supply, traffic and businesses, increased insurance premiums and costs relating to burst damages.

Estimations on social costs from various case studies vary considerably from around 25% of direct costs for certain no-dig techniques, to around 400% of direct costs (NRC, 2005). Although these costs are very subjective, a reasonable estimate (as a percentage of direct costs) should be possible based on certain key information, e.g.:

- Number of consumers affected
- Urban / rural area
- Road / pavement type
- Failure-related costs – the consequences of a large diameter pipe failure can be very significant and need to be factored into any calculations. The purpose of inspection should be to maximise the life of good assets whilst singling out weaker segments and reducing the number of such incidents.
- In-ground value – the value of ageing, yet structurally sound, buried infrastructure is underestimated (indeed for assets over 40 years, utilities currently consider the book value as zero in Norway). Based on the residual life (determined by inspection rather than using an average value for the particular cohort), the in-ground cost will be between zero and the full 'as new' value of a replacement pipe.

Table 5: Direct cost summary for Oslo VAV

Recommended action	% of Inspections	Length (km)	% of length	Cost /m (€)	Total cost (€)	Total cost * (€)
Structural rehabilitation (No-Dig)	33	8.0	35%	1300	10.4M	29.4M
Point rehab./repair	13	3.3	14%	154	0.5M	3.5M
Internal lining or coating	23	6.1	27%	520	3.1M	11.8M
No action needed in short or middle term	**24**	**4.6**	**20%**	**0**	**0**	**0**
No recommendations possible	*8*	*0.8*	*4%*	-	-	-
Total cost of BIT inspection	-	-	-	65	1.5M	
New pipes laid (with digging)	-	--	2080	-	47.4M	
Total cost of recommendations	**100**	**22.8**	**100%**	**-**	**15.5M**	**-**

*** If particular method was used on all pipes**

Table 6: Potential cost savings

Savings from declaring pipes healthy compared to other potential actions (€)	
Renewal by digging	9.6M
structural (NoDig)	6.0M
Lining / coating	2.4M
Savings from point repair comp. to other method (€)	
Renewal by digging	6.9M
structural (NoDig)	4.3M
Lining / coating	1.7M

- Environmental costs – these are of increasing importance as stricter regulations are introduced (e.g. CO2 emissions)

New and future developments

A new PipeScanner will shortly be produced, capable of inspecting larger diameter pipes (up to 600mm). Combination with other sensory devices such as leakage or water quality sensors is also being considered. The more information that can be gained, the more cost-effective the inspection becomes and the greater the benefit to the utility. The inspection results to-date can be used to validate new or improved corrosion models. In particular, 3D thickness profiles add significantly more information to a model or rehabilitation decision than using a few sample measurements. Visual representation of numeric data is also a useful tool and has been investigated (Figure 4). Each inspection can be viewed as a 'movie', showing both the internal topology and the thickness along the pipe (shown as a ring around the 3D plot).

Conclusions

In recent years, the number of inspections carried out by BIT using the ART PipeScanner has increased significantly. The large number of pipe segments inspected has allowed BIT to build on its knowledge database, providing a better understanding of certain patterns and their likely cause. There are now sufficient inspection data from the Oslo VAV network alone to begin statistical analysis of the condition data. This in turn is a step towards a corrosion model that is capable of using the high resolution data to make better predictions of residual life time. Initial basic statistical analysis shows that trends exist at the cohort level, but that each pipe is too heterogeneous to allow generalisations for rehabilitation planning. However, this information is useful in planning further inspections, with pipes from poorer condition cohorts generally being targeted for inspection first.

Trends in both thickness measurements and type of anomalies encountered are consistent with other experience and observations from statistical break analysis. These trends are sometimes counterintuitive but plausible explanations are offered.

The economic argument for inspection is presented based on the recommendations from previous inspections in Oslo. It is important for utilities to appreciate the in-ground value of their assets – a pipe that is over 100 years old but is still in good condition may be considered to have the same value as a brand new pipe. Inspection is most cost-effective when rehabilitation can be postponed or when relatively few pipe segments from a longer stretch of pipe need replacing. BIT is conscious of the importance of all data collected from an inspection, Add-on services besides thickness measurement (e.g. leakage detection) and improvements on how data are viewed and interpreted (e.g. 3D visualisations) are important developments. Further improvements will be researched and developed in parallel with an increased world-wide inspection programme.

From the utilities perspective, to achieve a sustainable rehabilitation it is imperative that the service criteria are defined, infrastructure data and supporting data are available in suitable quantity and are quality controlled, the decision support system is suitable for the analysis to be performed and the organisation possesses the necessary resources, expertise and authorisation to perform the work.

Oslo VAV is in the process of building the above foundation to prepare for future rehabilitation, maintenance and operation of its water network. ●

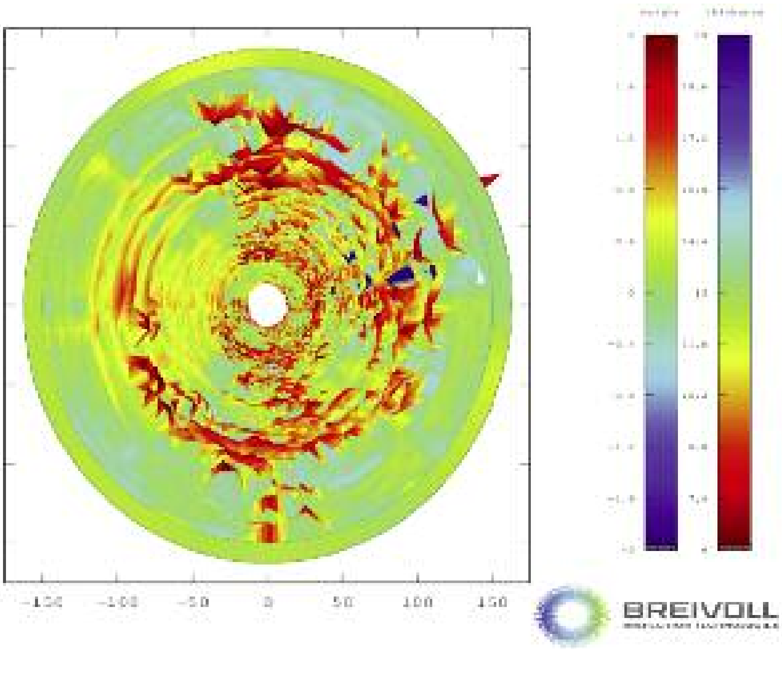


Figure 4
Example of a 3D thickness plot

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TThis paper was presented at LESAM 2013 – the IWA Leading-Edge Strategic Asset Management conference, held 10-12 September 2013 in Sydney, Australia.

Sydney Water's critical water main strategy and implementation - a quantitative, triple-bottom line approach to risk based asset management

A key challenge for Sydney Water is the proactive management of its critical water mains. To assist with this, Sydney Water and its consulting partner Sinclair Knight Merz have developed a quantitative risk-based approach for the management of critical water mains. Greg Kane, David Zhang, David Lynch and Michael Bendeli discuss the tool, which is used to support a multi-pronged risk treatment programme.

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Sydney Water is Australia's largest water utility, providing drinking water, wastewater services, recycled water and some stormwater services to over 4.6 million people in Sydney, the Illawarra and the Blue Mountains. Water is supplied through a network of over 21,000 kilometres of water pipes, across a 12,700km² area of operations. Sydney Water is a statutory state-owned corporation, with the Independent Pricing and Regulatory Tribunal (IPART) as the economic regulator.

Sydney Water manages its water main assets in two 'classes' – critical or non-critical, depending on the consequence of a failure. Critical water mains (CWMs) are defined generally as all water mains with a diameter of 300mm and above. Some smaller diameter water mains are also classified as CWMs due to their service and location characteristics – such as single feeds to large numbers of customers, single feeds to pressure reducing valve zones and pump-only systems, and mains in environments (natural and built) that will experience significant impacts should a pipe breakage occur. CWMs comprise approximately 4700km of water mains, many of which are old, large diameter cast iron mains with a relatively higher likelihood of failure. The different management approaches for critical and non-critical water mains is risk-based, as illustrated in Figure 1.

Non-critical water mains are generally of smaller diameter and have a lower impact when they fail. As such, Sydney Water employs a response-based maintenance strategy to manage non-critical water main failures, with renewals based on asset failure history. In contrast, CWMs pose a potentially high risk from the perspective of loss of water supply and other financial, social and environmental impacts. CWMs require a more proactive management approach based on risk assessment (the combination of likelihood of failure and the consequences of failure), including condition monitoring and performance measurement. However, little proactive maintenance and renewals had been conducted in the past, in part due to the lack of tools and quantitative data needed to justify programme expenditure.

To progress its proactive management of critical water mains, Sydney Water partnered with SKM to develop a targeted asset management strategy that integrates all relevant works programmes for critical water mains, as well as a number of tools and decision frameworks that Sydney Water use to implement the strategy and an asset management implementation plan. A key element of the project was the development of an asset management decision tool to quantitatively assess pipeline failure risk and assist in proactive maintenance programmes and renewal decision-making for individual CWM assets. This paper provides an overview of Sydney Water's quantified risk based tool, its effectiveness and future improvement areas.

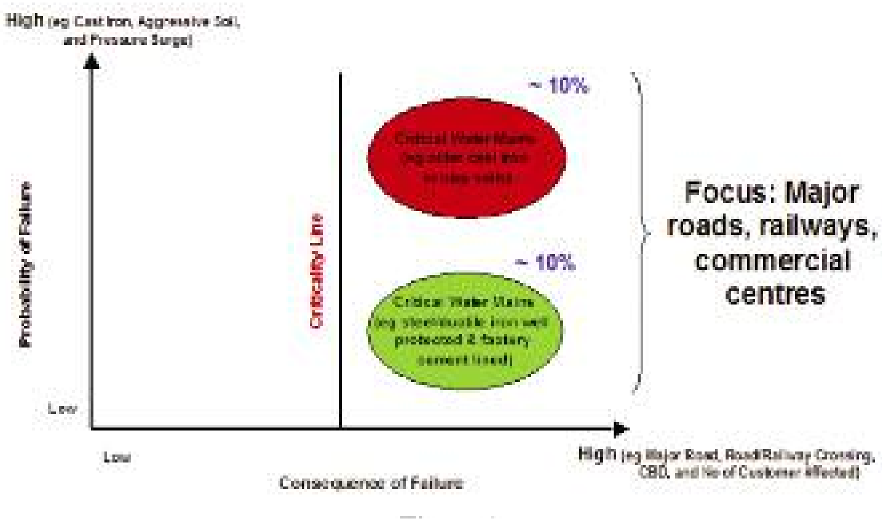


Figure 1
Management approaches for critical and non-critical water mains

Quantitative risk-based asset management tool

Utilities throughout the world face

Figure 2
Risk assessment component of the asset management tool

the challenge of determining the optimal timing for CWM renewal in order to balance risk exposure, customer satisfaction and limited funds. Asset management decision making is no longer a purely engineering decision, it is also an economic decision – requiring an understanding of economic cost-benefits when mitigating risks through either asset (renewal) or non-asset (system configurations, changing the operational regime or procedure) solutions.

Commercially available economic tools for water mains take a top-down approach based on broad conditions and statistical modelling of pipes at a cohort level. While this approach does provide an estimation of renewal expenditure, it does not provide any details of which specific CWMs are to be targeted for replacement or renewal. The quantitative risk-based asset management tool provides a powerful approach to prioritise CWMs by their risk profiles and to quantify risks in economic terms, using specific asset, condition and location data (linking with GIS data) to quantitatively determine the probability of failure and consequence of failure of each individual asset.

The risk tool quantitatively assesses the likelihood of failure of individual assets and calculates a range of economic and community impacts, measuring them in monetary terms. A high-level concept of the risk assessment component of the tool is shown in Figure 2. Detailed risk profiles – current year and future – are developed for individual CWMs as well as for mains and shutdown blocks (divisions of a pipeline that can be hydraulically isolated), on which some operations and maintenance activities are performed (e.g. contingency plans and valve exercising). As such, the tool enables timely intervention that reduces the number of CWM failures and hence reduces the loss of water, transport disruptions and impact to the environment (such as chlorinated water discharge and landslips).

The tool also takes into account cost-benefit considerations for the selection of risk mitigation measures to establish the most appropriate and cost effective response as a function of the CWM asset risk. As a result, the tool is able to both prioritise operations and maintenance work and to identify and justify future renewals projects – enabling Sydney Water to have a more efficient investment programme by better targeting intervention work.

As a consequence there is a more robust, transparent and defensible basis for investment in critical water mains to our Board, and in the pricing submission to our regulator, IPART. The tool also defines the relevant and targeted information that needs to be collected for economically efficient and effective decision-making (e.g. from contractors undertaking pipe condition assessment of CWM assets).

Likelihood of failure

The tool uses a hierarchy of values to quantitatively assess the likelihood of failure:

- Probability of failure estimated by using statistical analysis
- Probability of failure determined by the mains failure history
- Probability of failure determined by the condition assessments

While there are three possible measurements of probability of failure that are used in the tool, only one can be applied for the risk matrices. The default option is the probability of failure, calculated using the statistical analysis. Should a failure history P(f) be available, it will be applied in the tool in preference to the default P(f). Similarly, should condition assessment probability be available, it will be applied in the tool in preference to failure history P(f).

Desktop failure estimates

The default option is only used initially to prioritise the condition assessment works. The failure history and the results from condition assessment are then used in the later stages of the renewal decision-making process.

This approach is shown in 'The cost of customer preferences: the development of a pipeline asset risk management system – PARMS' report (CSIRO, 2002). The expected number of failures is a function of age, material, diameter, pressure, soil corrosiveness and length, and the annual probability of failure is estimated to follow a Weibull distribution. In determining likelihood of failure, it is important to understand the definition of failure associated with failure modes and various material types as these factors impact on the predicted likelihood of failure significantly. Commonly, a definition of failure can be defined as a certain percentage of the wall being corroded, the strength of the pipe no longer sustaining the stress, a through-wall corrosion, or there is a large patch or cluster of through-wall corrosion.

Condition assessments

During the past ten years Sydney Water has been actively working with consultancies, research institutes and other water agencies in Australia and overseas to investigate and develop various condition assessment techniques and industry capability. These techniques include direct pitting measurement, visual inspection, pressure monitoring, eddy current, remote field technology (intelligent pigging), linear polarisation resistance (LPR), finite element analysis, coating defect survey, Sahara technology, destructive testing and the external corrosion assessment tool (ECAT). Following on a series of trials of condition assessment techniques in 2005 a critical water main condition assessment programme has been developed.

To improve communication and understanding of the condition and performance of buried water mains between the condition assessment service providers and Sydney Water, a condition assessment technical specification was developed in 2009. This specification sets out Sydney Water's generic requirements for condition assessment of critical water mains made from mild steel, ductile iron, and cast iron. The condition of each pipeline is assessed using a two-stage approach; general inspection and detailed inspection.

For each stage, there is a need to develop a consistent approach based on an agreed methodology such as definition of failures based on maximum stress or full wall penetration or fracture mechanism theory. The information gathered is integrated into the quantitative risk tool for the use of assessing the condition and planning future work of Sydney Water's critical water mains system.

To further improve the understanding of likelihood of failure, Sydney Water initiated a collaborative research project in August 2011 on advanced condition assessment of critical pipe through working with international water research organisations, Australian water utilities and three Australian universities, and committed overall funding of $16 million (including $4 million cash) over five years. The Advanced Condition Assessment and Pipe Failure Prediction Project undertakes fundamental research in order to deliver practical outcomes to help water utilities manage critical water pipe assets effectively. The research is organised according to three Activities and these three research Activities are conducted at Monash University, University of Technology Sydney and the University of Newcastle respectively:

- Activity 1 – How, when and where will pipes fail within the entire network?
- Activity 2 – How do we assess the condition of the pipe cost effectively?
- Activity 3 – How do we calculate pipe deterioration rates accurately with respect to the pipe environment?

Failure history

Sydney Water's maintenance management system has captured over 13 years of maintenance history, permitting failure history data to be easily obtained from the maintenance system. Where failures have occurred, a likelihood of failure can be derived on the basis of the theoretical probability of failure and the actual failure history.

Consequence of failure

The consequence of failure is calculated in dollars by considering the triple-bottom-line impacts to Sydney Water, including costs of repairs, water loss, restoration, property damage and customer rebates, as well as the social impacts to the community, including water discontinuity, community disruption (e.g. traffic) and any environmental impact.

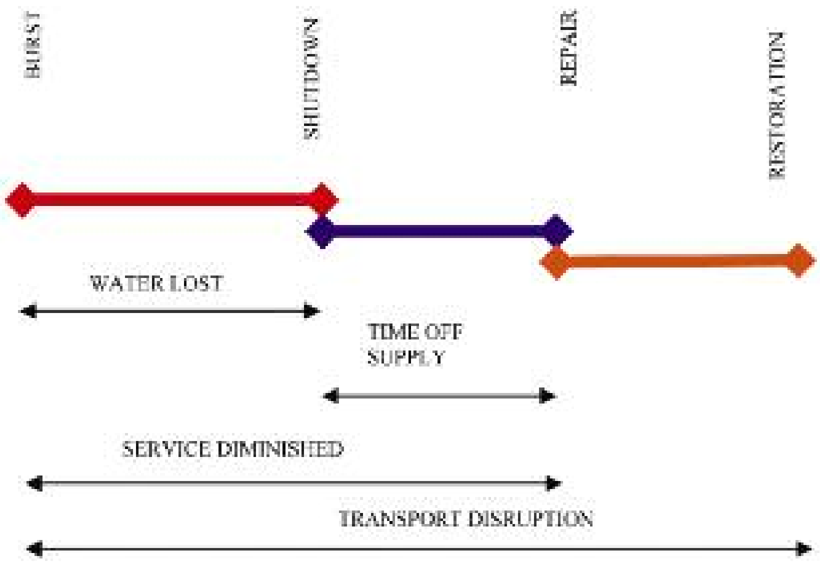


Figure 3 Duration of key intervals

Time of disruption estimates

A significant aspect in the calculation of failure impacts is to understand the duration of several key intervals from the time of a failure. These include:

- Burst to shutdown: This is the period from the failure of the main until its isolation.
- Shutdown to repair: The period from isolation until it is repaired and the water flows.
- Repair to restore: This is the period until restoration of the surface above the main, e.g. roads.

These different periods influence the calculation of a range of financial and social costs. For example, water loss is calculated from burst to shutdown, water discontinuity is calculated from burst to repair and the transport disruption period is calculated until the road surface is restored to the point that traffic flow can start. This is outlined in Figure 3.

The period of disruption is affected most by the physical location of the burst. It is generally accepted that the period to attend and repair the burst increases for more highly developed areas (e.g. the central business district). To calculate the period of disruption, geographical factors are included in the calculation to take into account increased shutdown and repair times in the central business district and equivalent areas.

Repair and restoration costs

Repair costs are calculated based on the analysis of Sydney Water's maintenance management system coupled with the general repair methods and with a geographic factor applied to repair costs. Restoration costs are also taken into account on a local government area basis as different councils have different policies on road restorations.

Loss of water

Loss of water is estimated using the multiplication of flow rate, loss factor, the duration of water loss and the value of water lost. The value of water can be calculated by using long run marginal cost or the cost of the next cheapest alternative source of water supply.

Water discontinuity costs

This is calculated using an estimate of the number of customers affected by the water discontinuity. The number

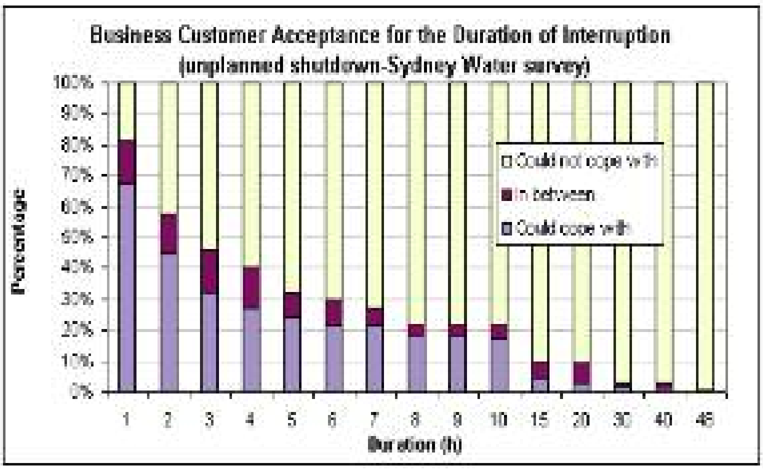


Figure 4 Business customer acceptance for the duration of interruption (unplanned shutdown – Sydney Water survey)

Table 1: Average hourly cost of delay

Category	Vehicles per day	Cost per hour of shutdown
Minor road	5000	$592
Major road - single	30,000	$7,735
Major road - dual	60,000	$23,833
Freeways	95,000	$73,487

of customers affected due to water discontinuity is initially sourced from operational experience. To accurately estimate the number of customers affected, water network system hydraulic modelling is required due to the complexity of the water network system configuration.

The calculation of social cost aims to value in monetary terms the inconvenience caused by a lack of water service. Like the transport disruption cost, the inconvenience suffered will be a function of a number of factors:

- Length of service interruption
- Time of day and day of week
- Availability of suitable substitutes
- Demographics of customers

In general, a short period of discontinuity of water supply is unlikely to cause significant disruption as bottled water can easily be obtained at a relatively minor cost. The social cost can effectively be estimated by looking at the direct cost of purchasing bottled water.

Figure 4 shows the business customer acceptance of unplanned water disruption at various durations. Survey results show that business customers have less tolerance than residential about the unplanned water discontinuity.

The current calculation is based on the time and cost of purchasing drinking water, with less emphasis on the inconvenience associated with the lack of potable water for other than drinking purposes. This is likely to be the most important driver of social cost for a longer period of discontinuity of water supply. The longer the outage the higher the inconvenience is likely to be. The supplementation of water supplies through a water tanker is not likely to significantly reduce the social cost as it is primarily associated with ensuring drinking water supply and not returning water service provision.

Table 2: Risk matrix

		Probability of failure	4	3	2	1
			above 20%	10.0% - 20%	5% - 10%	0% - 5%
Consequence	5	above $5.00M	0.0 km	0.0 km	12.8 km	88.4 km
	4	$2.00M - $5.00M	0.0 km	2.4 km	23.4 km	157.2 km
	3	$0.75M - $2.00M	19.2 km	20.7 km	70.9 km	383.8 km
	2	$0.35M - $0.75M	9.6 km	14.9 km	90.2 km	632.5 km
	1	$0 - $0.35M	84.6 km	191.5 km	442.2 km	2798.6 km

Transport disruption costs

When a critical water main breaks close to a major road, it has the potential to cause a significant interruption to the traffic and the local community. This occurs as the failure of the main and its repair causes the closure of part of, or the entire, road. To calculate the costs of traffic disruptions, an estimate of delay time and the value of time lost for various road users are required.

The economic cost of traffic disruption can be estimated by delay per impacted passenger multiplied by the value of time to calculate the economic cost. The delay time can be estimated with a good understanding of the following factors:

- Time of day when failure occurs
- Availability of alternative routes
- Provision of warnings (e.g. radio announcements) of delays
- Type of road and traffic volumes
- Flow-on impacts to other roads in vicinity especially as cars divert around a closure

The road types included in the tool are: minor road, single major road, dual major road and freeways. A spatial analysis has been carried out to identify the relationship (cross, carriageway, or road reserve) between water mains and various types of roads. For each road type, an estimation of the number of vehicles per day using the road can be obtained from the New South Wales Roads and Traffic Authority (RTA). If a water main breaks in the vicinity of a road, it will impact the local traffic. In many instances, delay time will be close to zero if traffic conditions are low and there are available alternative routes.

However delays are more likely to be higher during peak hour on main commuter routes where similar substitutes are not available. Duration of impact is the period in which road users are impacted as distinct from the period of repair and restoration. While road closures may occur, traffic will not continue to be impacted as drivers find alternative routes around the disruption. The duration of impact varies according to the road type. Based on traffic management statistical information, it is assumed that the maximum delay for a minor road, single major road, dual major road and freeway is between ten minutes to one hour. The value of time per vehicle is estimated at AUS$23 per hour, which is calculated using the RTA Economic Assessment Manual. The calculation of the average hourly impact is based on the assumption that there is equal probability that a main will fail in

Table 3: Management action plan for condition assessment and renewals

Risk level	Condition assessment	Renewal
Very High	Test, inspect or review immediately to assess the likelihhod of failure	Renew or replace within 2 years
High A	Conduct detailed condition assessment within 2 years to confirm likelihhod	Renew or replace within 5 years
High B	Conduct detailed condition assessment within 5 years to confirm likelihhod	Identify for renewal based on cost benefit analysis
Medium	Annual review of performance data and asset characteristic information and update of risk ranking	Identify for renewal based on cost benefit analysis

every hour of the day.

The cost for each hour of the day is based on assumed traffic level and weighted such that the maximum delay time coincides with the peak traffic periods. The calculation sheet is provided in the tool and the average hourly delay is shown in Table 1.

As the volume of water from the water main break have different impacts on the traffic and the community due to the size of water mains, a diameter factor has been applied to take into account the consequence cost for transport delay due to various sizes of water main.

Third party liability

When a critical water main breaks, it often has a significant impact on the local community, such as flooding of residential properties and impacting commercial activities. This is calculated using the multiplication of geographic location factor, size factor and average third party liability. Broadly, the third party liability cost is dominantly related to third party damages that are associated with flooding (or flooding induced commercial losses). Because of the complexity of this data, general insurance policy and its assessment, the tool currently assesses flood costs as part of 'Third Party Liability' cost, which uses average claim cost, severity factor and geographic location factor to assess the liability.

Risk profile

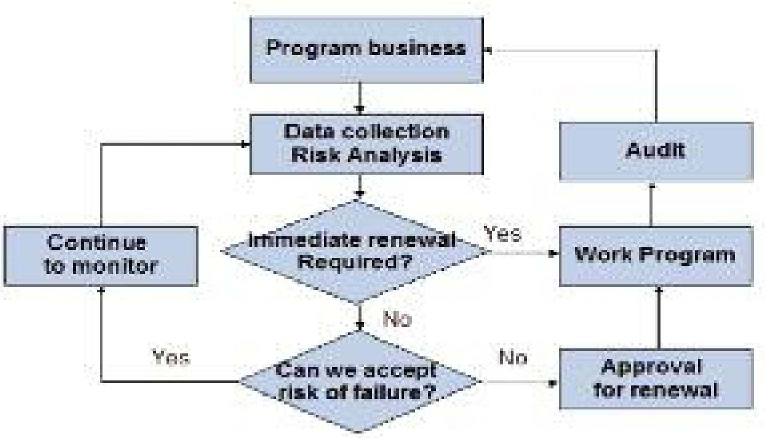
Based on the above quantitative calculations of likelihood of failure and consequence of failure, the risk of critical water mains failure is categorised in a risk matrix (Table 2). The risk categorisation is based on best available quantitative information from actual field condition assessment and cost data or best quantitative estimates by other means unless field data is unavailable.

The risk profile is updated regularly. This ensures recent failure history and condition assessment information is incorporated in the updated profile prior to finalising the annual condition assessment and renewal programme.

Critical water main management framework

Sydney Water currently applies the quantitative risk-based asset management tool in the critical water main replacement decision-making framework. The critical water main decision framework is a formal decision process that identifies, prioritises and recommends critical water mains for condition assessment and / or renewal based on a quantified risk level of the assets. The decision to renew is made where the main has an unacceptable risk ranking or where the economic risk cost is higher than the mitigation cost. Based on the current regulatory framework, operating licence, asset performance and the above risk profile, a high-level management action plan for condition assessment and renewals has been developed (see Table 3) – where a risk level of 'very high' could be considered as worthy of priority action, at least for condition assessment.

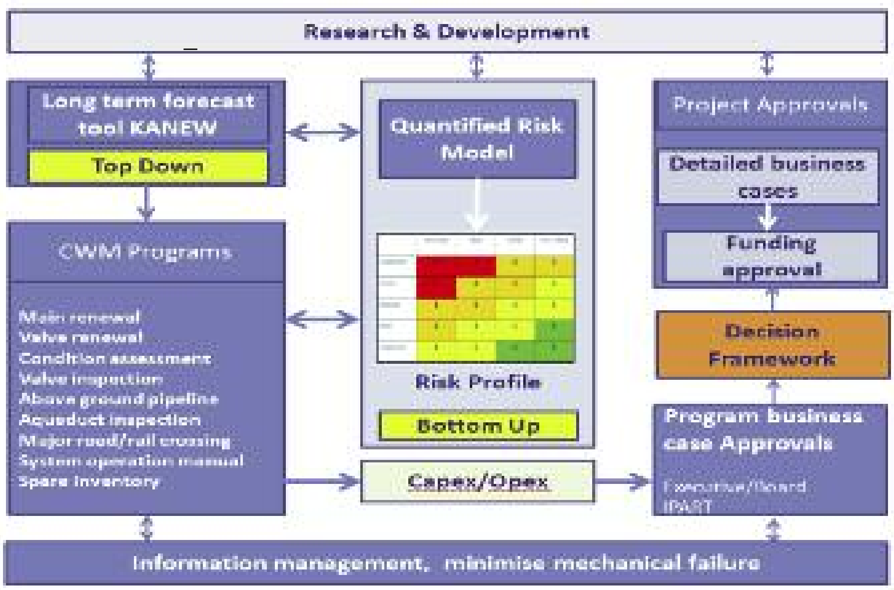
Figure 5
Risk mitigation decision flow



Risk mitigation may also include non-asset solutions (such as 'decommission') if hydraulic modelling reveals that the system reliability and redundancy are not compromised through reconfiguration of the system. This decision logic has been incorporated in business processes, and roles and responsibilities identified and assigned. This is summarised in Figure 5. Delegations have been identified for efficient implementation of the process in line with the decision logic. The process includes an initial risk assessment based on available information, prioritisation and progressive refinement of the risk assessment through condition assessments and analysis of failure history. Application of the process includes:

- Determine risk profile with available information. Prepare and gain approval for high-level programme business case based on the business' acceptance of risk levels. Development of the programme business case will be assisted by long-term capital forecast tool.
- Prepare and conduct condition assessment programme. This provides improved probability of failure information. Consider non-asset risk mitigation solutions
- Update risk profile and identify mains that fall in the risk categories which are unacceptable to Sydney Water and also mains where risk cost is greater than the cost to mitigate the risk and within the overall funds of the programme business case. Gain approval for individual projects in line with defined delegation.

Figure 6
Sydney Water business strategy



More broadly, the CWM strategy seeks to make informed decisions about CWM management by comparing risk costs with the net present value of relevant risk mitigation activities. Information from the quantitative risk-based asset management tool assists Sydney Water in the development of business cases for individual CWM projects and in the application of strategy business rules. The overall strategy incorporate a range of capital, operating and policy / procedural activities, including: asset renewals; condition assessments and data collection; valve inspection / exercising; minimising third party damage; operational procedure development (contingency plans and system operational manuals); and spare inventory management.

The strategy is centred around the quantitative risk-based asset management tool and supported by a long term forecast tool, information management and research & development in condition assessment technologies for buried pressurised pipelines. The overall strategy is summarised in Figure 6.

Conclusion

Sydney Water, partnering with SKM, has developed a quantitative risk-based strategy to manage Sydney Water's 4700km critical water mains. The strategy is able to demonstrate to its Board and the economic regulator consistent decisions that the expenditure programmes for the management of specific individual assets within this asset class are objective, transparent, economically efficient and sustainable. This is achieved through a clear strategy that uses leading edge economic management and decision tools linking outcomes and expenditure programmes with defined performance objectives.

The quantitative risk-based asset management tool explicitly takes into account a wide range of social, community and environmental factors in quantitatively assessing the consequence cost of failure (and therefore of asset risk) on a triple-bottom-line, monetised basis and within a least life-cycle cost framework. As such:

- CWMs at greatest risk (with the most significant potential customer and community impact on failure) are identified for targeted remedial action early ahead of actual failure
- Shutdown plans are designed to minimise the impacts if failure does occur
- These and various other initiatives (e.g. valve management) are designed to reduce the likelihood of failure and the frequency and extent of the impacts.

This translates into the following specific expected benefits:

- Less of an impact on customers through fewer service disruptions and water loss
- Less of an impact on the community through: less disruption to traffic (rail, road); less of an impact on other services; less damage to property, and increased security of supply to community services and critical customers
- Reduced impact on the environment through reduced water loss, less soil erosion including through landslip and less chlorinated water impacts in waterways

We recognise however that the use of quantitative estimates to value social disruption and community impact remains an imperfect science and so retain in the decision making process a final opportunity for assignment of a qualitative benefit value as part of the final estimation of benefit/cost. A number of opportunities have been identified for further improvement of the tool. These include improving condition assessment technique and process, better understanding of condition assessment results based on various failure definition and better quantification of water discontinuity costs for commercial and industrial customers, and better understanding of customer needs and value. ●

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Adapting Leading Practices and Associated Tools

SAM1R06I

Authors: Frank Godin, Jon Varner, Sharon Peters, Terry Brueck and Penny Brink

This research looked at four utilities with asset management programmes at various stages who implemented WERF strategic asset management decision support tools focusing on Levels of Service, Condition Assessment, Life Cycle Cost Projection, and Capital Project Validation and Prioritization. This study looks at the success of the implementation and lessons learned.

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Automatic Vacuum Flushing Technology for Combined Sewer Solids

INFR7SG09

Author: Qizhong (George) Guo

An extensive literature review on existing sewer sediment flushing technologies was conducted. The innovative vacuum flush system recently developed by the U.S. EPA was tested under laboratory conditions. The tests revealed a strong correlation between the strength of the flushing wave and the speed of the vacuum break. The original design did not succeed in providing a fast enough vacuum break despite being tested in different configurations. To improve the vacuum brake time, Rutgers developed two alternative mechanisms. These alternative designs showed promising results in the laboratory but remain to be tested under field conditions.

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