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This special issue of Water Asset Management International presents papers from the IWA Leading Edge conference on Strategic Asset Management (LESAM), held 27-30 September 2011 in Germany.

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Plastics federation attacks regulator for plastic pipe leak claims

The British Plastics Federation's plastic pipes group has criticised Ofwat, the economic regulator for water and sewerage services in England and Wales, for what it calls 'ill-advised and groundless' comments made about leakage problems with high density polyethylene (HDPE) pipes.

A spokesperson for Ofwat was quoted as saying to Sky News that HDPE pipes can begin to leak not long after they have been installed, 'because the same pressures that act on old pipes, still act on new pipes – namely movements in the earth and changes in temperature'.

However, Ofwat says that these remarks were taken out of context and that HDPE pipes were 'the best available option'.

A BPF spokesman is quoted as saying: 'It is well known that the water utilities companies operate variable jointing and installation standards and that this can compromise the performance of the system. A lack of training, correct tooling and supervision result in poor installation, which is susceptible to leakage.'

The gas industry uses the same HDPE pipes but does not have a comparable leakage problem, the BPF added.

In a statement to *WAMI*, Thames Water, the UK's largest water and wastewater utility, said: 'When we replace a section of pipe we sometimes have to connect it to an old section of pipe which creates an inherently weaker joint. We are constantly looking to improve our laying techniques to try and reduce leakage and have stringent conditions for our contractors to meet. We also continue to work with the manufacturers of the pipes to ensure we comply with their best-practice policy.' ●

Grant and loan funding agreed for sanitation improvements in Kiribati

Asian Development Bank (ADB) president Haruhiko Kuroda and Kiribati finance minister Tom Murdoch have signed grant and loan agreements worth a total $21.5 million for the South Tarawa sanitation improvement sector project. South Tarawa is the capital of the Republic of Kiribati on Tarawa Atoll in the Gilbert Islands in the Pacific Ocean.

ADB is providing a loan of $7.6 million from the Asian Development Fund (ADF) while the government of Australia is providing $14 million in grant co-financing for the project. Mr Kuroda said: 'ADB's assistance will help Kiribati efforts to meet Millennium Development Goal targets in improving access to sanitation, which will lead to better health outcomes. The project will support the country's efforts to improve the quality and coverage of sanitation services for South Tarawa's urban residents.'

The project is the largest water and sanitation sector activity to date to be supported by ADB in Kiribati. It will rehabilitate sewerage networks, help foster better hygiene and sanitation practices at the household level, and improve the performance of South Tarawa's public utility service provider.

As a low-lying atoll, South Tarawa is also highly vulnerable to climate change. The project will fund investments to rehabilitate saltwater flush systems, which will help to conserve and protect scarce groundwater resources from overuse and pollution. ●

EBRD provides funding for Serbian wastewater network extension

The European Bank for Reconstruction and Development (EBRD) is helping to improve the quality of water services in Serbia with an €11 million ($14.3 million) loan to expand water supply infrastructure in the city of Subotica, in the north of the country.

As an EU candidate country, adopting the EU Environmental policy is one of Serbia's key priorities, the bank said in a statement. It is estimated that bringing Serbia's water infrastructure sector up to EU standards will require investments of some €5.5 billion ($7.2 billion).

Although improvements have been made in the Subotica water sector, only 40% of the city's residents are connected to the sewerage system. The new investment will enable Subotica to extend its wastewater collection and sewage network.

The project will connect about 12,000 new customers to wastewater systems, extending the overall sewage coverage to close to 60% of the population. It will also help prevent the pollution of Palic lake, one of the top five tourist destinations in Serbia, which is just 8km to the east of Subotica.

The project is co-financed by grants from the European Western Balkans Joint Fund. The government of Austria has provided extra technical co-operation in preparing the project. ●

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EDITORIAL

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Japan agrees funding for Cambodia water supply expansion

The Japan International Cooperation Agency (JICA) has signed a loan agreement with Cambodia of up to Y7161 million ($89.7 million) to help with the Siem Reap water supply expansion project.

Siem Reap is the third largest city in Cambodia and the site of the world-famous Angkor Wat temple, which attracts significant numbers of tourists each year. The project aims to secure the water supply by expanding the current network.

The funds from the loan will be used for civil works and consulting services, JICA says. The civil war in Cambodia in the 1990s destroyed water supply facilities, which have since been improved although some areas, including Siem Reap, continue to experience issues, JICA explained in a statement. ●

High-level panel urges action on sewerage in India

An Indian parliamentary panel has asked the country's ministry of housing and urban poverty alleviation to act to complete sewerage and drainage projects under the Jawaharlal Nehru national urban renewal mission.

The panel noted that almost 50% of households in cities like Bangalore and Hyderabad do not have sewerage connections and just 21% of wastewater is treated.

A report from the panel warns that 4861 of 5161 cities in the country do not even have a partial sewerage network, and that sewerage systems in major cities such as Delhi are discharging untreated wastewater directly or indirectly into water bodies. ●

Donors pledge to ramp up water and sanitation access

Donors at a high-level meeting on water and sanitation for all called by UNICEF and the World Bank recently announced plans to greatly expand access to improved water and sanitation for millions over the next two years.

Ministers from developing countries also promised to provide tens of millions that already have access to improved drinking water sources with access to improved sanitation.

The meeting brought together ministers from 40 developing countries and donors including DFID (the UK Department of International Development), the government of Japan and the Bill and Melinda Gates Foundation who together committed to design innovative new projects, work with the private sector and non-governmental organisations, and extend access to improved drinking water sources and sanitation facilities to millions more ahead of 2015.

UK secretary of state for international development Andrew Mitchell announced that the UK, through DFID, would double the number it reached with aid in water, sanitation and hygiene education over the next two years from 30 million to 60 million globally by that date.

Dutch minister for European affairs and international cooperation, Ben Knapen, announced new cooperation between The Netherlands and the UK to bring water and sanitation to an additional 10 million people in nine countries, mainly fragile post-conflict states in west and central Africa.

The initiative will involve match funding for the Netherlands and UK contributions from UNICEF and recipient countries.

At the meeting, USAID administrator Rajiv Shah announced that that organisation will join the Sanitation and Water for All Partnership, and Australia's foreign minister Bob Carr also announced that Australia would also join the partnership. ●

Report highlights restrictions on WASH sector in Palestinian territories

An Emergency Water Sanitation and Hygiene Group (EWASH) report warns that Palestinians face severe restrictions in accessing adequate water and sanitation, and that Israel's policies and practices have hindered both the development of the WASH sector, geared towards long-term sustainability, and the delivery of humanitarian aid.

EWASH recommends that donor governments provide 'vigorous diplomatic support' to ensure unhindered implementation of interventions in communities in Area C of the West Bank and take active measures to prevent destruction of donor-funded infrastructure after the project has ended.

It adds that donor governments should also accept financial and political risks associated with property or project destruction, and that donor best practice should include systematically recording all damage and requesting compensation from the government of Israel on projects that are delayed or destroyed.

Among other recommendations the report also says that donor governments should support legal proceedings for water and sanitation infrastructure threatened by demolitions and stop work orders and protect aid workers from undue restrictions on movement and access. ●

Monterey water authority seeks input to water supply project

The Monterey Peninsula Regional Water Authority is seeking official party status ahead of the first public session on California American Water's proposed water supply project with the Monterey Peninsula Water Management District and the Monterey Regional Water Pollution Control Agency.

The proposed supply project aims to provide a replacement water source for local customers ahead of a state-legislated reduction in abstraction from the Carmel river that is due to come into force in 2016. The proposal is for a three-pronged approach that combines a desalination plant, aquifer storage and recovery and groundwater recharge.

The Monterey Authority argues in its submission that it has a duty to ensure the 'transparent and timely' development of a reliable water supply for the peninsula as well as governance that is directly accountable to the area's homes and businesses. ●

Technical innovations, models and tools for asset management

Asset management has been making important strides forward in recent years to become a core function of utilities, and in the water and wastewater industry this has developed to allow utilities to meet stringent quality and environmental standards and understand more thoroughly the potential risks of failure. Jeremy Lumbers outlines some of the developments and innovations in asset management.

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The recognition and establishment of asset management as a core business function in the water industry has developed over the last ten to 15 years. Now most utilities (e.g. electricity, water, gas) have positions such as Director of Asset Management, Director of Planning and Asset Management or Director of Assets.

These positions reflect the realisation that the optimal management of assets, both maintenance and operation, is essential to ensuring that target levels of service to customers are achieved at least cost. For privatised utilities, cost-effective asset management is an area where competitive advantage can be achieved.

The development of robust approaches to the optimal management of assets is particularly important for the water industry because of the unique combination of potential health hazards, plus the broader environmental and economic impacts of the failure of the water supply or wastewater services. Key water treatment facilities are now classified as site of national strategic importance.

The introduction of more stringent quality standards (both internationally and nationally) for the provision of water and wastewater services, and the protection of the environment, has demanded a greater understanding of the adequacy and reliability of water industry assets required to achieve the necessary performance for compliance.

There have been a number of institutional initiatives that have arisen from the need to develop more advanced approaches to asset management, in particular the IWA Strategic Asset Management Specialist Group and the Leading Edge Asset Management (LESAM) conferences.

This paper comprises a high level overview of some of the developments and innovations in asset management, and was written primarily to promote discussion at the IWA LESAM 2011 conference.

Drivers for innovation in asset management

Approaches to asset management have evolved in a variety of ways, reflecting the increasing demands for higher quality standards and the need to minimise price rises to customers through the optimal targeting of expenditure. There have a number of developments in the approach to asset management that can be summarised under the following headings.

From reactive to proactive

In the past, many companies have managed their assets purely in a reactive manner, i.e. repair or replace only after an asset has failed.

There is now general agreement that for many assets the total of cost of unplanned maintenance is greater than undertaking proactive maintenance. Hence, the balance between reactive and proactive maintenance should be optimised and managed, with regular updates to reflect actual experience.

The quantification of whole life costs enables analysis to be undertaken that takes account of the benefit of averting the costs of asset failures, and hence provides an economic basis for determining the appropriate balance between reactive and proactive. For the decision to be based entirely on economics, monetary values must be place on all aspects of customer service and the environmental costs and benefits – in general this is not feasible and future investment requirements are a combination of that justified on economic grounds alone, plus what is needed to maintain forecast levels of service at least cost.

It was the requirement of the UK Economic Regulator (Ofwat) that water companies demonstrate that they are able to determine the 'economic level' of capital maintenance that lead to the development of the UK Capital Maintenance Planning Common Framework (Figure 1), referred to as the 'Common Framework', (Lumbers and Kirby, (2003), UKWIR, (2002)).

From condition grades to asset observations

Understanding the deterioration of assets with age and level of usage is essential to modern asset management.

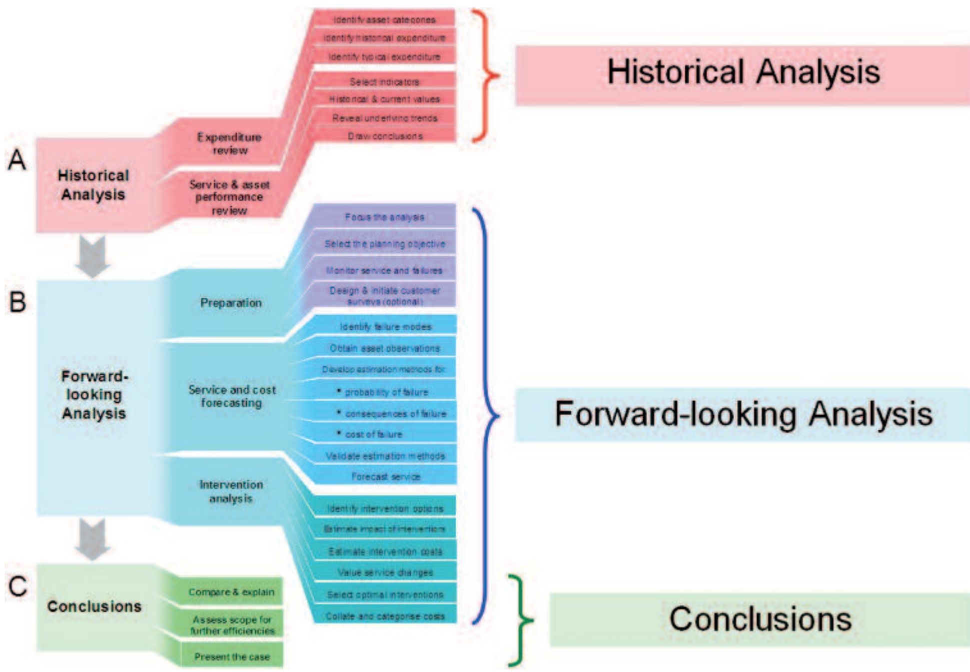

Figure 1 The UK Common Framework for Capital Maintenance Planning)

Traditional condition grading systems have tended to be over-simplistic and subjective, particularly when based on visual inspection only. Prior to the introduction of the 'Common Framework', condition grades combined with performance grades were used to justify asset replacement, e.g. all assets with the grade of combinations of 5-5, 4-5 and 5-4 would be assumed to be requiring replacement for budgetary purposes. This approach is no longer used in the UK.

The general concept of asset observations was introduced in the 'Common Framework'. These were defined as those measurements (observations) of performance or behaviour of an asset that can be associated firstly with an increased likelihood of asset failure and secondly the magnitude of the associated consequences. Observations can include any form of monitoring such as vibration detection, running temperature or noise, leaks, cracks, and reinforcement exposure, as well as other indirect measurements of asset or process performance. Statistical relationships are then developed to associate observations with likelihood and consequence of asset failure.

From backward-looking to forward-looking

Prior to recent developments in strategic asset management, the estimation of the required levels of future asset maintenance in the water industry has tended to be based solely on historical expenditure. It has been recognised now that this approach may have grossly over or under-estimated future requirements and takes no account of the age distribution of the assets, their current status, performance, rate of deterioration and the risk to customers of asset failures.

Forward-looking approaches are now based on an assessment of the current 'state' of the assets, predictions of future deterioration and the potential impact on levels of service. Predictive models of the performance of assets and the impact of their failure are identified from data wherever possible.

From qualitative to quantitative risk-based approaches

As in many areas of public and private decision making, asset management has developed to become more risk-based, recognising the uncertainties in data and modelling assumptions, including externalities such as climate change.

Although the use of risk analysis in the water industry in not new (Lumbers and Cook, 1993), the approaches used have developed from being predominantly 'qualitative' to being mostly 'quantitative'.

The requirements of risk-based approaches vary according to the perspective of the organisation. For example, a water company or authority may wish to understand the probability of meeting a specific level of customer service over a given time horizon, for a defined level of expenditure or asset maintenance activity, e.g. mains renewal or rehabilitation. By contrast, a regulator or government agency may be concerned that a company is 'gold plating its assets' at unnecessary cost to the customer or tax payer, i.e. reducing the risk to the organisation without proper justification.

This ability to assess the impact of uncertainty on forecasts of asset performance and customer service has become possible due to both the greater availability of data (both asset attributes and operating performance), together with the technology to collect and analyse these data, i.e. SCADA, telemetry and computing power.

It is now possible to run complex models and undertake advanced quantitative risk analysis, for example, to forecast the number of customers that might experience different periods of interruptions to their water supply at least once in a given time horizon, (Cook et al, 1999) (Figure 2). Such analysis provides a more meaningful measure of risk than the simple 5x5 risk matrix of probability and consequence that is still commonly used.

From a focus on asset performance to maintaining customer levels of service

Traditional approaches to asset management have been to focus primarily on the local performance of an asset and the cost of operation of the site. There remain water supply and wastewater operators whose objective is only to keep all installed plant operational and performing as designed, rather than considering the linkage to customer levels of service.

Such an approach can be challenged from two perspectives: first it takes no account of the criticality of the plant in the context of the system as a whole; and second it does not address the potential impact of asset failures on customers, the environment and the economic well-being of the company.

The aim in the UK since 2000 is to have service to customers as the central aim of asset management, and a regulatory requirement, (Ofwat, 2000).

From standard charges to cost-benefit analysis

In the UK there has been a move from standard charges for domestic water services based on property rateable value to increasing coverage of household meters.

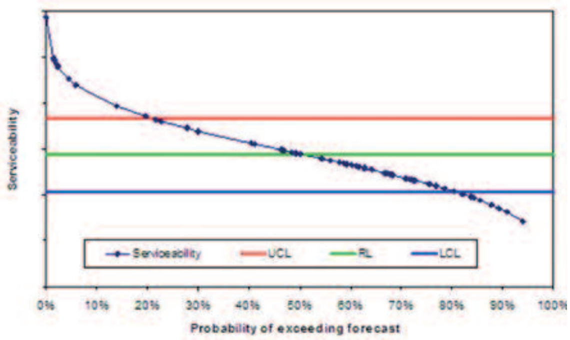

Figure 2
Probability of exceeding reference levels and control limits of serviceability

Greater engagement and consultation with customers has been encouraged by Ofwat, the economic regulator of water and sewerage services in England and Wales, in order to determine the 'willingness to pay' for different levels of service, where these are not governed by statutory obligations.

The maintenance of existing levels of service has been the 'starting position' for assessing the need for capital maintenance expenditure. Enhancements in existing levels of service are then justified by Cost-Benefit Analysis (CBA).

The use of CBA now includes consideration of social and environmental costs, such as traffic disruption, carbon and impacts on sites of special scientific interest.

From passive to active management

The term 'passive' is used here to describe asset management that does not involve online monitoring. In general the 'passive' options available for reducing the likelihood of asset failure are limited to the provision of static facilities, such as stand-by plant or overflows and bypasses.

'Active' asset management in contrast, implies real-time monitoring of assets and an associated capability, for example through remote control, to take operational actions to mitigate risk. Developments in monitoring and communication technology have made feasible the collection of real-time information on asset behaviour and / or performance, sometimes called 'condition-based' monitoring. Hence the 'active management' of assets can extend beyond the conventional decisions, such as replace or refurbish, to include operational actions that reduce the likelihood of failure or to mitigate the consequences.

Innovation in modelling

Data improvement

The advances in modelling for asset management planning have only been made possible by the greater availability and quality of asset data, which has been driven by the pressure for more cost-effective asset management to minimise increases in charges to customers. Companies have recognised the value of improving data quality to support asset management planning (Fynn, 2010).

Network data on water mains and sewers has become more available through a combination of pipe sampling, CCTV surveys and data collection following 'incidents' on the network. In addition the use of GIS systems has improved in many companies the ability to link for example reported bursts to pipes and the associated service consequences to customers. Arsénio et al, (2011) describe the use of CCTV to measure joint displacement in plastic pipes which appears to be linked to pipe failures (see page 30 of this issue).

Data on the age of pipes has been lacking for many of the older pipes still in use. Automatic analysis of historical maps has been used to estimate the initial installation data of sewers and water mains, assuming the pipes were laid at the time of the building development. Such analysis allocates the installation date of the pipes to the time period between the two maps when the development first appeared (Heywood et al, 2007).

Exploiting other sources of data, such as GIS and digital terrain data allows asset management to be prioritised to take account of the characteristics of the area served, such as the location of houses with cellars, sensitive customers (e.g. hospitals, nature reserves, etc.), the proximity of water courses and so on (Lumbers et al, 2009).

Standardisation of data collection protocols has been proposed. Heyen, (2011) describes the German DVGW Codes of Practice that cover the capturing and analysis of failure data on networks. In the UK a National Sewers and Water Failure Database (UKWIR, 2008) has been created to provide a resource for the water companies.

Beleza et al, (2011) describe the development of an integrated data management system to support asset management planning.

Modelling developments

Much focus has been given to the modelling of water mains and sewer networks to predict water main bursts and sewer collapse or blockage. There are fewer examples where the consequences of the failure event for customers and / or the environment have been included in the analysis, although this is a prerequisite for forecasting of the levels of service for alternative investment strategies. Recent work on modelling the impact of a pipe burst on surrounding areas is described by van Daal et al (2011).

The need for statistical models to take into account the left truncated and right censored is important for such long-life assets as water mains and sewers, where the historical behaviour of pipe lengths before the start of available data is unknown. Conversely, the behaviour of the assets for the time beyond the period covered by the data and until the eventual replacement of the pipe is also (obviously) unknown.

A further complication is that pipes may be replaced, relined or reinforced (i.e. duplicated) for reasons such as water quality, capacity (growth in demand) or security of supply. Hence good records of pipelines and the history of work undertaken on them is essential to the modelling of future investment requirements. The classification of water mains into 'cohorts' for analysis as recommended in UKWIR (2008) has been adopted by the UK water industry and regulators.

The lengths of mains in different cohorts must be considered in the identification of models – where lengths are too short the resulting models will not be robust. Data sharing has advantages for companies which can increase the total 'population' of data available for model calibration and validation.

Various statistical methods have been used to model mains bursts, such as Weibull: Herz, (1995), Poisson: Cox, (1984) and so on. Renaud et al, (2011) emphasise the need to recognise the possibility that a pipe may have been replaced prior to the period of data available (left truncation). It is equally important to have information regarding other maintenance activity, such as repairs and relining, which do not constitute replacement, but influence the likelihood of failure.

The use of survivor distributions such as Weibull to model repeatable failures may be questioned in that a repairable asset does not have a clear 'end of life'. The determination of 'end of life' can be based on the economic analysis of the cost of repairs versus the cost of main renewal. However, many workers have used models of the proportional hazard type e.g. Cox, (1972) calibrated against historical data. Le Gat et al, (2011) presents the results of three statistical methods based on survivor functions applied to the 'service life' of cast iron mains. In this work the definition of 'service life' appears to be related to the time of decommissioning of the pipe. Alternative definitions of 'service life' could be based on the economics of maintaining given levels of service.

Fuchs-Hanusch, (2011) similarly used a proportional hazard model to support the analysis of whole life costs for water mains. In line with forecasting levels of service over time, the objective was to estimate the number of failures in a given year rather than the cumulative sum over time.

It has been found by several researchers that there appears to be an increased probability of a mains burst on pipe lengths that have previously experienced bursts, over and above the predictions of models taking into account the particular pipe cohort and age. Unless and until the causal mechanism(s) for such conditional dependency is understood, it is appropriate to adjust the probabilities of failure (based on age, material, operation, etc.) for the unknown influence using a pipe-specific conditional probability adjustment.

The influence of errors in the condition classification on two modelling approaches is explored by Scheidegger and Maurer, (2011) using synthetically generated sewer condition grades. The modelling approaches evaluated were a Markov chain-based analysis and a cohort survivor function method. As observed by others, the Markov model is particularly sensitive to errors in the initial classification. Ward and Savić, (2011) describe the use of a multi-objective genetic algorithm to model sewer condition grades linked to a consequence criticality classification system. In both studies condition grades are used as a surrogate for the probability of failure, which appears to be focused only on collapse, rather than blockage.

Gabelli et al, (2011) report work related to modelling the consequences of sewer blockage and compare two strategies for collecting CCTV survey data. The sewers were classified according to diameter, material, slope and installation date, which were assumed to remain static over time for the purposes of the study.

The difficulty of using complex decision trees to include all relevant factors in determining sewer rehabilitation strategies is emphasised by Stein and Uhlenbroch, (2011) who used a Weibull distribution to model the transitions between condition grades in an analysis based on a semi-Markov process.

The use of the 'effective age' of a sewer (referred to as 'real age') rather than the calendar age is proposed by Syachrani et al, (2011). The so-called 'real age' was based on a combination of other attributes such as diameter, condition grade, 'sludge problem' and gradient, identified using principle component analysis. As observed in other studies (e.g. Heywood et al, 2007) the factors that influence the rate of

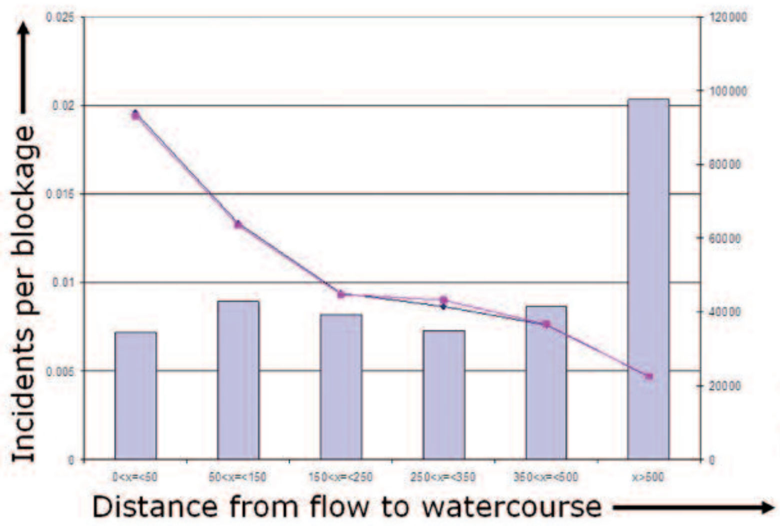

Figure 3
Modelled and observed pollution risk related to sewer blockages and distance to watercourse

sewer deterioration varying according to location, e.g. tree-lined streets are associated with sewer blockage.

Innovation in modelling tools

The following brief discussion addresses the general requirements for innovation in asset management modelling tools, rather than reviewing any of the software packages available.

The majority of modelling tools to date have been focused on sewers or water mains. The analysis tends to be restricted to specific aspects of the assessment of the frequency of failure and, to a lesser extent, combined with the consequences of asset failure.

The increasing focus on ensuring an overall level of service to customers requires modelling tools that can take into account all the assets needed to perform the 'end-to-end' business function, e.g. from the abstraction of untreated water through to the delivery of clean water in distribution systems. Whether a water quality problem or interruption to supply arises at source or at some stage within the system is of marginal interest to the consumer whose expectation is purely for a safe and reliable water supply. Understanding the relative importance of the different assets in the integrated water or wastewater system is therefore critically important for optimal asset management. The maintenance of customer levels of service at least cost requires risk and expenditure to be balanced objectively across the functional asset base.

Optimisation is a central requirement of asset management decision-support tools. Recognition of the combinatorial nature of the optimisation problem, often with dependencies between schemes together with constraints on resources, is an essential functional requirement of such decision-support systems.

Other, possibly unique, features of water industry decision making is the need to include changes to the asset base that are a requirement by growth in the catchment (i.e. increases in demand) or from the introduction of new quality standards. The timing and capacity of schemes required for reasons other than the deterioration of assets is a separate but linked optimisation problem. Capital maintenance should be planned taking into account known investments driven by other factors. The optimisation process should enable the selection of alternative 'growth' or 'quality' schemes alongside the requirements for capital maintenance.

There are inevitable uncertainties associated with the input data used in asset performance prediction models, in addition to the implicit assumptions of particular model algorithms. Recognition of the influence of such uncertainties and assumptions on the outputs of decision-support systems is an essential component of modelling tools through the application of generalised sensitivity analysis. The representation (and visualisation) of uncertainty and risk in the outputs of decision support systems is important for communicating with investors, management, regulators and customers alike.

Concluding remarks

The focus of modelling work to date appears to be related mainly to pipe networks. There are few examples reported regarding the modelling of other asset types such as above-ground installations – treatment works, pumping stations, reservoirs and so on.

Most reported deterioration models are based on survivor functions applied to repeatable failures such as pipe bursts, whereas theoretically such statistical functions were derived to predict the 'end of life'. The use of survivor function therefore depends on the definition of the end of life of an asset, and is as important as the attribution of the asset itself.

The increasing focus on levels of service to customers requires the integrated analysis of the water or wastewater systems as a whole to support optimal asset management planning, so that the risk of individual asset failures can be assessed and traded-off in a cost-effective manner.

There remains scope for innovation in:

- The modelling of asset deterioration and the resulting system performance
- The quantitative prediction of levels of service to customers
- The optimisation of investment in above and below ground assets using a formal 'systems analysis' approach. ●

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The role and importance of standardization of asset management

Sustainable asset management in the water industry in the face of aging infrastructure is an enormous challenge for the operators of facilities, and standardization is the means to help many small and medium-sized enterprises in developing and emerging countries build up their asset management capabilities to overcome this issue.

Horst Schlicht explains how through finding a common language and elaborating guidelines of general validity for organizational structure and processes, utilities of all sizes can gain benefit from the standardization of the requirements of sustainable asset management.

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The first question to ask is whether asset management can be standardized at all and what the aims of such standardization should be.

If we restrict the term 'asset management' to just financial asset management and banking it is hard to imagine that there are, or that there might be, any standardization approaches at all. Nevertheless, standardization might probably have been helpful in avoiding the outbreak of the financial crisis and also of the subsequent economic crisis at the end of last decade. It is, however, doubtful whether bank or hedge fund managers would have been prepared to be guided in their actions by standardization approaches.

Existing standardization

For material assets, and especially infrastructure assets with explicitly longer life cycles than financial assets, there have long been structured processes for the long-term conservation or inventory control of material assets. However, to date, standardization approaches have existed only to a limited extent and mainly at the national level. Leaving aside ancient systems, public water infrastructures were installed only 150 to 100 years ago. By the middle and the end of the last century water infrastructures were characterized by constant enlargement as a result of demographic growth and the continuous economic upswing. This is still true today for emerging and developing countries, whereas in Central Europe and especially in certain regions in Germany one is faced with the selective deterioration of water infrastructure due to demographic and economic developments. The planned maintenance of water infrastructure was put on the agenda only a few decades ago, and the wear and tear in newly built water supply facilities in developing countries in the last few decades shows that after construction the assets were neither operated in a qualified manner nor maintained with regards to sustainability. At the global level there are many approaches of different kinds towards planned maintenance of assets, i.e. rehabilitation of the water infrastructure. This subject has been under discussion since it was taken up by the IWA's Leading-Edge Strategic Asset Management (LESAM) conferences a few years ago.

Standardization objectives

Common terminology is still missing in this field, and practitioners still speak of strategic asset management (SAM), infrastructure asset management (IAM), technical asset management (TAM) and of asset management system standards (AMSS). In many cases, different terms are even used for the same activity.

In the drinking water sector the term 'rehabilitation' is used, which includes planned repair and renovation, by making use of the static function of existing pipelines and trenchless or open-trench replacement in a new pipe route, or by relining without making use of the static function of the old pipeline. In the wastewater sector, the term rehabilitation encompasses the repair, and renovation is using the old pipeline without recourse to its static function and the replacement of the pipe inside or outside the old trench. For this reason, the first and foremost task of standardization consists of the elaboration of a fixed terminology and standardized procedures.

Tasks of international standardization

Definition of a common language

Initial approaches to a common language can currently be found with the ISO. The ISO Project Committee (PC) 251 is elaborating three standards concerning the management of assets, which will published as ISO 55000, ISO 55001 and ISO 55002 in 2014. These standards will cover all types of assets, tangible and intangible, individual components or complex systems, with exclusion of financial assets and human assets.

ISO 55000 is to provide an overview of the field of asset management as a whole, to define the asset management terms and definitions and to describe the core principles of asset management. The essential elements are the description of the life cycle, the principles of good asset management and the interfaces between physical assets on the one hand and financial assets, information assets and the human and intangible assets on the other hand. It includes a description of the vertical integration and alignment of asset management, including the company's asset management policy at the top and the strategic, tactical and operative stages following behind. At this elevated level of standardization related to the overall utility it becomes clear that the standard will be dealing only with the basic asset management structures and processes.

Asset management systems – what to do?

ISO 55001 stipulates the requirements to be fulfilled by an asset management system (AMSS), i.e. 'what to do' for establishing, operating, evaluating and improving a management system for the management of assets, rather than stipulating 'how to do'. In accordance with the valid ISO philosophy, this series of standards will therefore fit in with a large number of other management system standards such as, for instance, the well-known ISO 9001 'quality management' or ISO 14001 'environmental management systems'. Besides describing the requirements for process and structural organization, an essential objective of these management system standards is to create a means for the certification of the structures in the respective companies. ISO 55002 is to provide guidelines on the application of ISO 55001 for a sector-independent asset management system, ISO 55001 states also that there are two different approaches, one for solving general / systemic tasks on 'what to do', which are covered in the ISO 55000 series, and the other solving asset-specific technical tasks on 'how to do', which should be covered by sector / asset specific standards.

The standards do not contain requirements or provide support for asset management in the water sector. The problems linked with the applicability of such management system standards become obvious when the differing sizes of water supply companies is considered. In Germany there are approximately 6000 drinking water supply companies of which only about 400 have a staff of more than 20. In the wastewater sector the situation is comparable. The usefulness of such an asset management standard will be restricted to a maximum of 5% of all water companies, as the company size will not permit organizational structures of this kind to be implemented. For big companies in the water sector with a large number of employees, however, such a structure is meaningful for operating a well-controlled asset management system. This leads us to the question whether asset management like risk management, environmental management and health and safety management could not be or even would not have to be part of an integrated quality management system in accordance with ISO 9001.

Technical guidelines – how to do?

But what kind of support can standardization offer for the many small drinking water and wastewater utilities? This can only be by way of concrete information about the required activities within the limits of asset management. For this case, quite a number of standards or guidelines already exist at the national and European levels without, however, referring to asset management in the title. Some of these standards will be discussed in subsequent reports. At the ISO level, working group WG6 'Asset Management' within the TC 224 'Service activities relating to drinking water supply systems and wastewater systems – quality criteria of the service and performance indicators' has been charged with the elaboration of the 'Guideline for the Infrastructure Asset Management (IAM) of drinking water and wastewater systems', where the intention is to combine best practice approaches for substance preservation from all over the world and to structure and formulate them as guidelines in a technical support document of general validity.

Technical tasks

Asset management includes the following technical tasks:

- Systematic inventory documentation
- Documentation and assessment of state
- Safest possible prognosis of state
- Comparison of actual state and state prognosis with the system require ments and / or the utility's services as defined or requested by the various stakeholders.

This includes the specifications of admissible values for:

- Drinking water or wastewater quality
- Quantities
- Pressure
- Failure frequencies
- Water losses (infiltrations and leakage)
- Service interruptions, blockages or flooding events

Standardization with regard to regulation

Cost-covering rates

The demands placed on the system and the utility services often constitute a further challenge to standardization. The EU Water Framework Directive requires the water industry to work with full cost recovery. This means that the rates charged for a sustainable drinking water supply and wastewater disposal must meet the costs. This is not the case everywhere in Europe and above all not in many emerging and developing countries. Due to the income situation in these countries it is often not possible to offer water services with full cost recovery.

Standardization requirements regarding regulation

In many countries the water market is regulated, i.e. the regulators do not only control the efficiency of the companies, but they also regulate the rates. In general, regulators do not implement measures to ensure that uniform standards regarding supply quality and sustainability are maintained, for their effectiveness is not assessed. If the cost of sustainable preservation of the water infrastructure is not approved by the regulators, the quality requirements of the drinking water and wastewater service cannot be fulfilled. This means that infrastructure will deteriorate, leading to an inability to meet users' needs and expectations as stated in ISO 24510.

From definition of quality standards to terms of reference for sustainable asset management

One of the tasks of standardization therefore consists of defining requirements of water supply and wastewater services and hence provide the regulators and / or Trade Commission with quality standards which have to be taken into account when fixing water rates. In Germany the first terms of reference have already been incorporated in some codes of practice and discussed in technical papers.

Since standards are on principle elaborated and passed by way of consensus, i.e. with the participation of all important stakeholders, the aim must be to establish consensually these quality requirements within in order to avoid being at the mercy of the political interests of particular parties e.g. public authorities.

Small and medium-sized enterprises (SMEs) should expect the following advantages from the application of standardization:

- To have access to a common language
- To apply best-practice procedures
- To achieve greater efficiency in business processes
- To gain credibility and the trust of the customers
- To gain a competitive edge

With standardization, it should be possible to reach these aims in connection with the management of assets. ●

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AM DIARY

A listing of upcoming asset management-related events and conferences. Send event details to WAMI for inclusion.

Water Reform: Customers, Competition & Conservation - The Impact of the White Paper and the Evolving Regulatory Landscape
4 July 2012, London, UK
Web: www.marketforce.eu.com

9th International Conference on Urban Drainage Modelling
4-7 September 2012, Belgrade, Serbia
Web: http://hikom.grf.bg.ac.rs/9UDM

IWA World Water Congress & Exhibition
16-21 September 2012, Busan, Korea
Email: 2012busan@iwahq.org
Web:www.iwa2012busan.org

9th International Symposium on Water Supply Technology 2012
20-22 November 2012, Yokohama, Japan
Web:http://www.jwrc-net.or.jp/aswin/en/symposium_archive/index.html

5th IWA International Conference on Benchmarking and Performance Assessment (Pi2013)
9-12 April 2013, Medellin, Colombia
Web: www.iwabenchmarking.com/pi2013

Asset Management for Enhancing Energy Efficiency in Water and Wastewater Systems
24-26 April 2013, Marbella, Spain
Web: http://iceam2013.es

3rd International IWA Conference on Water, Economics, Statistics and Finance
24-26 April 2013, Marbella, Spain
Web: http://iceam2013.es

7th International Conference on Sewer Processes and Networks
28-30 August 2013, Sheffield, UK
Web: www.shef.ac.uk/spn7

13th International Conference on Urban Drainage 2014
7-11 September 2014, Sarawak, Malaysian Borneo
Web: http://www.13icud2014.com

An integrated approach for infrastructure asset management of urban water systems

A paradigm shift is required towards managing urban water services in a more integrated and efficient way, which includes the use of advanced asset management in order to ensure high quality and adequate water supplies in the future. Here, Helena Alegre, Dídia Covas, Sérgio T Coelho, Maria do Céu Almeida and Maria Adriana Cardoso present the AWARE-P R&D project, which aims to produce adequate and effective support tools for assisting urban water utilities in decision making and rehabilitation planning.

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Infrastructure asset management (IAM) is increasingly becoming a key topic in the move towards compliance with performance requirements in water supply and wastewater systems.

Sustainable management of these systems should respond to the need for:

- Promoting adequate levels of service and strengthening long-term service reliability
- Improving the sustainable use of water and energy
- Managing service risk, taking into account users' needs and risk acceptance
- Extending service life of existing assets instead of building new, when feasible
- Upholding and phasing-in climate change adaptations
- Improving investment and operational efficiency of the organisation
- Justifying in a clear and straightforward manner the investment priorities

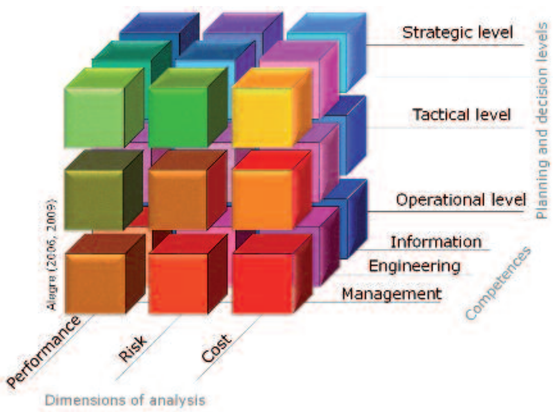
Effective decision making requires a comprehensive approach that ensures the desired performance at an acceptable risk level, taking into consideration the costs of building, operating, maintaining and disposing capital assets over their life cycles. Brown and Humphrey (2005) summarize these concepts by defining IAM as 'the art of balancing performance, cost and risk in the long-term'. IAM is most often approached based on partial views: e.g., for business managers and accountants, IAM means financial planning and the control of business risk exposure (Harlow and Young, 2001); for water engineers, IAM is focused on network analysis and design, master planning, construction, optimal operation and hydraulic reliability (Alegre and Almeida, 2009); for asset maintenance managers, the infrastructure is mostly an inventory of individual assets and IAM tends to be the sum of asset-by-asset plans, established based on condition and criticality assessment; and for many elected officials, since water infrastructures are mostly buried, low visibility assets, IAM tends to be driven by service coverage, quality and affordability in the short run. Common misconceptions include reducing IAM to a one-size-fits-all set of principles and solutions, mistaking it for a piece of software, substituting it for engineering technology, or believing that it can be altogether outsourced. In practical terms, many existing implementations tend to be biased by one or several of these perspectives.

The integrated IAM approach described in this paper aims to avoid the shortcomings inherent to those partial views. It is driven by the need to provide adequate levels of service and a sustainable service in the long-term. This approach is the result of work developed during AWARE-P – Advanced Water Asset Rehabilitation, an R&TD project aimed at producing adequate and effective support tools for assisting urban water utilities in decision making and rehabilitation planning (www.aware-p.org).

The AWARE-P methodology and associated tools incorporate the principles generally recommended and adopted in IAM by leading-edge research, consultant and utility organizations (Hughes, 2002; INGENIUM and IPWEA, 2006; Saegrov, 2005; Saegrov, 2006; Sneesby, 2010). It approaches IAM as a management process, based on PDCA (plan-do-check-act) principles and requiring full alignment between the strategic objectives and targets, and the actual priorities and actions implemented. It expressly takes into account that a networked infrastructure cannot be dealt with in the same way as other collections of physical assets – it has a dominant system behaviour (i.e., individual assets are not independent from one another), and as a whole it does not have a finite life – it cannot be replaced in its entirety, only piecemeal (Burns et al., 1999). The methodology allows for the assessment and comparison of intervention alternatives from the performance, cost and risk perspectives over the analysis horizon(s), taking into account the objectives and targets defined (Alegre and Covas, 2010; Almeida and Cardoso, 2010). In summary, the objective of the AWARE-P IAM approach is to assist water utilities in answering the following questions:

- Who are we at present, and what service do we deliver?
- What do we own in terms of infrastructures?
- Where do we want to be in the long-term?
- How do we get there?

Figure 1 The AWARE-P approach



Infrastructure asset management

The problem

Let us put ourselves in the position of a utility manager in charge of infrastructure planning and rehabilitation. The utility's executive board has defined 'Improving the sustainable use of water and energy while minimizing the carbon footprint' as one of the key corporate strategic objectives. This utility's networks display undesirable failure rates (pipe breaks and sewer collapses) and the energy bill for pumping is rather high; the water supply network has unflattering losses,

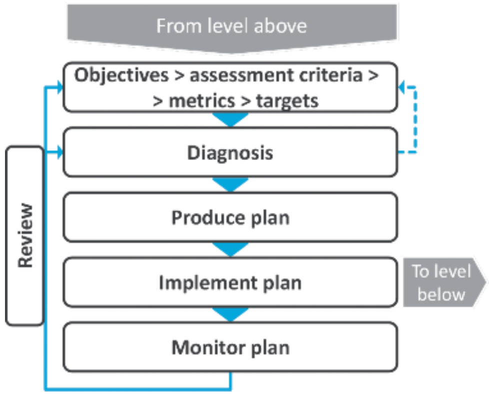


Figure 2
The planning process (at each planning level)

and localized pressure problems at peak consumption hours remain; there are floods or overflows from the waste-water network even under moderate rainfalls. The following questions are due:
- How would we act?
- How would we prove that our decisions are effectively addressing the strategic objective?
- How would we quantify the impact of our decisions and of subsequent actions?

Traditional AM practice
The traditional approach would probably be to start with an updated and reliable inventory of the existing assets by compiling as many reliable records as possible of their condition and failure history. Locations could try to be identified where there are pressure problems, flooding and overflows, and pump efficiency and energy consumption could also be looked at. The relative importance of each asset could also be assessed.

Combining these types of information, we would prioritize interventions within our budget constraints. This would contribute to the first question. What could be done about the other two? Fixing pumps and replacing some pipes or sewers will undoubtedly help save water and energy, but would that maximize the utility of the investment made? A discerning board might be less than satisfied, and the third question would still remain unanswered. They might ask some additional questions:
- How did we deal with the hydraulic problems? Were we able to allocate levels of service to each individual asset when dealing with pressures, water losses and floods?
- How did we select the sizes and materials of the new pipes and sewers?
- Did we assume that the existing networks configurations (e.g., layout and diameters of networks, location and characteristics of storage tanks and pumping stations) are adequate from the energy point of view?

These are the types of issues that the proposed approach is designed to tackle in a structured, aligned and transparent way. The following sections explain how.

The AWARE-P approach
The cube shown in Figure 1 symbolizes the AWARE-P approach. It advocates that IAM must be addressed at different planning decisional levels: a strategic level, driven by corporate and long-term views and aimed at establishing and communicating strategic priorities to staff and citizens; a tactical level, where the intermediate managers in charge of the infrastructures need to select what the best medium-term intervention solutions are; and an operational level, where the short-term actions are planned and implemented. It also draws attention to the need for standardised procedures to assess intervention alternatives in terms of performance, risk, and cost, over the analysis period. The other relevant message is that IAM requires three main pillars of competence: business management, engineering and information.

At each level of management and planning – strategic, tactical and operational – a structured loop (Figure 2) is proposed that comprises the following stages: definition of objectives and targets; diagnosis; plan production, including the identification, comparison and selection of alternative solutions; plan implementation; and monitoring and review. Most utilities already have several elements of this process in place. What is often missing is a review mechanism – a way to measure compliance with set goals – as well as an effective alignment between the different management levels.

Setting up objectives, assessment criteria, metrics and targets is a crucial stage in order to set up clear directions of action, as well as accountability of results through timely review. Clarifying the four distinct but sequential concepts:
- Objectives are the goals that the organization aims to achieve. The AWARE-P approach, in accordance with the ISO 24510:2007, 24511:2007, 24512:2007 and EN 752:2008 standards, demands that objectives are clear and concise, as well as ambitious, feasible and compatible, and take into account the ultimate goal for the utility of providing a sustainable service to society. For each objective it is recommended that key assessment criteria be specified.
- Criteria are points of view that allow for the assessment of the objectives. For each criterion, performance, risk and cost metrics must be selected in order for clear targets to be set, and for further monitoring of the results.
- Metrics are the specific parameters or functions used to quantitatively or qualitatively assess criteria; metrics can be indicators, indices or levels.
- Targets are the actual proposed values to be achieved for each metric within a given time frame (short-, medium- or long-term).

For instance: for an objective of environmental sustainability, one possible criterion could be water usage efficiency, measured through areal losses per service connection (l/conn./day) metric, for which a target of 100 l/conn./day might be chosen.

Assessment metrics are a key element of the whole process: they are used to establish targets, to set up a diagnosis, to compare and select alternative courses of action, and to monitor and review the process. They should be relevant, reliable, simple, and effectively measure success. The AWARE-P software offers a wide variety of metrics that the users can choose from, or define their own (Coelho and Vitorino, 2011). Objectives and targets are also a powerful means of communication within the organisation and with other stakeholders. For our utility example, Table 1 illustrates possible assessment criteria, metrics and targets that might be used for the strategic objective of improving the sustainable use of water and energy while minimizing the carbon footprint. Only performance indicators are shown, but risk and cost metrics might also be considered.

As illustrated in Figure 3, the process cascades through the decisional levels within the organisation's management structure. The global approach is based on PDCA principles, aiming at the continuous improvement of the IAM process. The key notions in this process are alignment, feedback, involvement and empowerment:
- Alignment among strategic, tactical and operational objectives and targets is paramount in ensuring that efforts and resources are not wasted in the long run. In other words, making the best out of limited resources cannot be achieved without smart alignment across the utility.
- Feedback is crucial because alignment cannot be assured through a top-down process alone. It is fundamental to have feedback mechanisms within each level, as well as between levels.
- People are the key element in this process. First of all, top management must be engaged in the shift of paradigm to an integrated IAM approach. It is equally important

Table 1 - Example of assessment criteria, metrics and targets

Strategic objective 1: 'Improving the sustainable use of water and energy while minimizing the carbon foot print'

Assessment metrics	Current situation	Targets In 5 years	Targets In 20 years
Criteria 1: Sustainable use of water			
Real losses per connection (l/connection/day)	250 (poor performance)	150	100
Wastewater reused (%)	0 (poor performance)	5	20
Criteria 2: Sustainable use of energy and minimization of carbon footprint			
Standardized energy consumption (kWh/m^3/100 m)	0.6 (fair performance)	0.40	0.40
Excessive energy per revenue water[1] (kWh/m^3 revenue water)	0.15 (poor performance)	0.10	0.05

[1] This represents the maximum theoretical potential of energy reduction per m^3 of revenue water (Duarte et al., 2009).

to ensure the involvement of the entire organization, from the CEO to the asset operators, and the empowerment of the staff, in order to promote leadership, co-ordination, collaboration, corporate culture acceptance, motivation, commitment and corporate know-how.

Quoting Plant (2008), the commitment to continuous improvement is not just needed during the production of the plan documents, but it is an on-going commitment of the organization to ensure strategic success.

Going back to above-mentioned example, the implementation of the AWARE-P approach would have required the board to be more specific, identifying how to assess success by means of metrics and targets over time (see example in Table 1) and providing some directions for action. These guidelines would have been useful in assisting the utility to establish its own tactical objectives and targets, carrying out diagnoses, devising and assessing alternative solutions and monitoring their impact, once implemented.

From problems to solutions

The previous section made the case for effective IAM and for the AWARE-P approach as an organizational and management process. However, it is equally a problem-driven process, guiding and assisting the utility decision makers in addressing the key infrastructure-related issues by carrying out diagnoses, assessing and comparing alternative solution paths, and selecting the best performance, risk and cost trade-offs in view of the stated objectives.

In order to decide where and how to act in an infrastructure, it is essential to carry out a sound diagnosis, in particular at the strategic and tactical levels of planning. This diagnosis should be grounded on the objectives, criteria, metrics and targets, as introduced in the previous section. These are established not only based on input from the level of planning above (or from the mission and vision, if at the strategic level), but also based on a preliminary assessment of the existing situation and on contributions resulting from the existing feedback mechanisms.

Diagnosis begins with the assessment of the existing system. This must be done not only for the present time but over the planning horizon (usually one year, 3-5 years or 15-20 years, for operational, tactical or strategic planning, respectively) and the analysis horizon (e.g., 20-40 years). The analysis horizon should be significantly longer than the planning horizon, to make sure that the implemented solutions adequately respond to expected changes. For instance, if the planning horizon at the tactical level is typically 3-5 years, the analysis horizon should not be less than 20 years.

In the AWARE-P approach, diagnosis should be carried out from the whole infrastructure to each individual asset. At the strategic level, the infrastructure is assessed as a whole, aiming at the identification of global, core problems. At the tactical level, and at a first stage, the infrastructure should be partitioned into smaller subsystems (e.g., trunk system, pressure zones or district metering areas in water systems; catchments or sub-catchments in wastewater or stormwater systems). At this stage, diagnosis aims at prioritizing such subsystems for intervention, by looking for areas with poor performance, areas containing black spots or areas with fair performance but higher priority due to external factors (e.g., coordination with road works or municipal rehabilitation). At a second stage of tactical planning, a more detailed analysis is carried out for each of the selected priority subsystems, by looking at components (e.g., condition, construction and maintenance costs, criticality) and their system behaviour (e.g., hydraulics, water quality, energy, operational conditions and costs).

The assessment of the existing system should be carried out using the established metrics for the above-mentioned three dimensions– performance (MP), cost (MC) and risk (MR) – and for different scenarios. Scenarios are defined as conditions not controlled by the utility, but which may influence the analysis and should therefore be considered (e.g., demographic or economic trends, regulatory changes). In this context, the existing system is assessed over time. From the comparison of assessment values with the set targets, it is possible to identify problems and to explore potential causes.

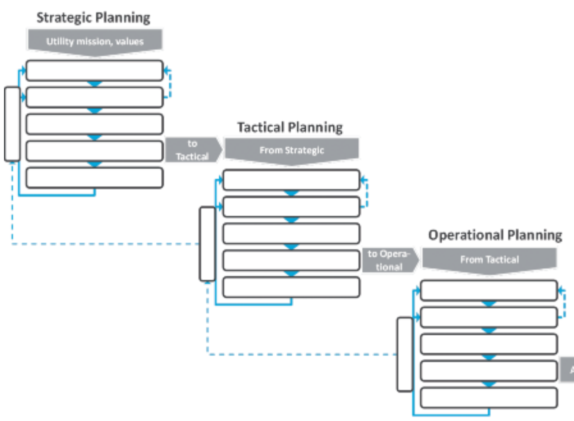
Once the diagnosis is carried out, alternative solutions (i.e., strategies, tactics or actions, according to the level of planning) can be identified. For instance, if the tactical objective was to reduce wastewater overflows, possible types of alternatives might be: (A0) keep the existing system, assuming the current O&M practices – this is termed the status quo alternative, often also called the base case; (A1) reduce infiltration and cross-connections; (A2) increase the internal storage capacity of the system; or (A3) change operational procedures.

The AWARE-P software provides tools for developing and analysing the alternatives (Coelho and Vitorino, 2011). Engineering solutions associated to each alternative must be specified (e.g., sewers to replace, CCTV inspections to carry out, O&M procedures).

One of the main innovations inherent to the AWARE-P approach is the realisation that the alternative solutions cannot be exclusively established based on the probability of failure of individual assets and that like-for-like replacement is not the only available option. System behaviour cannot be ignored:

- The cause of a problem and its associated symptoms often occur at different locations; therefore, levels

Figure 3
Alignment and feedback between planning (decision making) levels



of service cannot be directly associated to individual pipes or sewers.

- Most existing networks gradually expanded over the decades, in response to urban growth and needs. These rarely match the systems' long-term design assumptions, so consequently the vast majority of existing systems are some distance (often far) from their optimal configurations, both at present and for future needs and expectations.

For these reasons, the development of planning solutions should be firmly anchored on a system's view, looking at cost-efficient alternatives that globally make the best trade-offs between the required performance and the acceptable risk levels. This will often lead to evolving the system to a more rational or more ideal configuration – in view of the stated objectives – over the medium- and long-term, and / or changing O&M procedures to improve efficiency. Marques et al. (2011) show the application of these concepts to a real case, analysing system-driven solutions as well as like-for-like replacement solutions.

Alternative solutions should be assessed based on the same metrics, targets and scenarios previously used for the status quo case (Figure 4). Alternatives should be compared among each other and with the status quo, and the solution will be found among those that ensure the best trade-offs between performance, cost and risk. The AWARE-P software (Coelho and Vitorino, 2011) provides performance, risk and cost assessment tools (Almeida et al., 2011). It also offers features for simplified multi-criteria comparison and ranking of alternatives, as well as for more sophisticated multi-criteria analysis for sorting and ranking (Carriço et al., 2011).

The previous section already provided an insight on the topic of performance assessment. As regards cost assessment, the AWARE-P software will contain a feature (under development) to assess the net present value of each alternative, including investment, operating cost and operating revenue occurring in the period of analysis of the plan. The current version considers neither intangible costs nor external costs, assuming that these are taken into consideration under either the risk or the performance perspective. With regard to risk, the current AWARE-P materials are based on a qualitative approach (Almeida et al., 2011). The software contains features to assess both the probability of failure for the cases of pipe breaks and sewer collapses, and the corresponding consequence.

When the alternatives are selected (i.e., strategies, tactics or actions), the plans can be produced. A plan should be a short and clear document, avoiding repetition of other references. The geographical, temporal and thematic scope of the plan should be specified, as well as objectives and targets for short, medium and long-term. The plan should contain a summary of the diagnosis and of selected alternative solutions. It should specify the procedures (tasks and responsibilities), the scheduling of the intervention, the financial plan, and the monitoring and revision frequency.

Tactical plans are the most complex documents among the three levels of planning, often needing support from external consultants. The diagnosis and the formulation and analysis of alternatives require the use of engineering expertise, greatly corresponding to an evolution of the most traditional master plans. However, it is important to note that not only infrastructural alternatives should be considered, but also operations and maintenance or other non-infrastructural measures (e.g., demand management, geographic information system improvement) should also be considered, if relevant.

Back to the problem – what would have been done differently using the AWARE-P approach? Firstly, the utility would have clarified its understanding of corporate vision, objectives, targets and strategies, and kept them as its long-term direction. Based on those, and on its knowledge of the infrastructure and its performance, it would have defined its own tactical objectives and targets. The data it would have gathered in the traditional AM approach would be just as relevant here. However, the specific information really needed to support the decisions would probably have been clearer.

Since the utility would start with a global, bird's eye view of its systems, followed by a subsystem-level evaluation, before an asset-by-asset analysis, it would have a clearer diagnosis and would have been driven to alternative designs that are globally more effective. It might have also found out that the present layout and diameters are far from optimal, and may have concluded that some structural changes would have a higher priority than using up the entire budget on replacing poor condition assets on a like-for-like logic. Indeed, some well-judged adjustments to the system configuration and operation modes might have much more impact on energy consumption than just improving the individual efficiency of the pumps. it would have dealt with the hydraulic issues (pressures, floods, overflows) at the system or subsystem level, not at an asset-by-asset basis. Asset condition and relative importance would still inform the alternatives under consideration, and those components in most need of replacement would still be replaced, but with the broader view of a path to a better system, rather than to a collection of better parts.

By carrying out a systematic alternative assessment and comparison for the relevant scenarios, based on the pre-selected metrics and targets, communication and negotiation among internal and external stakeholders would have become clearer and easier. Decisions would hopefully be less subjective and more easily accountable to the board or to the elected politicians, and their impact on corporate objectives better assessed. The utility would be able to improve monitoring of results and to learn from them and act accordingly. Practical applications and business cases illustrating this methodology can be found in Marques et al. (2011), Cardoso et al. (2011) and Carriço et al. (2011).

A word on data

A key issue for IAM is the need to have available information to support diagnosis and assessment. Information is the set of data necessary for decision making, and which allows for the

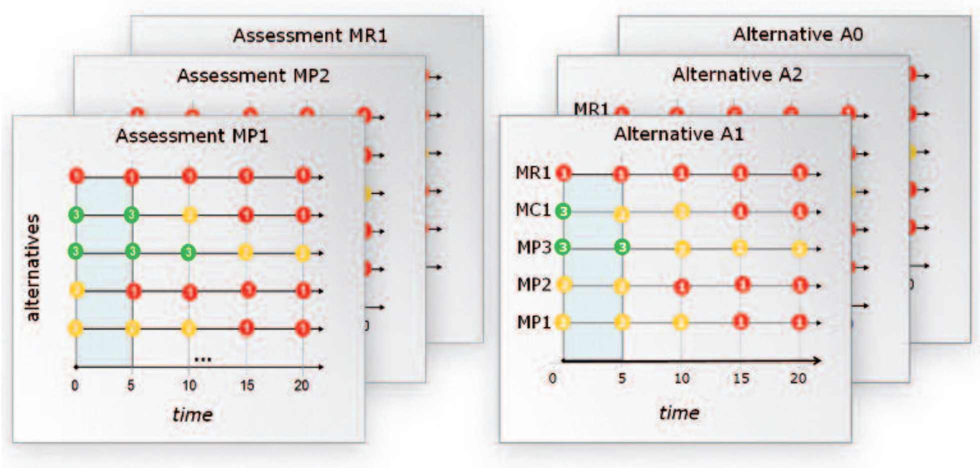


Figure 4
Assessments per scenario, comparing all alternatives for each assessment (on the left) or all assessments for each alternative (on the right)

establishment of actions. Important decisions are grounded in reliable data, inaccurate or missing data can lead to poor decisions. Thus, step one of IAM is to have updated and reliable asset inventories. But other types of information are also needed. Alegre and Covas (2010) and Almeida and Cardoso (2010) identify the most relevant information to be taken into consideration in each level of the IAM planning. Beleza et al. (2011) address the issue of information management, including data availability, accuracy, integrity, usability relevance and transformation into information.

Given the importance of data, the diagnosis should necessarily include the assessment of available data and produce recommendations regarding the improvement of data quality (in terms of reliability and uncertainty), the coherence and fluxes between different data sources, data use, integration of different information systems and data bases and procedures for data update.

Final remarks

In the current world context it is essential to ensure that urban water services are managed in a more dynamic, rational and efficient way than up to the present. This is a strategic sector of great social and economic relevance, supported on expensive and long-lasting physical infrastructures, with a reputation for high inertia and low efficiency. A change of paradigm is urgent and requires advanced asset management, assuring adequate levels of the service in present and in the future, particularly with regard to reliable and high quality drinking water supply, efficient use of natural resources and prevention of pollution and flooding.

The AWARE-P project aims at creating awareness to this need, changing current practices, improving technical know-how in the industry and providing guidance tools and software. The objective of the proposed approach is to encourage and assist urban water utilities in implementing a coherent and structured procedure for infrastructure asset management. It builds on existing leading-edge IAM know-how, integrating and complementing it with new knowledge and methods. This methodology has been published in two IAM manuals of best practice for urban water systems – one for water and one for wastewater (Alegre and Covas, 2010; Almeida and Cardoso, 2010) – complemented by web-based software (Coelho and Vitorino, 2011) and by other training and dissemination materials. All project output is public domain (www.aware-p.org). The recently launched TRUST project (7th Framework Program of the European Union) will allow for the further development of the IAM techniques and software launched with AWARE-P. ●

Acknowledgements

The authors are grateful to the entire AWARE-P project team for their contributions and commitment, as well as to the Financial Mechanism Office of EEA Grants for their support to the project. Special thanks are due to the participating water utilities – AdP Serviços, S.A., AGS, S.A., Veolia Águas de Mafra and SMAS Oeiras and Amadora – and to the National Authority for the Regulation of Water and Waste Services, ERSAR.

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WERF research into improving utilities' strategic management of assets

Despite increased efforts from more utilities in the United States and Canada to integrate strategic asset management at the national and local level, utilities are still working to fully develop their leading practices in areas such as integrating risk management, establishing levels of service, and analyzing life cycle costs, and many smaller utilities have yet to advance beyond the most basic level of asset management. Walter Graf, Jr and Linda Blankenship discuss the research efforts of the Water Environment Research Foundation as part of its strategic asset management communication and implementation programme to provide tools for utilities to help them implement leading practices and strategically manage their assets in a comprehensive, cost-effective way.

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In 2002, the United States Environmental Protection Agency Office of Water published its report highlighting the gap in funding of future drinking water and wastewater infrastructure needs (US EPA, 2002). Subsequently, in 2004, the United States General Accounting Office published its report that examined the potential benefits of comprehensive asset management for drinking water and wastewater utilities and the challenges that could hinder its implementation, and the role that the federal government might play in encouraging utilities to implement asset management (US GAO, 2004.) Since that time, the speed of uptake of asset management in the United States has been increasing.

It has been 12 years since the first edition of the International Infrastructure Management Manual was published in 2000. Even in the most recent 2006 edition, the United States was represented by only a handful of practitioners – Doug Stewart (then with the Orange County Sanitation District) and Tony Urquhart (with MWH, but previously with organizations in New Zealand), as well as Duncan Rose and Roger Byrne with GHD. However, since 2006, uptake has been proceeding more rapidly, in large part due to research that the Water Environment Research Foundation (WERF) has sponsored, with participation from the Water Research Foundation (WaterRF), UKWIR and the Global Water Research Coalition. WERF's research in strategic asset management has been a key element in creating that enabling environment at both the national and utility level.

In 2002, WERF convened a workshop to characterize the range of asset management programmes among water and wastewater utilities and recommend a research agenda for asset management. Participants were invited from throughout the United States and Canada and included utility managers, regulatory officials, and consultants. Criteria for selecting participants included factors such as utility size, location, type, and age, with the goal of achieving a balance of key utility and management characteristics. In addition, WERF invited representatives from both the utility and consulting fields from Australia, New Zealand, and the United Kingdom, all countries recognized to have advanced asset management experience.

Through presentations, plenary sessions, and 'breakout' workgroups, the workshop participants developed criteria for asset management research needs, identified barriers, and assessed gaps in programmes, tools, and techniques. Using decision science techniques, the participants then developed a list of new research initiatives, to which they assigned priorities, conceptual scopes, and budgets (Wagner et al., 2002).

Several key efforts recommended in that workshop have been completed, including a comprehensive set of strategies and protocols on condition assessment for water and wastewater utility assets (Marlow et al., 2007) and the development of WERF's Sustainable Infrastructure Management Program Learning Environment (SIMPLE), an online knowledge base for asset management. Subsequent to the initial version of SIMPLE, WaterRF added support to include a drinking water asset component to the existing wastewater-only focus. (SIMPLE can be accessed on WERF and WaterRF's websites). SIMPLE is an online knowledge base that brings the ability to train personnel and provides guidance and tools to utilities of all types, sizes, and levels of practice in asset management. SIMPLE now contains over 16,000 pages of best practices and processes from around the world, offering users state-of-the-art asset management strategies, tactics, tools, and resources. It functions as a training tool, research repository, learning environment, and knowledge hub. SIMPLE houses research produced under the Strategic Asset Management (SAM) Challenge and any other relevant WERF research, further strengthening its position as the leading reference for asset management knowledge and guidance.

In 2006, WERF decided to focus on a research approach in which teams of subscribers, researchers, volunteer experts, and WERF staff work together to identify and solve issues of critical importance to the water quality community by building on accumulated knowledge. WERF subscribers are more involved in the research every step of the way, identifying priorities and observing how one idea can grow into a valuable research outcome. This leads to solutions and practical tools – research they can use. This approach is well suited to address the needs of utilities for comprehensive approaches, guidance, and tools to implement strategic asset management.

Subscribers had previously

identified their asset management issues. There was a critical need to identify existing communication barriers to strategic asset management implementation at the local / utility level. Guidance was lacking for carrying out asset management in incremental stages to suit the needs of a wide range of wastewater facilities. In addition, decision support tools were needed to estimate performance and remaining economic life for buried and aboveground assets.

WERF further defined the goals of the research to define SAM practices and develop associated tools and techniques for implementation. Specifically, in its request for pre-proposals, WERF indicated that it wanted the research programme to accomplish the following goals:

- Improve communication and awareness among the key stakeholders (public officials, policy makers, utility staff and the ratepayers) regarding the benefits (as well as costs) of embracing a SAM programme in the utilities
- Help enhance the understanding of the barriers and obstacles faced by wastewater utilities in implementing a SAM programme
- Help develop a utility-friendly, step-by-step SAM implementation programme to suit the needs of a diverse range of wastewater facilities (small, medium and large)
- Establish a web-based database for compiling case studies on successful SAM implementation experience and lessons learned
- Develop analytic tools (gap analysis, cost-benefit analysis, risk management, etc.) for SAM implementation (that are stand-alone and also can be integrated with WERF-developed SIMPLE web tool)
- Forecast and proactively plan for asset failures, as well as related adverse effects on the environment
- Increase accuracy in predicting economic life of assets with the objective of improving long-term capital planning by proactively allocating funds when most needed
- Help utilities to extend current CIP (Capital Improvement Plan) projections from five years to a ten-year cycle, to a 20-year cycle
- Help realize cost savings or make improved financial decisions for the utilities that have to do 'more with less' increasingly in the current economic climate and given the vast backlogs of deteriorated infrastructure
- Help forge strong partnerships with agencies (national and global) that are involved in asset management

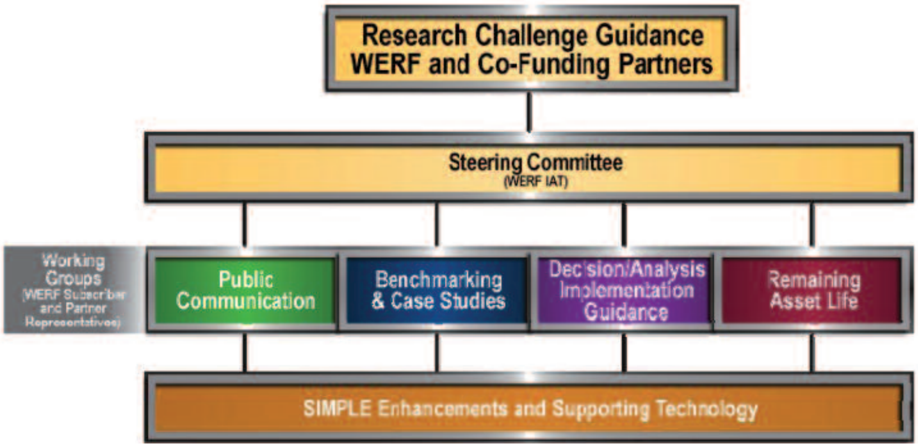


Figure 1
WERF's Strategic Asset Management Implementation and Communication research programme consists of four main research tracks, with a technology track enhancing its SIMPLE knowledge base.

This programme, 'Strategic Asset Management Communication and Implementation' (known as 'the SAM Challenge') is being managed under the direction of Program Director Walter Graf of WERF. Since 2007, EMA, together with partner firms GHD, MWH, and CSIRO, has led the broad research programme addressing these above-noted goals through four principal tracks of research: public communication; benchmarking and case studies; decision / analysis implementation guidance; and remaining asset life, as shown in Figure 1.

The SAM Challenge

The goal of asset management and of the SAM challenge is to develop a comprehensive set of integrated management strategies (including operations, maintenance, and capital) for all assets in the enterprise. The SAM Challenge strives to achieve this objective through what is called the five-core question, ten-step method. This framework can be used by utilities with varying levels of sophistication and asset knowledge. This framework:

- Identifies the current state (performance) of the assets
- Defines the level of performance (service) that the assets aim to deliver
- Identifies those assets that are 'critical' to sustained performance
- Based on the above, integrates operations, maintenance, and capital investment strategies to sustain performance at lowest total cost of ownership to achieve the desired level of performance (service) and risk profile
- Design a financing plan to fund the integrated strategies

These items are the five core issues, or when put into an inquisitive form, questions, of asset management. To answer these questions, a ten-step process is used, as illustrated in Figure 2.

Presently, WERF offers a suite of tools and guidance that any utility can use to improve its practice of strategic asset management. The research is based on providing utilities with the tools to address the ten-step model for development of an asset management plan and programme.

These ten steps are described briefly as follows:

Step 1 – Inventory assets and develop a robust hierarchy based on parent-child relationships
Step 2 – Assess condition and performance of the assets
Step 3 – Determine residual life of the assets
Step 4 – Determine replacement cost and date
Step 5 – Set target levels of service
Step 6 – Assign the business risk exposure (BRE) rating for the asset (where BRE or criticality is defined as the consequence times the likelihood of failure)
Step 7 – Determine appropriate maintenance strategies for the asset classes and / or assets based on desired risk and service levels
Step 8 – Determine appropriate capital improvement projects plan for investment based on desired risk and service levels as well as life cycle cost evaluations
Step 9 – Address funding requirements and strategy
Step 10 – Complete building of the asset management plan and programme

These steps represent the core steps to develop an asset management plan, and most utilities will not complete them in a linear process. In practice, each utility will define its unique drivers and focus accordingly to build the strategic asset management plan and associated programme, and continue to refine it over time in an iterative manner.

Getting started with a gap analysis

Determining the level and extent of application of strategic asset management is an essential step that all utilities should undertake. Utilities can assess their progress using the gap analysis tool, SAM GAP. SAM GAP is an online, self-assessment process that allows an organization to rapidly measure its performance against data from over 170 of the world's best asset management practitioners. It is a detailed and comprehensive multiple-choice questionnaire consisting of 166 questions.

SAM GAP is comprised of leading practice statements in seven focus areas:

1. Processes and practices
2. Information systems
3. Data and knowledge
4. Service delivery
5. Organization
6. People
7. Asset management plans

The utility can assemble its cross-functional team to do the SAM GAP assessment. Ideally, this team should include all core and business functions of the utility. However, it is possible to focus on one or more core functions in the event that the level and extent of practice differs substantially for the utility. Utilities can rate themselves, input the data into SAM GAP and receive a generated report that compares them to leading practice as well as the current level of practice based on the utilities that have completed SAM GAP to that point. The report identifies areas for the utility to advance its application of strategic asset management. These areas are not prioritized – the utility cross-functional team should decide in which area to begin. Utilities can also periodically re-assess themselves to determine the advancement of their SAM programme and to identify remaining gaps.

Adopting leading practices

Having identified and prioritized relevant gaps, utilities can use the leading practices identified as a result of the benchmarking component of the research. The team can individually and / or as a group evaluate the applicability of practices and review utility examples of application. While all tracks of research address leading practices, Track 2 in particular has focused on benchmarking asset management leading practices among utilities, as well as development of case studies that utilities can use to learn how to implement SAM. An initial survey was completed by over 50 utilities to identify areas of opportunity for strategic asset management, based on the ten-step SIMPLE process that guides utilities to develop their asset management plan. Responses to this survey resulted in initial identification of gaps for improvement. More than 30 utilities completed a more detailed self-assessment of practices with a multi-functional team from across the utility business processes to answer 160 asset management practice questions using SAM GAP. Leading utilities generally scored over 85 (out of 100) in their SAM GAP results for multiple practice areas. The research included utilities in the United States and Canada, as well as utilities in Australia and the United Kingdom.

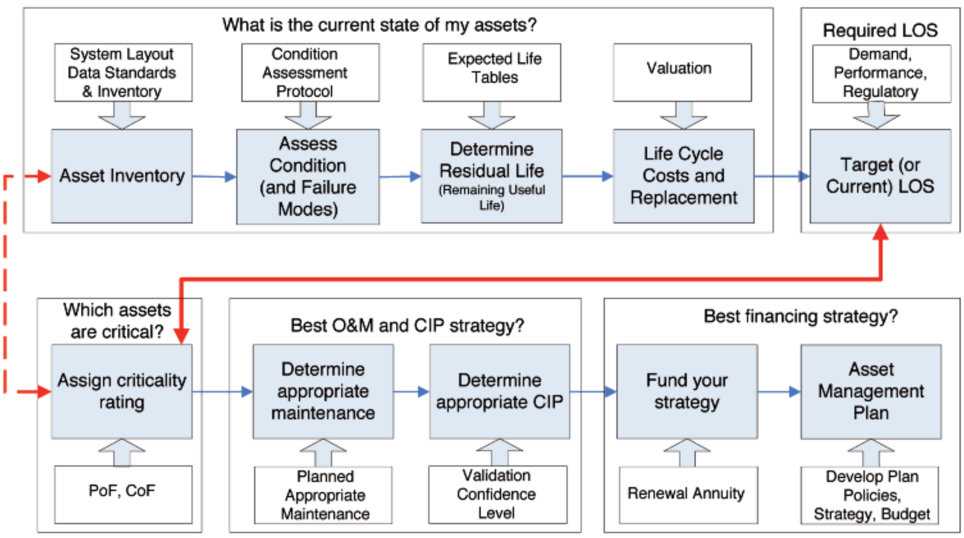
By examining where utilities scored relatively well, and relatively poorly, six key areas of opportunity were identified:

- Organization and people
- Accounting and costing
- Business risk management
- Maintenance
- Secondary data and knowledge
- Strategic asset planning

Six utilities were identified that had leading practices in some or all of these six areas: Seattle Public Utilities (Wash.), Orange County Sanitation District (Calif.) and DuPage Water (Ill.) in the United States, EPCOR in Canada, United Utilities in the United Kingdom and Sydney Water in Australia.

The research team validated these results via telephone interview. Members of the team then visited each utility to identify the specific leading practices and examples of their application. Some examples are:

Figure 2
Five Core Question – 10-Step Process for SAM Plan Development



Organization and people

This practice area includes organizational issues (roles and responsibility for AM) and people issues (culture, managing change, etc.). A leading practice in this area includes a Corporate Asset Manager and Steering Team with well-defined roles and responsibilities for strategic asset management as well as continuous improvement processes.

Accounting and costing

This practice area includes asset valuation, tracking and reporting, residual life, and future renewal liabilities. A leading practice in this area includes condition-based assessment of all asset classes on a five-year rolling basis, with the use of the Modern Engineering Equivalent Replacement Approach to determine future renewal.

Business risk management

This practice area includes business risk exposure, probability and consequence of failure, and risk analysis and reduction. A leading practice in this area includes using a standard risk assessment methodology with a business risk exposure score for assets and inclusion of capital project for assets that score above a threshold level.

Maintenance

This practice area includes maintenance policies, use of reliability centred maintenance and maintenance planning, scheduling and control.

Secondary data and knowledge

This practice area includes asset condition and performance data, Strategic (asset) planning, and asset management plans. This practice area includes predicting likely failure modes, life cycle cost, and optimized decision making (repair, rehab, replace), and state of the asset portfolio reporting.

Strategic asset planning

This practice area includes drivers, business goals, and asset management development, leading to a comprehensive knowledge of the state of the assets and optimizing renewal decision-making.

The complete set of practices is pending publication as part of IWA Publishing's WERF Research

Report series later this year (Blankenship, 2012).

In addition, case studies of utility implementation of elements of SAM have been prepared. To look at options for current asset state, the approach being used by the City of Atlanta (Ga.) to assess and prioritize combined and sanitary sewer system improvements was described. To identify the best operations and maintenance (O&M) strategies, the Massachusetts Water Resources Authority's use of reliability-entered maintenance to lower maintenance costs at the Deer Island Treatment Plant was examined. To understand which assets are critical to sustain performance, Seattle Public Utilities' (Wash.) business risk processes developed for identifying critical sewer infrastructure were documented. To understand stakeholder expectations of required level of service better, the Columbus Water Works' (Ga.) independent customer survey programme was described. Lastly, in looking at the best funding strategy, the approach that the City of Hamilton, Ontario uses to gain support from its elected city representatives was documented.

Engaging stakeholders and setting service levels

Given that strategic asset management has the potential to significantly change the way that services are provided and assets are managed, WERF has also focused on public outreach elements of SAM. A report was published in 2009 (Blankenship and Houston, 2009) on leading practices for working with customers and stakeholders. To develop recommendations on practices, interviews with elected and appointed decision-makers on issues related to public support for strategic asset management and infrastructure sustainability were conducted. While officials agreed that the public does not need to understand asset management, it is critical that it understands and supports water infrastructure sustainable. Given that every community has some form of water infrastructure challenge, these public officials agreed that a key part of their role is to conduct outreach to the community on them. A plan for engaging officials was identified as well as key messages. In addition, numerous available public outreach materials were catalogued. Case studies of successful outreach programmes were described.

In a follow-on report, utility experience using Citizen Advisory Committees (Blankenship, 2010) was analyzed to focus on their experiences, lessons learned and successful practices in working to address challenging water infrastructure issues. Committee development and engagement practices were identified. The experience of ten communities with different processes and lengths of time working with citizen advisory committees

Results

Utilities now have extensive guidance, tools, methods, practices, and case studies available to them to help design and implement strategic asset management. The involvement in research has seen a significant amount of knowledge transfer because of involvement in the WERF SAM case studies, peer review, benchmarking process and the use of the guidance and tools developed. There is no doubt that the focus on strategic asset management by US and Canadian utilities has greatly increased during the time that US General Accounting Office published its 2002 report.

A good example of WERF research enabling strategic asset management is the experience of the Water Services Division (WSD) of Gresham, Oregon. Implementing the WERF SAM programme and the recommendations of a WERF peer review group has allowed the City to understand and identify all the assets within WSD. Prior to 2008, they could not have easily identified asset install date, age, condition, business risk exposure, life cycle cost, etc. They are now on a pathway where information is available to allow staff to manage the assets better and understand future financial requirements. As the asset management journey continues, WSD, and ultimately the entire City, will be able to 'tell their story' to their customers. This is a direct result of the WERF peer review and tools in SIMPLE helping the City towards its goals of implementing a best in class strategic asset management programme.

Conclusions

WERF's research is having a significant impact on the practice of infrastructure management in the United States and Canada. In particular, the approaches and tools available through WERF provide utilities with significant benefit in implementing strategic asset management. More and more, utilities are recognizing that strategic asset management is not a software application but rather a process and a programme. WERF's guidance and tools provide significant value to allow utilities to improve. SAM GAP enables utilities of all sizes to measure their performance and determine areas for improvement.

Ultimately, application of WERF's research will help utilities meet the challenges presented by aging infrastructure, increasing regulatory requirements, financial constraints, and other utility drivers. Utilities in the US and Canada are well under way in having an enabling environment for AM at the national and utility level. WERF's research in strategic asset management has been a key element in creating that enabling environment at both the national and utility level.

A utility manager summed up the value of WERF research helping utilities improve their strategic asset management by saying: 'I am sure there are lots of municipalities like ours that are transitioning into asset replacement, repair, and refurbishment experts as our assets age. I believe the honeymoon's over with our young assets and we need to make sure we are doing the right thing when evaluating their replacement.' ●

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Whole of life cost calculations for water supply pipes

Repair and rehabilitation of water supply network assets depend on costs and time of failure. Daniela Fuchs-Hanusch, Birgit Kornberger, Franz Friedl and Robert Scheucher discuss research into whole of life costs of aging pipes through using failure prediction to determine the years when failures will occur, and the use of data from three Austrian utilities to investigate the factors influencing the costs of repair.

Daniela Fuchs-Hanusch
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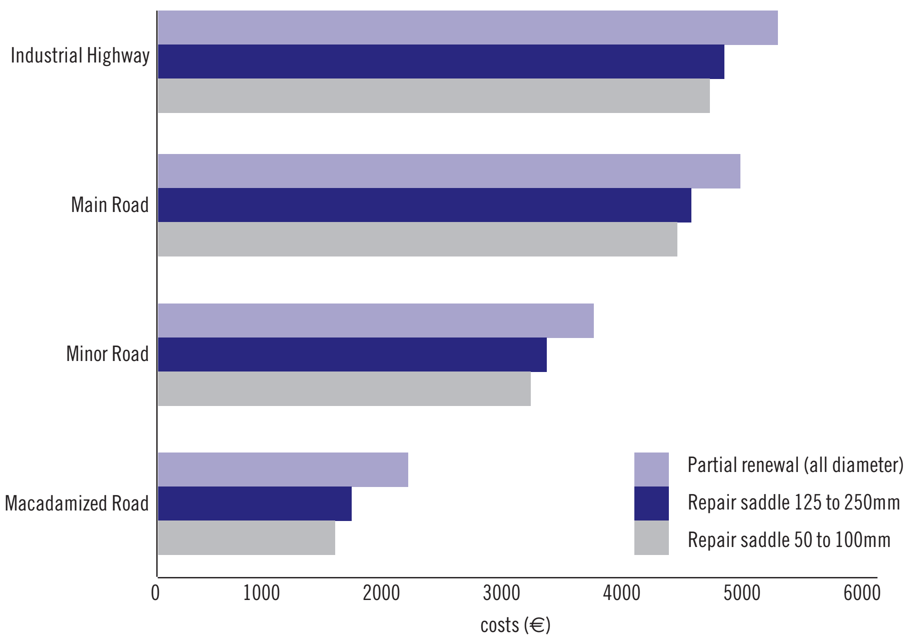
Selecting the right pipes at the right time for rehabilitation is one of the main challenges in asset management. As water supply pipes have a long lifetime in which they have to be operated and maintained, the replacement decisions should focus on long-term cost calculations. The costs associated with aging pipes are mainly related to pipe breaks and maintenance work as well as water losses. As the factors that influence break occurrence and pipe maintenance, repair and water loss costs are manifold there are two challenges of life-time costs calculations – one is to predict future breaks of pipe units, the other is to estimate how costs differ from pipe to pipe and how they will alter with time.

Pipe failure prediction models can be classified into physical and statistical models. Physical models (e.g. Rajani, at al 1996) require detailed data about the surrounding situation and the internal and external loads that affect the pipes. The collection of such data causes high costs. This data collection seems to be justifiable only for pipes with a high vulnerability and a high risk to cause external damage, like it can be expected for transmission mains. Therefore, to calculate future breaks in the entire supply systems statistical models are preferred. Kleiner and Rajani, 2001 gave a review of statistical models for predicting pipe breaks proposed in the scientific literature. The statistical models described in Kleiner and Rajani, 2001 are classified into deterministic, probabilistic single-variate and probabilistic multi-variate models. Deterministic and probabilistic single-variate models are particularly applicable to determine the breakage rates for pipe groupings (same material, same vintage, same soil type). To calculate whole of life costs (WLC) for individual pipes, failure prediction at the pipe level is essential. Therefore, in our research of using a probabilistic multivariate model, the proportional hazards model (Cox, 1972) was adapted. For the purpose of pipe failure prediction the proportional hazard model (PHM) was first used by Marks et al., 1985 and further amended by Andreou et al., 1987 and Le Gat and Eisenbeis, 2000. The purpose of these models mainly was to calculate the yearly number of failure accurately. In this paper's analysis a PHM was adapted to fulfil the requirements for whole of life cost calculations. These requirements can be described as follows. Inflation and changes in construction prices costs alter with time on a yearly basis. Therefore, the focus in the analysis was to estimate the years when the failures occur with a defined probability, rather than to estimate the cumulated number of failures over time.

Figure 1
Direct failure cost variations due to repair type, road type and diameter (Data source: 2 Austrian utilities)



Estimating the costs of aging pipes due to maintenance and failure is the second challenge in whole of life cost calculations. Kleiner, et al 2010 describe a life cycle cost equation for supply pipes which involves rehabilitation costs, failure costs including repair costs, external direct costs and costs for water losses due to failure as well as indirect external costs and social costs. Kleiner at al., 2010 neglected costs of maintenance, like inspection and smaller repair works and leak detection which increase with the deterioration of pipes as well. Further the prize increases and inflation rates were neglected as well. In this paper we describe an amended equation of the one given in Kleiner at al., 2010 where these additional cost factors have been taken into account. The sensitivity of these factors on the results of the optimal time of rehabilitation was investigated. Therefore influencing factors on the variance of repair costs including external damage and water loss costs were investigated by analyzing cost data of three Austrian water utilities. These utilities were participating in the research project IRM – 'Infrastructure Rehabilitation Management', part of the KNet 'Waterpool', a competence network between Austrian research institutions and the water economy, funded by the Austrian Ministry of Economy, Family and Youth.

Whole of life cost calculations for water supply systems

Definition of whole of life cost functions

The costs of a deteriorating pipe (i) over time (t) are mainly caused by pipe

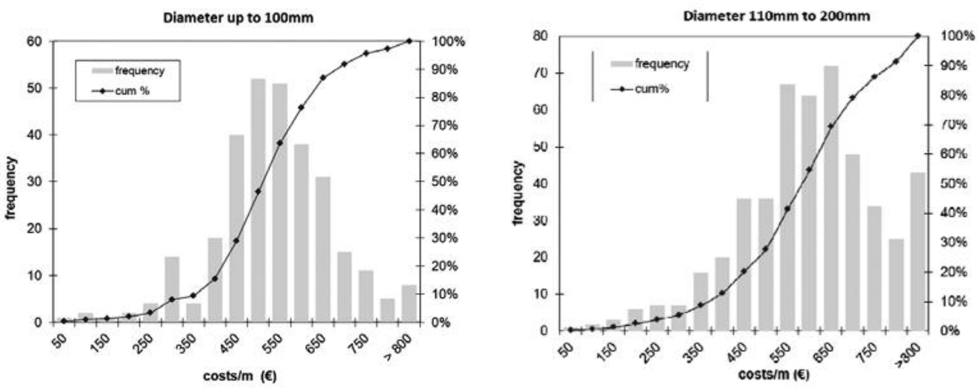


Figure 2
Rehabilitation costs/m for pipes up to 100mm and 110mm to 200mm (Data source: 1 water utility)

failure (PF) and include direct and indirect costs. Direct costs are costs for pipe repair (C^{Rep}) as well as external costs (C^{Ext}) due to external damage like street body reconstruction and costs for water losses per leak or break (C^{PFWL}). Mentioned in Kleiner et al., 2010 indirect costs include social costs (disruption, time loss or loss of business) and indirect external costs (sewer damage, accelerated street deterioration). These costs were neglected in this paper's investigations, because to estimate them on a monetarily basis is an additional and complex topic. Therefore, the direct costs wre concentrated on, but in addition to Kleiner at al., 2010 further direct costs have been taken into account like inspection and maintenance costs ($C^{I\&M}$). These costs rise with the age of a pipe as well, as aging pipes have higher reparation needs of valves and hydrants as well as a higher necessity of water loss detection campaigns. Further higher water losses due to higher background leakage (C^{BL}) may occur at deteriorating pipes. Finally, at a specific time in the life cycle, the pipe has to be rehabilitated (C^{Reha}). Then the life cycle starts again for the new pipe.

(1) $C^{tot}_{(i,t)} = C^{Reha}_{i,t} \cdot e^{-z_1 \cdot t} + C^{oldPipe}_{i,t}$

(2) $C^{oldPipe}_{i,t} = \sum_{j=1}^{t} \Big(PF_{i,j} \cdot \big[(C^{Rep}_i + C^{Ext}_i)$

$\star e^{-z_1 \cdot j} + (C^{PFWL}_i) \cdot e^{-z_2 \cdot j}\big] + (C^{I\&M}_i \, e^{a_i \cdot t} + C^{BL}_i$

$e^{b_i \cdot t}) \cdot e^{-z_2 \cdot t}\Big)\Big)$

To calculate these costs over time, equation (1) and (2) were formulated. The aim is to derive the optimal time of rehabilitation (t_{opt}). It is reached when C^{tot} becomes a minimum. In distinction to Kleiner et al., 2010 the influence of future price increases into the discount indices was included. Therefore, the index z_1 considers the discount rate minus building cost index and z_2 considers the discount rate minus consumer price index. For all costs which refer to the construction sector (C^{Reha}, C^{Rep}, C^{Ext}) z_1 is taken into account, for all costs which are influenced by inflation, z_2 was used. For the increase of background losses (BL) and inspection and maintenance work (I&M) with time, the factors a_i and b_i have to be estimated.

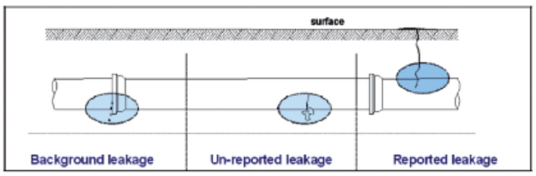


Figure 3
BABE (Background and Bursts Estimates) concept for types of leakage (Lambert, 2009)

The factors, that influence the specific costs as well as the failure rates, and hence the WLC, vary strongly from pipe to pipe. Data acquisition to derive specific costs per pipe unit for the entire supply system can be a time extensive work. For a better understanding of the main influencing factors on the result of t_{opt}, a comprehensive sensitivity analysis has been started, using a Monte-Carlo-simulation and the method of Morris. For this analysis the open source software SIMLAB (2011) was used.

It is obvious that the amount of expected failure in the near future is a main influencing factor on the result for t_{opt}. Later this this topic will be dealt with separately and describes the derived failure model, uncertainties and verifications of the model in detail. In a first sensitivity analysis, it was assumed that the number of future failure is given. An extended sensitivity analysis (SA) incorporating the SIMLAB SA Methods, the external failure prediction model and the WLC calculation model is still in progress. So far failure and rehabilitation cost related factors and factors related to water losses and maintenance work intensity have been taken into account by analyzing equation (1) and (2) for a fixed future failure rate.

The parameter range of these factors were derived from data and expert information of three Austrian water utilities, with data provided by Statistic Austria (www.statistik.at) for the prize indices and data from the official report of the Austrian Benchmarking Project (Neunteufel et al., 2008). From this report the water prize range in Austria was derived. For the factors related to water losses, results of Lambert, 2009 were taken into account.

Value ranges of WLC factors for the Monte Carlo Simulations

Figure 1 shows cost variations for direct failure repair costs. The main influencing factor on costs is the road type, due to different pavement structures. As material cost variations per diameter are low the influence of pipe diameter is low as well and can be neglected when pipe-specific repair costs are derived. The repair type has a slight influence on the costs as well. The data analysis of the participating water utilities has shown that the repair types mainly result from pipe type. For example, PVC pipes, due to longitudinal cracks, have to be partially renewed, while most cast iron pipe breaks are round cracks and can be repaired with repair saddles. Due to these results we recommend in any case to include data acquisition about road type and frequent pipe crack types if a pipe individual WLC cost calculation is planned. The influences on rehabilitation costs were investigated on the basis of rehabilitation cost of the utilities (Figure 2). The costs were accumulated to the present. The analysis has shown that an influence of diameter is given in this case. Figure 2 shows that the cost vary significantly and that the distribution type depends on the diameter. While for diameters up to 100mm the values follow a

Table 1 - Value range for relevant factors of equation (1) and (2) to investigate the sensitivity at an average pressure of 50m, a fixed failure rate for pipes with a diameter up to 100mm and an average length of 200m

	Min	Max	Distribution	Data source
C^{Reha}	250 / m	750 / m	Normal	Utilities data
C^{Rep}+C^{Ext}	2500 / m	6000	Normal	Utilities data
Z_1	0	0.02	Uniform	Statistic Austria
Z_2	0.02	0.05	Uniform	Statistic Austria
WP	0.7 €/ m³	1.6 €/ m³	beta (α, β=2; a=0.7; b=1.6)	OEVGW Benchmarking
WLperB	300m³	7000m³	Uniform	Lambert, 2009
BL mains	0.02m³ / km / h	0.04m³ / km / h	Uniform	amended from Lambert, 2009
BL per SC	0.001m³ / SC / h	0.003m³ / SC / h	Uniform	amended from Lambert, 2010
SC / km	10	60	Uniform	OEVGW Benchmarking
bi	0.005 / a	0.01 / a	Uniform	Utility experts
$C^{I\&M}$	0.5 €/ m	1.5 €/ m	Uniform	Utility experts, utilities data
ai	0.005 / a	0.01 / a	Uniform	Utility experts

normal distribution, for the bigger diameter the distribution tends to be left skewed.

For quantifying the range of water losses due to pipe failure (PFWL) and background leakage (BL) estimations of Lambert, 2009 were taken into account. Physically C^{PFWL} depends on the type of failure, the diameter of the pipe or the extent of the leak and on pressure. Lambert, 2009 gives a range for losses per pipe failure for an average pressure of 50m. It classifies the losses per failure in losses from reported leaks and breaks with short runtime and losses from unreported leaks and breaks with longer runtime (see also Figure 3). Further it provides an empirical function to calculate background leakage in dependency of water main length (LM) average zonal pressure (AZNP) and the number of service connection (SC/km) per water main length (Equation 3).

(3) BL (litres/hour) = (20xLM + 1.25xSC)*(AZNP/50)$^{1.5}$

The amount of the pipe individual background leakage depends on the type / vintage of pipe joint and on the amount and the age of the connected supply pipes. Equation (2) assumes an exponential increase of this background leakage with time. The hypothesis of an increase of background losses is physically constituted in the hypothesis that the amount of leaking joints and house connections increase with time. These types of leaks are not detectable because the leakage itself is small but the amount of such leakages increase. To verify this hypothesis an extended literature research and an expert's opinion poll according to background losses has been started. So far the factor bi of equation (1) varied between a 0.5% and 3% increase of background losses per year due to experts' estimations.

According to the expected inspection and maintenance costs the range was defined by expert opinion as well. It was set between 0.5 and 1.5 €/m pipe and includes leak detection, valves and hydrants inspection and small maintenance works. Table one gives an overview of the defined value ranges for the parameters used in equation (1) and (2) for WLC calculations.

Sensitivity analysis – Morris Screening method

A sensitivity analysis using the Morris screening method provides the opportunity to define factors that influence the result, as well as factors which have a high dependency to other factors and to input data. If C^{tot} is analyzed with a Monte Carlo Sample for the cumulated costs of aging pipes $C^{oldPipe}$ plus rehabilitation costs C^{Reha} the significance of C^{Reha} and z_1 is dominant. Hence, a detailed investigation of expected rehabilitation costs for different pipe units is essential for WLC calculations. As a more detailed identification of the cost driving factors was desired, the sensitivity of costs factors with an impact on $C^{oldPipe}$ (Equation 2) were also of interest. In Table 1 all factors from C^{Rep}+C^{Ext} downwards are related to $C^{oldPipe}$.

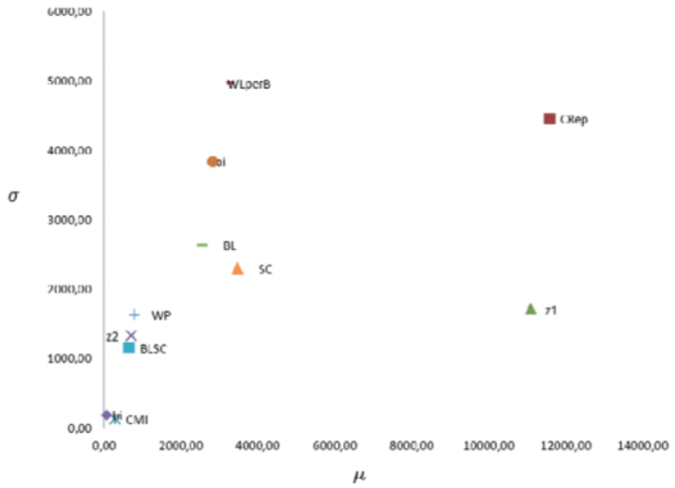


Figure 4 Sensitivity of ColdPipe on the parameters given in Table 1 for fixed break intensity and pipe length for pipes with diameters up to 100mm under an average pressure of 50m

Figure 4 shows the result of the Morris screening of $C^{oldPipe}$. Factors with high μ-values reflect a high impact on the result of $C^{oldPipe}$. High σ-values reflect a high dependency on other factors of the equation or on the input data, which are pressure, pipe length and the amount of failure. For example CMI and bi have no dependency on other parameters and are generally of low influence on the calculations. The analysis shows that repair costs (C^{Rep}) over time and the factor z_1 have the strongest influence on the costs of the aging pipe if future pipe failures are given. Further the calculations of $C^{oldPipe}$ are sensitive on the amount of water losses per break (PFWL) and the number of service connections (SC) and the background leakage per m pipe length (BL).

The sensitivity analysis has shown that for a detailed data acquisition per pipe unit, with the aim to prioritize them for rehabilitation on the basis of a WLC calculation, information about expected rehabilitation and repair costs and the expected price index z1 are of the highest interest. The PFWL as well as background losses in their amount but not how they increase in future (bi) are of further interest as well. According to maintenance and inspection costs the variations in the specific costs CMI are of no significance, but if and how they increase with deterioration (ai).

Calculating C_{tot} for an example pipe (fixed failure rate, 100mm diameter and 250m length) using the average value of Table 1 for each of the factors of equation (1) and (2) provides 15 years to reach t_{opt} as result if only C^{Rep} + C^{Ext} and C^{Reha} are taken into account. Ten years are left to reach t_{opt} if costs for PFWL are incorporated as well and only three years to reach t_{opt} if costs for BL and I&M are incorporated as well. If a reduction of rehabilitation costs can be achieved, for example due to coordinated construction sites, t_{opt} is reached at present because the rehabilitation costs currently are less than at any time in the future.

Two of the main WLC influencing cost factors C^{Rep} and PFWL depend on the amount of future failure and the time of occurrence of failure. So far the failure rate was presumed as given for the sensitivity analysis. The following chapter describes a failure prediction model which was adapted to fulfil the needs of WLC calculations. Further the constraints of failure prediction are shown.

Pipe failure prediction and rehabilitation prioritization with WLC calculations

Pipe failure prediction models in context with pipe rehabilitation prioritization have the purpose to

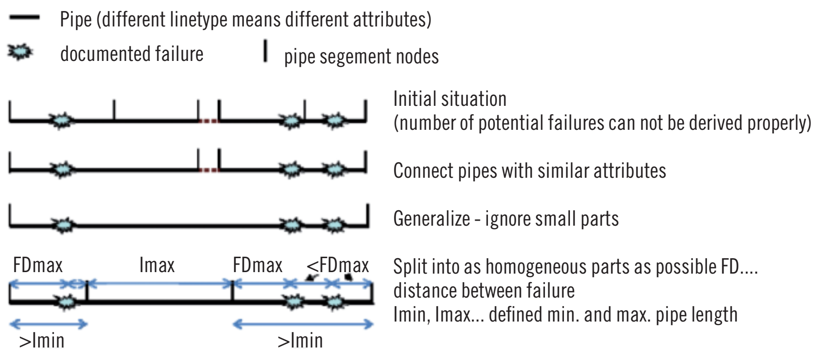


Figure 5 Restructuring of GIS data to define representative pipe segments for failure prediction and rehabilitation prioritization

estimate the amount and the time of occurrence of future failure. The purpose of modelling the amount of future failure is to describe how the entire system reacts on rehabilitation of specific pipes. Estimations of the time of failure occurrence on the pipe level are of interest if prioritization itself is the target. Both targets have been taken into account within the described research.

Data preparation

To analyze failure data on the pipe level and to calculate the optimal time of pipe replacement the use of GIS data is common practice. As there are no standards, and the aims of the GIS can differ from utility to utility the data basis and the data structure vary widely. The pipe data of the participating Austrian Utilities were structured into very small units, as they were divided by each house connection. Further many of the older segments were divided by smaller younger segments due to past partial replacements. Therefore the data were restructured to fit to the needs of failure prediction and WLC calculations. On the one hand the segments should be representative units for the deterioration processes and on the other hand the segments should be convenient units for rehabilitation. The aim was to have pipe segments which represent the current state of deterioration, especially due to the number of previous failure (NOPF) and segments with an average length of 200m, which represents the average rehabilitation length in the investigated systems. Several rules have been defined to derive these applicable pipe segments.

Figure 5 shows a scheme of the restructuring process, which has two steps. The first step is to generalise the pipes to bigger units and the second is to split them into representative segments again. The main rules for generalisation were to unite pipes with the same material, vintage (± five years) and the same diameter and to ignore small parts in between which are not longer than a specific length. For the splitting process a maximum and minimum pipe length were defined. Further, a maximum distance between failures was set. The documented failures are finally relinked to the new pipe segment.

For each new pipe segment the number of previous failures and the year of the last failure were added. The amount of service connections per pipe unit were added as an additional attribute. This new data structure provides an optimised basis for rehabilitation prioritisation and failure prediction.

Failure prediction with proportional hazards model

The Proportional Hazards Model (PHM) (Cox, 1972) was designed to calculate the hazard rate h(t) of units (i). The hazard rate describes the probability of a unit i at a time t to fail in the next time step (t+1). The survival function of a unit S(t,i) can be derived from the hazard rate. By calculating S(t,i) the probability for the units to survive a specific time is given (Figure 7). Hence the time of occurrence and the amount of failures for a calculation period can be estimated with a certain probability.

To analyse the main influencing factors on failure occurrence in the participating systems a cox regression analysis was undertaken. The covariates which were investigated were material, diameter, length, vintage, soil type and the number of previous failure. One aim was to derive a general model to be used for individual pipe systems failure prediction by end users of the software PiReM Systems (Fuchs-Hanusch et al., 2008). This software was developed within a previous research project of the competence network KNet 'Waterpool'.

As shown in Figure 6 and in previous research (Le Gat & Eisenbeis, 2000; Rostum, 2000; Park & Longanathan, 2002; Gangl et al., 2009 amongst others) the number of previous failures (NOPF) is of high significance in failure prediction. For the failure data of the participating Austrian supply networks the significant covariates were found to be NOPF, material, diameter, vintage and length. It was decided not to include NOPF as a covariate of the model directly. Instead, a model for each time to failure (installation to first, first to second, second to third,...) was built. This allowed for the incorporation of right censored data of each survival to failure time properly into the estimations. Right censored data in this case are pipes which still wait for the next event. If this fact is neglected for parameter estimations the model tends to overestimate the failure probability.

Equation (4) describes the survival function S(t,i) for the first failure considering the influencing factors material (mat) as categorical covariate and the diameter (dia), pipe length (len) and the Vintage (vin) of a pipe as numeric covariates. These covariates were found to be significant for all three example supply systems.

(4) $S(t,i)=[S_0(t)]^{\exp(x_{mat}'\beta_{mat}x_{dia}'\beta_{dia}=x_{len}'\beta_{len}=x_{vin}'\beta_{vin})}$

The survival function S0(t) and the parameter β_{mat}, β_{dia}, β_{len} and β_{vin} vary

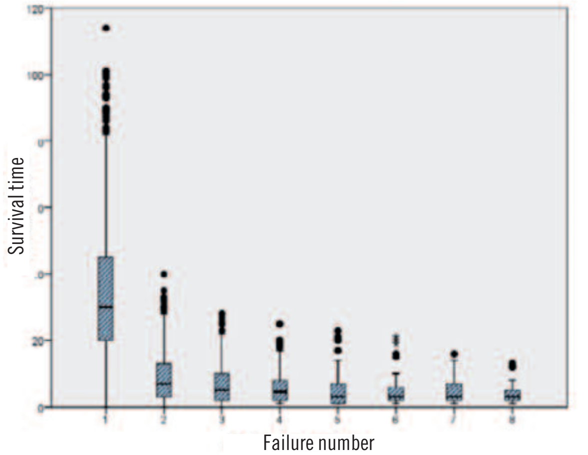


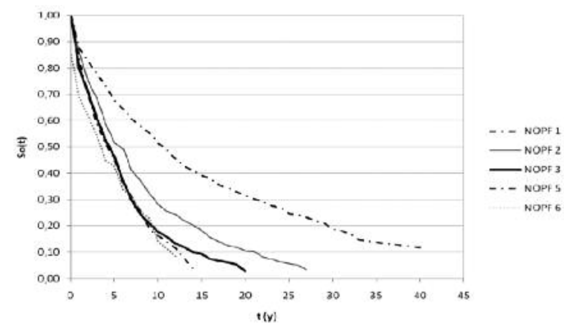
Figure 6
Survival time dependency on NOPF for the supply networks of 3 Austrian utilities.

between the supply systems. Further the significant covariates for the failure models of the second and further failures may differ from the first failure model. Table 1 shows the estimated parameters for an Austrian supply network. The number of significant covariates decreases with the number of failures. The statistical significance of the model covariates was tested with the Wald test and log-likelihood ratio using the software PASW Statistic 18 (2009). The bigger the Wald values of a covariate in Table 1, the higher the significance. The covariates of low significance are excluded in a next model estimation step. The remaining parameters are estimated anew.

The investigations have further shown that PVC pipes tend to have higher failure rates at bigger diameters but for all other materials the failure rate decreases with the diameter (negative β_{dia}). Therefore it is advisable to build a separate failure model for PVC pipes or include a combined variable material times diameter. For the implementation of the failure model into the software PiReM Systems we decided to group the pipes before estimating the remaining parameter βi, which then are β_{dia}, β_{vin} and β_{len}.

As recognizable in Figure 6 and Figure 7 the steepness of the survival function increases with the amount of previous failure. Hence the insecurity in failure occurrence prediction decreases with the number of previous failure. For pipe rehabilitation prioritization it was found out in previous research (Gangl et al., 2009) that only pipes with more than four failures are

Figure 7
Survival probability baseline hazard for different numbers of previous failure (NOPF)



of interest. This allows to assume that for pipes relevant for WLC calculations the insecurities in failure prediction can be minimized if previous failure data are recorded. Nevertheless for a better understanding of the insecurity in failure prediction regarding the sensitivity of WLC calculations further analysis is in progress.

Finally, to validate the accuracy of the model, the number of predicted failures over time was compared with the observed failures. Therefore the pipe data were structured as described above and for each pipe the time to failure occurrence (median value) was calculated for a defined time period. The validation for a partial network of one participating utility is shown in Figure 8. The satisfying adjustment is assumed to be a result that the break data of the example network reach back to 1974.

The accurate calculation of the cumulated future breaks, like it is shown in Figure 8, is the basis for calculating the effects of rehabilitation priority decisions on the future amount of failures (Figure 9) and on future failure costs. PiReM Systems (Fuchs-Hanusch et al., 2008) provides a module to define scenarios for yearly rehabilitation amounts. Figure 8 shows future failure trends for a defined scenario under rehabilitation of pipes prioritized with cost calculations.

Conclusion and outlook

Predicting when failures will occur is undoubtedly the main interest in decision support for prioritizing water mains for rehabilitation, and hence is an essential part of WLC calculations. For failure time prediction of individual pipes statistical methods are preferred to physical models, as failure data collection has started to be common practice at water utilities, but the exact physical circumstances of breaks is still unclear. The described adapted PHM allows users to predict the time when failures will occur with a certain probability. The uncertainty in failure time prediction decrease with the NOPF, hence for pipes which are of relevance for WLC-oriented prioritization the uncertainty in failure prediction decreases. Nevertheless for minimizing this uncertainty in failure prediction an extensive pipe oriented failure statistics is essential. We assume that this statistic may include only a few describing factors, like pipe length, material, diameter, vintage and the time of occurrence, but pipes with frequent failures have to be identified properly. It is advisable to structure the data basis into pipe units, which can be expected to be homogeneous due to their deterioration. The failure statistics may also be a short time series, but

Table 2: Significant covariates and parameters βi for several survival time models of one Austrian supply network

	1st failure		2nd failure		3rd failure		4th failure		6th failure	
Events (#)	871		457		262		158		98	
Censored (#)	4750		370		169		91		56	
Missing values	0		44		26		13		4	
Covariates	**β**	**Wald**	**β**	**Wald**	**β**	**Wald**	**β**	**Wald**	**β**	**Wald**
DN	-0.004	41.886	-0.004	11.399	-0.005	11.049	-0.006	6.109	-	4.371
MAT_Cat		264.811		16.95		6.623		8.499	-	4.74
AC	0.406	2.745	-1.063	4.215	-	-	1.006	0.624	-	-
CI_LJ	0.564	18.018	-0.146	0.304	-	-	0.421	0.277	-	-
CI_SJ	0.928	91.795	0.058	0.048	-	-	0.651	0.258	-	-
All others	-2.096	60.721	-0.51	0.987	-	-	-	-	-	-
St	0.479	5.783	-	-	-	-	-10.466	165.137	-	-
DI_NCP			-2.66	0.95	-	-	-	-	-	-
DI_TC	-1.622	74.29	-0.984	4.566	-	-	-	-	-	-
Length	0.002	196.33	0.001	29.859	0.001	21.852	0.001	9.549	-	4.678
Vintage	0.042	179.625	-	4.29	-	2.189	-	1.872	-	0.99

enough of the pipe units should have achieved a certain amount of failure so far. An extended sensitivity analysis (SA) incorporating the SIMLAB SA Methods, the failure prediction model and the WLC model is still in progress. This analysis will provide more conclusions about the impact of uncertainties in failure prediction on WLC calculations, and hence rehabilitation prioritization.

Assuming the future failure as given, the sensitivity of the WLC function on

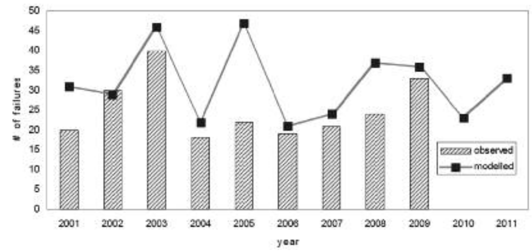
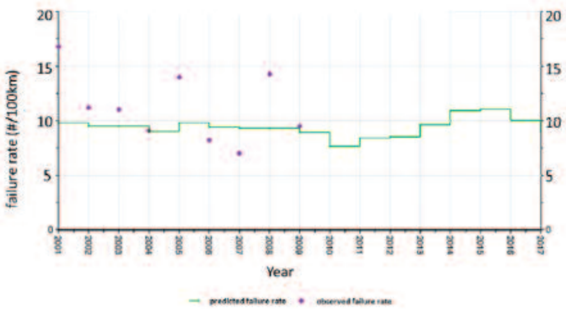


Figure 8: **Model validation for a partial network of a participating utility**

the variability of the remaining factors on lifetime costs has been analysed. The main influencing factors on WLC were found to be the rehabilitation costs (C^{Reha}), the repair costs including external costs ($C^{Rep} + C^{Ext}$) and the prize index z1. These factors are followed by the water losses per break (PFWL) and the amount of background losses (BL, SC) as well as the expected increase in inspection and maintenance intensities for aging pipes (ai).

Therefore, a pipe unit oriented allocation of expected rehabilitation costs should be a central part of WLC calculations. The example data of the

Figure 9: **Failure prediction for a rehabilitation scenario in an example network (PiReM Systems)**



Austrian utilities have shown that the rehabilitation costs distribution depends on the diameter. While at small diameters the cost values are normally distributed, the variations of the costs for bigger diameters are left skewed. It can be expected that the variations themselves are caused by pavement structures, the number of service connections and the number of other pipes crossing. But this additional information could not be provided for the cost data used in the described analysis. Further, according to C^{Rep} and C^{Ext}, information about the position of the pipe in the street body and the pavement structure is essential. Supplementary the expected failure types are of interest as they influence the repair type and hence the repair costs as well. z1 as an additional sensitive factor represents the discount rate minus the expected construction prize index, which in this case were derived from data provided by Statistic Austria. Finally, for a better estimation of pipe individual water losses, further research on the extent of water losses per break with respect to pressure and failure type is of interest. Regarding background losses the amount of service connections as well as pressure and type of pipe joint is of relevance. While the number of service connections per pipe can be easily derived from GIS data, less is known about individual background leakage per pipe joint and service connection. Closing this information gap is also of interest for future research. The influencing factors on the increase of pipe individual inspection and maintenance intensities should be incorporated in further information gathering processes as well. ●

Acknowledgements

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Stated and measured benefits of small potable water supply upgrades in New Zealand

Water suppliers do not measure the diverse ways in which proposed potable water supply investments are likely to impact a small community. This lack of measurement means that it is not known if proposed projects are likely to contribute to the overall wellbeing of a community. Here, Anna Robak and Henning Bjornlund discuss the necessary information for water suppliers to begin measuring the costs and benefits of potable water supply investments in the first comprehensive model of the economic, social, and environmental impacts of a potable water supply investment.

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The New Zealand government is imposing increasing legislative compliance requirements on water suppliers. Many small and medium sized water suppliers are struggling to maintain existing levels of service, and some of the legislation has come to be viewed as an unnecessary financial burden (New Zealand Parliament 2009). The legislation is intended to protect the public and the environment, yet the government has not previously evaluated the social, economic, and environmental costs and benefits of implementing projects to meet those legislative requirements. Under New Zealand law, local authorities may evaluate the overall costs and benefits of complying with legislation's underlying standards and conditions, yet they have no tools with which to do so.

Local authorities who are charged with promoting communities' economic, social, environmental, and cultural wellbeing through their infrastructure services struggle to identify the investment portfolio that will deliver the greatest community wellbeing. More and more water suppliers are turning to benefit cost analysis (BCA) and multiple criteria analysis (MCA) as a means of prioritising investment projects, but there are still significant gaps in measuring the benefit components of the BCA (Tadle 1990; Hanley, Spash et al. 1993; van Pelt 1994; Hajkowicz, Young et al. 2000; Hatton MacDonald 2004; Baffoe-Bonnie, Harle et al. 2007; WHO 2008; Simal 2009). In the field of potable water supply, there are a number of guidelines, handbooks, and papers on valuing the impacts of potable water infrastructure projects (Stober and Falk 1967; Finney 1984; Tadle 1990; Abeygunawardena 1999; Asian Development Bank 1999; Queensland Treasury 2000; Hutton 2001; UKWIR 2006; Baffoe-Bonnie, Harle et al. 2007; WHO 2008) and policies (USEPA 2002; Hutton and Haller 2004; USEPA 2005; USEPA 2006). Each of these documents focuses on only one or two water supply attributes, or has limited applicability to smaller water supply projects due to the extensive resources required for the evaluation. None of the guidelines addresses how to measure the impacts of all water supply attributes on each major stakeholder group.

To the authors' knowledge, this paper represents the first attempt at modelling the economic, social, environmental, and cultural costs and benefits of investments in a potable water supply system from first principles. The aim is to identify and estimate the magnitude of the most significant gaps inherent in traditional least cost analysis of potable water supply system investments as least cost analysis, aided by key performance targets such as customer satisfaction and legislative requirements, may degrade rather than improve community wellbeing. It is a concern that current investment decision mechanisms may tie communities to long-term unnecessary spending. Local authority decision makers will be able to use this model to understand and communicate the major impacts of a single investment type, or of an investment portfolio, on economic, social, environmental, and cultural wellbeing. The first principles model introduces a more robust, scientific, defensible approach to investments in potable water supply systems, and follows an increasing trend of using influence diagrams and systems thinking to understand complex systems (Checkland 2000; Petkov, Petkova et al. 2007). The model has been simulated through a hypothetical test case.

The only way to confidently estimate the magnitude of these social, environmental, economic, and cultural impacts is to map out the cause-effect relationships between the water supply system, consumers, wider society, and the environment. This mapping process, and the development of an explanatory model, highlights the system's most significant uncertainties. Once water suppliers have mapped the range of likely outcomes, they can estimate the value of any changes through revealed or stated preference methods. Where possible, we have modelled the impacts from first principles.

Recognising that not all impacts can be monetised, the model has been compared to New Zealanders' willingness to pay for various performance attributes to identify those costs and benefits for which stated preference studies will be required at community level.

Model development

To develop the first principles model an influence diagram of all elements of a potable water supply system and all stakeholders of a potable water supply system was produced, including upstream and downstream water users. Identifying stakeholders helps the understanding of who may benefit from the investment and who may bear the costs (Louw and Kassier 2002), and was therefore key to the development of the model. Yet stakeholder theory, while providing guidance on evaluating stakeholder salience (Fineman and Clarke 1996; Mitchell, Agle et al. 1997; Harrison and Freeman 1999; Ogden and Watson 1999; Hämäläinen, Kettunen et al. 2001; Harvey and Schaefer 2001; Currie, Seaton et al. 2009), is silent on how to identify 'candidate' stakeholders in the first place. In an attempt to capture all stakeholders and impacts, a stakeholder identification approach was developed based on project drivers, physical flows, major industries, water use trends, and project types (Robak and Bjornlund, in preparation).

An initial list of stakeholders was prepared based on a literature review of groups that initiated, constructed, operated, used, or were otherwise affected by potable water supply systems throughout history. The stakeholders were categorised according to their role, and 15 national level representatives selected from at least one of each of the categories presented below, as well as two 'generalist' water supply industry representatives. Some stakeholders represented more than one category. In-depth in person interviews were conducted with the 15 stakeholders to explore the benefit and costs (impacts of) infrastructure investments.

- Water suppliers – includes territorial local authorities. Two local authorities were interviewed.
- End user – includes consumers, territorial local authorities' other water uses such as street cleaning and pipe flushing, and system losses. Representatives from two territorial local authorities were interviewed – Federated Farmers, and the New Zealand Fire Service.
- Goods and service providers – includes physical works contractors, design engineers, equipment suppliers, legal services, and the insurance industry. Representatives from the physical works contracting, power generation and distribution, and insurance industries were interviewed.
- Legislators / regulators – includes public health, building, occupational health and safety, and environmental legislation and regulation. Representatives from the Ministry of Health (MoH), Parliament, and regional councils were interviewed.
- Investors – a representative from an infrastructure investment company was interviewed.
- Iwi – the Maori population – an Iwi values academic was interviewed. Iwi water values vary significantly across Iwi groups; the person interviewed has a broad view of Iwi issues and values.
- Environment – includes non-governmental organisations, regional councils, etc. Representatives were interviewed from one regional council, which is responsible for water take and discharge consents as well as fish and game, and Iwi, who value clean water.
- Water resource competitors – includes other water users impacted by, and who impact on, potable water suppliers' use of water resources. Representatives were interviewed from a regional council, who is aware of diverse water users within a catchment, and a power generation / supply company, which is affected by water resource abstractions upstream of their hydro dams.
- Major industries – includes tourism and dairy, two of New Zealand's largest industries. We interviewed a Member of Parliament and a representative from Federated Farmers.

Most New Zealand territorial local authorities survey residents to gauge their satisfaction with council services every one to three years. Many of these surveys allow open ended comments, which allow us to understand the scope of domestic water users' concerns related to potable water supply systems. Access was gained to these surveys from 49 of New Zealand's 67 councils. Following the interviews and an analysis of the survey reports, including open ended comments, the underlying models were begun to be developed, drawing on further academic and professional literature and general knowledge in each of the stakeholders' industries.

Partial models were initially developed to estimate the magnitude of the impacts across New Zealand, inferred from our interviews and from the literature. The cost of illness due to lack of a protozoa barrier was estimated using catchment risk and protozoa compliance data from MoH's Water Information New Zealand (WINZ) database. Other costs were estimated, including the number of illnesses due to service interruptions, the potential to reduce operating costs by reducing

Table 1: 'Typical' New Zealand potable water supply system attributes and targets

Drinking water standards	Actual	Target
Protozoa compliance		
Catchment risk	3 log	
Protozoa barrier provided	0 log	3 log
Reticulum pressure		
Maximum pressure (60m)	1000 kPa (100m)	600 kPa
Average pressure	930 kPa (93m)	
Water quality aesthetics		
Hardness	200 mg/l	<50 mg/l
Per capita demand		
Demand (per person per day)	500 l	350 l
Leakage		
Current leakage	30%	15%
Discharge consent conditions		
Current compliance	None (no sludge handling facilities)	Comply (do not discharge alum sludge to natural waterways)

Table 2: Potable water supply stakeholders and concerns

Category	Sub-category	Impact / concern
Water supplier		Costs / consumer satisfaction / legislative compliance* (see legislator / regulator categories below)
End user	Domestic (53%), industrial / commercial (25%), agricultural (6%)	Availability / affordability / reliability* (customer minutes) / taste* (avertive costs) / hardness* / odour* (avertive costs) / appearance / safety/health* (protozoa barriers and bacteria entering reticulation) / pressure / household costs*
	Losses (15%)	Costs* (water suppliers' costs)
	Public uses – flushing, fire, parks (1%)	Availability / pressure
Goods and service providers	Physical works contractors and design consultants	Predictability of future works
	Insurers	Damage due to pressure / breaks and bursts / backflow prevention
	Legal advisors	Legislative compliance
Legislators / regulators	Health (Ministry of Health)	Safety (protozoa, bacteria, viruses, toxins, chemicals)* (protozoa barriers and bacteria entering reticulation)
	Environmental (regional councils, Ministry for the Environment)	Abstraction volume and velocity / discharge quality* (based on cost of downstream treatment – see below)
	Fire (Fire Service)	Availability / flow / pressure
	Civil Defence	Availability
	Building and housing	Availability and reliability
Investor		Financial stability
Iwi	Consumer	Avoid use of chemicals / avoid mixing waters from different sources
	Downstream water user	Cultural celebrations in water / ability to source food from water to host cultural events
Downstream water resource users	Downstream water consumers (industry, agricultural, domestic)	Availability / flow / quality – health and safety / quality – clarity / quality – cost to treat
	Hydrogeneration schemes	Availability / flow
	Anglers	Abundance and variety of fish life
	Other recreational users, including tourists	Availability / flow / quality – health and safety / quality – clarity
	Aquatic life	Quality – fish health
	Viewers, including tourists	Clarity
Upstream water resource users	Water consumers and land users (industry, agricultural, urban runoff, forestry runoff, wastewater discharge)	Availability / flow / runoff / discharge quality – health and safety, solids* (impact of sediments on cost of water treatment)
Environment – other	Air quality	Emissions in water supply construction and operation through use of electricity and vehicles* (electricity in operation only)
	Natural resources	Abstraction – natural resource sustainability
	Landfills	Waste production – land availability
Major industries / 'New Zealand Inc'	Tourism	Health and environmental reputation
	Export market (food)	Health and environmental reputation

*Negative value suggests economic loss would occur

system pressures or implementing demand management initiatives, the increased risk of fire damage due to pressure reduction, and the value of water abstracted, from data provided two New Zealand benchmarking initiatives. The Auckland Water Group (AWG) and Water New Zealand (WNZ) undertake annual benchmarking exercises (Auckland Water Industry 2009; Water New Zealand 2010), providing base data for the estimates such as the number of service interruptions, population covered by metering, operational costs / consumer water rates, reticulation pressures, number of connected properties, and leakage. Between them the reports cover over 60% of New Zealand's water supply systems. It is mostly the larger cities and towns who make up members of the benchmarking group. For this reason, the extrapolation of these data is conservative when applied to the remaining 35-40% of cases.

Partial models

The source data and relationships that form the models are highly uncertain, as they draw from a variety of countries that are likely to have different environmental conditions, risks, and values. However, for the purpose of a preliminary assessment of the impacts of one or more investment types, the following models have been pulled together.

Water quality

Drinking Water Standards compliance – protozoa barrier. Following the approach by USEPA (2005) as adapted for the New Zealand case by Robak & Bjornlund (2009). Risk of illness is estimated based on catchment risk assessment and protozoa treatment barrier provided. Cost per illness case is based on international ex post analysis of the costs of *Cryptosporidium* illness cases.

Aesthetics – hardness. Adopting MWH (2007) estimates for household expenditures on soaps, water heating costs, and water heater maintenance.

Pressure

Reduced number of breakages due to reduced maximum pressure based on Thornton & Lambert (2007). Reduced risk of bacterial illness due to service interruptions using Nygård et al's (2007) Norwegian gastrointestinal illness (GII) estimates, New Zealand's base GII rate, and international ex post analysis of the costs of waterborne bacteriological illness cases. The leakage reduction was modelled following Thornton & Lambert (2005), where leakage is linearly related to pressure. To value the reduced operating costs of leakage reduction the variable operating costs of water supply were reduced proportionally to the reduction in water abstracted. To value the environmental benefits of reducing abstraction Frederick, Hanson & VandenBerg (1996)'s US estimates for freshwater were applied. Finally, fire protection sprinkler systems are designed to operate only as low as 80% of a reticulation's recorded operating pressure range and may not function if the pressure is reduced below this (pers. comm. Bob Oldnall, insurance industry, January 2011). The interviews suggest that the insurance industry increases premiums by 30-35% if a fire sprinkler system is not in place – it is assumed this reflects the additional damage if a fire sprinkler system fails.

Demand management

Research suggests that demand management may reduce consumption by more than 50% (Burn, De Silva et al. 2002). We have estimated a conservative 20% reduction in demand and applied this reduction to variable operating costs, as well as benefits of reduced abstraction. Furthermore, we have estimated the equivalent reduction in wastewater produced with a corresponding reduction in variable operating costs.

Model build and simulation

Using national level data it was not possible to estimate the capital costs and many of the operating costs associated with investments in potable water infrastructure due to variability in environmental conditions and potable water supply system makeup and performance. To understand if the savings, or benefits, are likely to outweigh the costs of each of these investment types, the model was constructed around a 'typical' New Zealand potable water supply. Four thousand people are served by this water supply, with approximately three people per household. The reticulation pressure, length, break frequency, and condition are modelled after Panmure in Auckland. However, to ensure that a range of investment types were covered, water hardness, leakage, demand, and protozoa barriers and treatments from other New Zealand water supply systems were also used that the authors are familiar with. The attributes and targets have been summarised in Table 1.

The model was developed in STELLA v9.1.4 to simulate the interactions between the various project types. To test the model, the most topical and politically controversial investment types were used: improving water treatment to comply with the New Zealand Drinking Water Standards; demand management; pressure management / leakage reduction; constructing sludge diversion facilities; and reducing hardness. As a development to the partial models, the reduced costs due to reactive repair per break were also estimated, and a decrease in annual depreciation costs due to extended pipe life. Both the national level estimates and 'typical case' estimates to willingness to pay values were compared and gaps identified in both the first principles model and willingness to pay values.

Stakeholders and impacts

Table 2 summarises the list of stakeholders and impacts of potable water supply systems, yet current practice only values the first impact on the first stakeholder: the impact of operating costs on the water supplier. The peer reviewed and grey literature, however, suggest there are significant costs and benefits not being measured – New Zealanders are willing to pay at least NZD$90 (US$68)/household (hh)/yr to soften their water (WDC 2007), up to NZD$500 (US$377)/hh/yr to internalise ecological impacts (Creagh 2010), up to NZD$3100 (US$2340) /hh/yr to ensure a long-term supply and maintain natural flows (Kerr, Sharp et al. 2001), and, according to resident satisfaction surveys, 30-45% of affected households are willing to install filters to remove taste and odour. Furthermore, in earlier papers we have estimated significant potential health benefits associated with water quality improvements and reduced service interruptions (Robak and Bjornlund 2009; Robak and Bear 2010). Through this simple exercise we have demonstrated there are significant cost and benefits not currently being quantified, but the question remains, who is being impacted and how significantly?

Table 3: Potential economic savings by project type at national level, total and per household savings

Improvement type	Economic savings: Nation-wide (millions NZD)	Economic savings: Per affected household or property (NZD)
Water quality		
Expected protozoa illness cases due to inadequate water treatment	82	1300
Pipe renewals / pressure management		
Expected bacterial illness cases due to mains breaks	8600	7000
Pressure management		
Potential to reduce operating costs by reducing pressure	34	30
Water – potential to reduce abstraction	5	4
Potential property damage losses due to fires*	-6	-300
Demand management / metering		
Potential to reduce operating costs by reducing consumption	60	74
Water – potential to reduce abstraction	9	10
New centralised water supply system		
Potential to reduce fire damage if install retic to all properties in NZ	21	170

*Negative value suggests economic loss would occur

National estimates

The significance of potable water supply investments nationally was estimated and it was found that bacterial illness due to service interruptions may be the most significant unintended economic cost of a potable water supply system, at annual costs of NZD$8.6 billion (US$6.5 billion), or NZD$7000 (US$5284) per affected household (Table 3). In the case of the reduced cost of bacterial illness, our greatest uncertainties lie in the relative risk of illness due to low pressure events in New Zealand reticulation, for which we have only overseas data to rely on. Furthermore, the costs do not consider the impracticality and cost associated with eliminating all service interruptions; nor do they consider deferred maintenance benefits due to the aggregate level of data. To estimate the net benefits of an investment and to simulate the interactions of the partial models for different investment types, a 'typical' New Zealand case is used.

Model simulation for typical case

The simulation was run through STELLA for five major project types, to estimate the household level economic, social, and environmental benefits of each. The results of the simulation, provided in Table 4, suggest that pressure management investments may provide the most significant benefits, in terms of public health as well as operating costs.

Gaps between willingness to pay literature and first principles models

According to economic theory, willingness to pay represents the full value of an improvement. Table 5 summarises the only New Zealand willingness to pay studies related to potable water supply. Due to the lack of New Zealand willingness to pay studies, in an effort to make initial estimates about the scale of New Zealanders' values for different attributes, grey literature has also

Table 4: Model outputs – annual benefits of investments per household

Investment type	Pressure management	Water softening	Drinking water standards compliance (protozoa)	Demand management
Reduced cost of illness (protozoa)	0	0	20-10	0
Reduced cost of illness (bacterial)	170-8200	0	0	0
Reduced household expenditures	0	46	0	0
Reduced water rates	100	-36	50	5
Reduced water rates	0	0	0	23
Reduced cost of abstractions	0.12	0	0	0.6-32
Reduced cost of fire damage	-0.25	0	0	0
Total	*270-8300*	*10*	*-30-110*	*60*

Table 5: New Zealand published willingness to pay studies

Attribute	Mean willingness to pay (2009 NZD/hh/yr)	Source
Water services		
Hardness	90	(WDC 2007)
Avoid water treatment (cultural)	830-1500	(Kerr, Sharp et al. 2001)
Environmental services		
Avoid decreased flows in rivers and eventual water use restrictions	700-3150	(Kerr, Sharp et al. 2001)
Maintain surface water flows	190-980	(Kerr, Sharp et al. 2003)
Maintain groundwater flows	250	(Sharp, Kerr et al. 2000)
Internalise environmental / ecological externalities	120-190	(Creagh 2010)
Internalise environmental / ecological externalities	180-490	(Creagh 2010)

been drawn on (Table 6).

Based on national estimates, a hypothetical case study, and willingness to pay values, the most significant costs and benefits typically left out of a traditional least cost analysis include the costs of reduced illness, avoidance of eventual restrictions, maintenance of natural flows, and avoidance of chemical treatment.

Conclusions

The scientific information is available to begin estimating some of the economic, social, environmental, and cultural impacts of potable water supply system investments from first principles. By examining costs and benefits of different investment types using a single model, some of the most significant unintended impacts of a proposed investment can be estimated.

New Zealand willingness to pay studies and the first principles model suggest that the most significant impacts of investments are as follows:

- Drinking water standards compliance: protozoa barrier – cost of illness – increased operating costs (water supply) – possibly all costs related to sludge diversion if filtration is introduced for the first time
- Pressure management: Cost of illness – value of water abstracted – reduced operating costs (water supply) – property damage – customer time – fire damage
- Demand management: value of water abstracted – household costs – customer time – property damage – wastewater operating costs – fire damage
- Hardness treatment – household equipment (avertive / renewals and operating expenditures)

In New Zealand, the state of the water service delivery may be incurring the following costs to the economy:

- Cost of illness (bacterial) NZD$8.6 billion (US$6.5 billion)
- Cost of illness (protozoa) $82 million (US$61.9 million)
- Operating costs due to lack of metering $60 million (US$45.3 million)
- Fire damage $21 million (US$15.8 million)
- Operating costs due to excessive pressure $19 million (US$14 million)
- Value of excessive water abstraction $5 million (US$3.8 million)

At national level, our model suggests the most significant cost savings could be made through reducing the number of service interruptions through pressure management projects. At a potential economic cost saving of NZD8.6 billion, the improvement seems to be worth a more targeted effort.

The national level estimates and hypothetical case study application suggest the types of investments that should receive the most focus are:

- Pressure management (to reduce risk of bacterial illness, defer capital expenditure, reduce operating costs, and reduce water abstracted)
- Demand management (to defer capital expenditure, reduce operating costs, and reduce water abstracted)
- Water quality improvements (to reduce protozoa risks)

Willingness to pay studies suggest New Zealanders are willing to meet the environmental costs of their water services; New Zealanders have yet to be asked about their willingness to avoid bacterial and protozoal illnesses and their preferences for avoiding fire damage. To the authors' knowledge, this paper is the first to consider the various intended and unintended costs and benefits of various types of potable water supply system investments, and significant gaps have been left. For example what has not been considered is the cost associated with water supply restrictions, customer value of time during service interruptions, household expenditures to prevent taste and odour, or the impact of poor tasting water on dairy productivity, for those dairy farmers who use potable water. Further research is needed to fill these gaps, and to confirm many underlying assumptions, such as the risk of illness to New Zealanders. In the next stage of research the model will be tested on two real New Zealand communities.●

Table 6: New Zealand unpublished willingness to pay studies

Attribute	Mean willingness to pay (2009 NZD/hh/yr)
Water services	
Build new reticulated supply to replace self-supply	Unwilling to pay $500
Reduce source water vulnerability, improve water quality, reduce frequency of service interruptions, provide growth capacity	1000
Improve water quantity, not specific	6
Improve water quality, not specific	8
Reduce taste and odour	11
Increase maintenance frequency	-0.4
Environmental services	
Maintain stream flows	14
Improved environmental quality (not specific)	9

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Table 7: Gap between first principles model and New Zealand willingness to pay literature

Attribute	First principles ($/hh/yr)	Willingness to pay ($/hh/yr)	Difference ($/hh/yr)
Water services			
Water quality – protozoa barrier	20-1300		20-1300
Water quality – hardness	50-230	>=90	<=120
Water quality – avoiding treatment		830-1500	830-1500
Water quality – 'improved' – not specific		8	8
Water quality – taste and odour		11	11
Pressure	270-8200		270-8200
Demand management	4-84		4-84
Multiple attributes – quality, reliability, and growth capacity		1000	1000
Move from self to community supply		<500	<500
Maintenance frequency		-0.4	Negligible
Environmental services			
Maintain stream flows		14-980	14-980
Maintain stream flows and avoid eventual water use restrictions		700-3150	700-3150
Maintain groundwater flows		250	250
Improve environmental quality		9	9
Internalise environmental / ecological impacts		120-490	120-490

Real-life inline inspection of buried PVC push-fit joints

Half of The Netherlands' water supply network is constructed from PVC pipes, with 29% of failures taking place at the joint, however deterioration mechanisms in PVC pipes are not well documented. In this paper, A Arsénio, J Vreeburg, R de Bont and JC van Dijk explore the possibility to identify the current condition of a push-fit joint through inspection of the gap between pipes in joints, which gives valuable information on the pipe's condition.

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In 2010 the Dutch drinking water network stretched for almost 116,000km, supplying water to more than 16 million people. Almost 50% is made of PVC (Geudens, 2010). The analysis of the failure registration of five Dutch drinking water companies showed that around 29% of the total number of failures in the PVC Dutch network is detected at joints. In the Netherlands the PVC joints are single pieces with two rubber rings.

According to Rajani & Kleiner (2001) the long-term deterioration mechanisms in PVC pipes are not well documented, mainly because these mechanisms are typically slower than in, for example, metallic pipes and also because PVC pipes have been used commercially only in the last 40-50 years. Similar conclusions were presented by Breen et al. (2004).

Moreover, the joint must accommodate movements of the pipe throughout its life and be subjected to bending due to soil settling. In addition to this, the rubber ring(s) may stop sealing properly due to the effect of abrasion, for example due to the intrusion of sand into the joint. Therefore, this study focused on condition assessment of PVC push-fit joints.

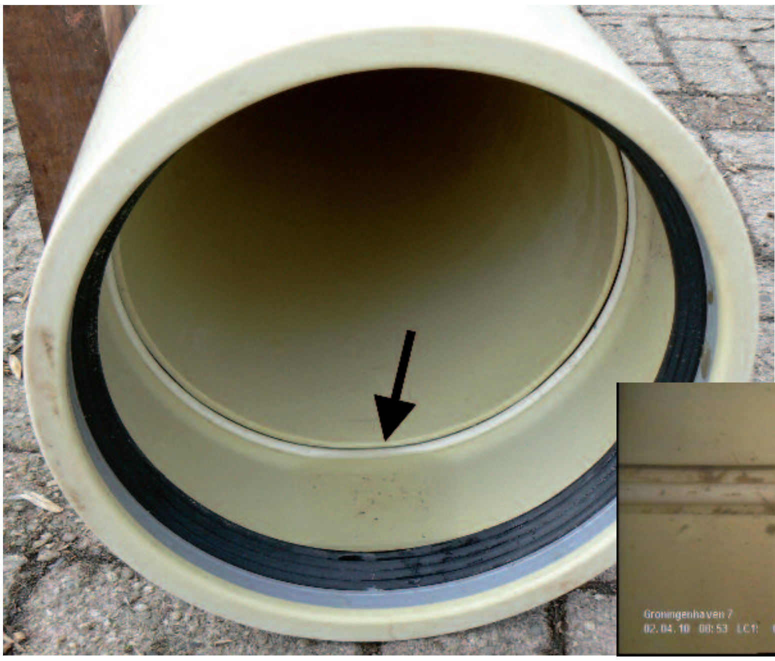

Figure 1
Left) image of the interior of a PVC joint, the gap is signalled with an arrow. Right) image of the interior of the same PVC joint.

Condition assessment can be performed using non-destructive evaluation (NDE) equipment. NDE equipment is a valuable tool to help water companies anticipating failures in PVC joints.

Condition assessment of joints

Definition of a joint's condition

The alignment of the pipes connected using a joint can be used to characterize the joint's condition on its criticality. The pipes inside of a joint are separated by a gap (Figure 1). Different alignments of the pipes will correspond to different shapes of the gap (Arsénio et al., 2010). The shape of the gap can be obtained through measuring its width at different positions. If the width of a gap is obtained at four different locations (pipe crown, invert and both spring-lines), its 3D orientation can be determined. Using the values of the gap's widths, using simple trigonometry, the relative angles between the two pipes inside the joint can be obtained. One angle is obtained for the relation crown-invert and another for both spring-lines. Three situations can be hypothesized (Figure 2):

- Correct alignment: the joint will show the same gap for the four measured points
- Downward joint bending: the gap at the bottom is bigger than the gap at the top. In the present work this is defined as a negative angle
- Axial pull-out: the gap width is uniform for the whole pipe diameter

Ideal and limit condition of a joint

A PVC joint is designed to accommo-

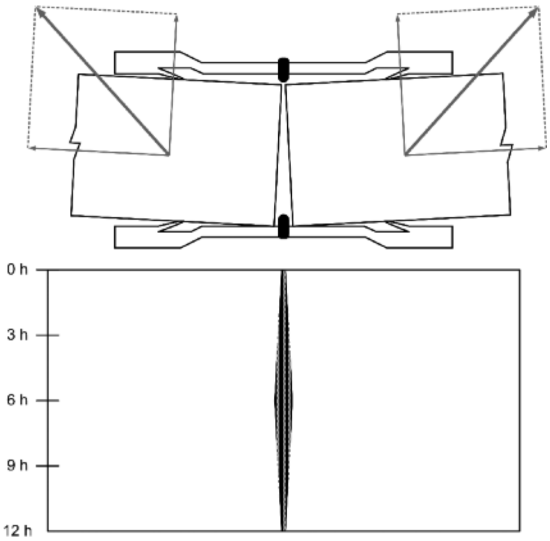

Figure 2
Downward bent joint and corresponding unfolded image of its interior (below). The unfolded images show the shape of the gape for the complete perimeter of the pipe.

date changes in alignment. The limit bending angle varies with diameter and with the shape of the joint. The ideal conditions of a joint can be defined as the alignment inside the joint that minimizes the occurrence of leakage and allows for a certain movement of the pipe. In this situation the pipes inside the joint are perfectly aligned and are not touching each other or the joint's inner-wall. The limit condition of a joint is an alignment inside the joint for which a slight variation in the joint's alignment leads to a failure. A failure is defined as leakage. In the case of joint bending the limit condition is given as an angle. In the case of axial pull-out the limit condition is given as a distance.

Non-destructive evaluation equipment

The shape of a joint's gap can be obtained using non-destructive evaluation (NDE) equipment. The current shape of the gape is indicative for the condition of the joint. The development of the gap overtime, observed with repeated inspection, is indicative for the lifetime expectancy of the joint.

According to Dingus et al. (2002), no vendors had field-ready methods to examine polymer pipes such as PE and PVC. The authors went on saying that polymer pipe inspection was lagging behind NDE for other piping materials. Moreover, when the same authors published their report, the most promising idea at the moment of this research was an ultrasonic system mounted on a pig. In the context of this work, the basic need is to observe the surface of the pipe, being the joint's gap presented as a discontinuity of the pipe wall. The ultrasound equipment usually consists of a pulser / receiver and a transducer (typically piezoelectric). The pulser / receiver is an electronic device that generates high voltage electrical pulses. Due to these pulses, the transducer generates high frequency ultrasonic energy that propagates in the form of waves. When there is a flaw in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Signal travel time can be directly related to the distance that the signal travelled. With this approach, information about the location, size and orientation of the flaw can be obtained (Hellier, 2001). The assessment of PVC joints in laboratory using ultrasound was discussed by (Arsénio et al., 2010). Another possibility for the assessment of the gap in the joints is a visual technique. CCTV examination using a mobile camera system is the typical approach to this type of examination. Table 1 presents the characteristics of both CCTV and ultrasound. This work is focused on PVC joint but the procedure can be extended to other pipe materials.

Inspection of a PVC pipe

A DN500 PVC pipe was inspected, which burst in 2011. The burst occurred at a barrel, not at a joint. The objective of the inspection was to gather information on the condition of the PVC joints. The pipe was empty and inspected using CCTV. The equipment was an IBAK Modular II system with an Argus 4 camera.

The access to the pipe's interior was made through the burst section. Two valves were closed to isolate the burst point. The distance between the burst and the valve to the north was around 200m. The distance between the burst point and the valve to the south was around 400m.

The inspection took four hours and a total of 54 joints were inspected. For each joint the gap width for the crown, invert and both spring-lines was obtained. Using these four values two angles could be obtained using trigonometry: one angle for the pair pipe invert-pipe crown (horizontal plane); and one angle for the both spring-lines (vertical plane).

Figure 3 plots the gap width at one spring-line (9h) plotted against the gap width at the opposite spring-line (3h). An open marker represents an inspected joint. As can be seen, with the exception of four joints, all joints are aligned along the x=y dashed line. No explanation was found for this discrepancy and these values are scattered along the pipe length. This indicates that the pipe is aligned along a vertical plane.

Figure 4 plots the gap width at the pipe's invert (6h) against the gap width at the pipe's crown (12h). An open marker represents an inspected joint. With the exception of two joints, all joints align above the x=y dashed line. This indicates that, according to a horizontal plane, the gap at the bottom of the joints is bigger than the gaps at the top of the joints. The pipe is sagging below the joints and these results demonstrate that this procedure can be used to detect this effect.

On Figure 5 each black marker represents an inspected joint. The vertical dashed line at x=200m represents the burst point. This was also the access point for the inspection. Values of pipe angle in degrees are plotted against axial position (m). Axial position is equivalent to inside's pipe position. This is a different representation of the data given on Figure 4. A negative angle indicates that the gap at the bottom of the pipe is bigger than the gap at the top. Only two joints have positive angle, the remaining indicate that the pipe is sagging at the joints. A cluster of angles below -3° is also detected around the burst point.

What these results show

Figure 4 and Figure 5 clearly demonstrate that the pipe is sagging below the joints. In Figure 5 it can be seen a cluster of high value angles close to the burst point. Some angles are below -4° and one is ca. -5.8°. This might indicate that the barrels close to the burst point are under high stress. No quantitative evaluation of the joints' condition can

Table 1: Characteristics of CCTV and ultrasound

Technique characteristics

CCTV	Ultrasound
• Operated with water filled or empty pipe	• Requires the pipe to be filled with water
• Requires the pipe to be kept out-of-service	• Requires the pipe to be maintained pressurized
• Useful for out-of-service applications for in-service inspections	• Ultrasound mounted on a pig is useful
• Existence of an umbilical cable	• Lengthy post-processing data
• Inspection may be affected by water turbidity	• Equipment does not have umbilical cable
• Requires continuous control	• Assessment is independent of water turbidity
• Maximum inspectable distance in one run is affected by the presence of bends, elbows, pipes with different diameters, < 600m	• Does not require continuous control
	• Maximum inspectable distance in one run
	• Inspections in PVC pipes >4km have been reported
	• Determination of the wall thickness

be made since data on limit conditions of joints is, at present, unavailable. Testing standards with tolerance values for PVC pipes and joints are publicly available. However, these do not give information on limit conditions of joints.

The pipe is aligned according to a vertical plane (Figure 3). It is hypothesized that the distribution of the horizontal and vertical angles would have been similar when the pipe was laid. In the Netherlands in the 1970s-80s during the installation of a new pipe, a small hole was dug under the joints to ease the installation procedure. The compaction of the support below the pipe remained insufficient. This may explain the pipe sagging below the joints. Measuring the gap widths seems, therefore, to be an accurate procedure to obtain information about the current condition of joints.

A 10m section of the pipe in which scratches on the inner wall were detected has been planned to be removed and further studied in laboratory. This is the barrel located at x=250m. The rest of the pipe appeared to be in good condition. This was not, however, the main objective of the inspection. Nevertheless, it points to the variety of significant results that can be obtained from a pipe inspection with CCTV.

An attention point with the utilization of NDE is the access to the pipe's interior. This is a process that requires adaptation of the existing network. For repetitive inspection it would be efficient to have permanent access points. This could be done, for example, on important transport mains. It also requires a disinfection procedure of all equipment. Nevertheless, this work demonstrates that the interior of pipes can be inspected without problems of impacted water quality if proper disinfection procedures are followed.

Conclusion

The type of joint typically used in the Dutch PVC network has two rubber gaskets and connects two pipes. An alternative is the bell and spigot, with a single rubber gasket that is attached to the bell. This system is also used with other materials. The principles discussed in this paper are the same for both jointing techniques and for all pipe materials despite the present work being focused on PVC networks.

In this work it is clearly demonstrated that the inspected pipe was sagging under the joints, probably due to improper installation procedure. The burst occurred on a barrel. Near the burst point more extreme joint gaps were detected. This seems to indicate that a barrel might fail due to extreme bending on a joint and that this can be detected using joint inspection. The present work also shows that CCTV inspection of PVC pipes gives information on current condition of inspected joints and is a promising procedure for pin-pointing joints in a pipe that might be under risk.

Acknowledgements

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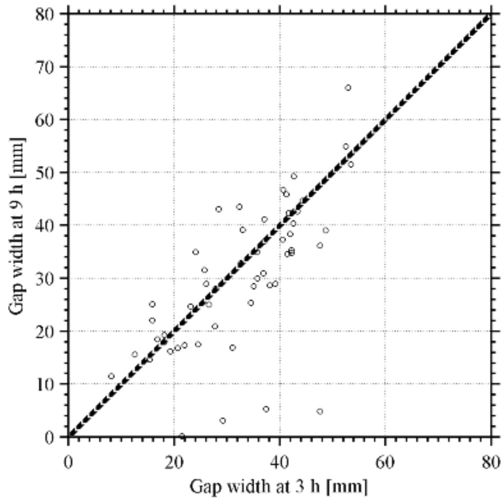

Figure 3
Joint gap at one spring-line (9h) vs the joint gap at the opposite spring-line (3h). An open marker represents one inspected joint. The dashed line represents x=y.

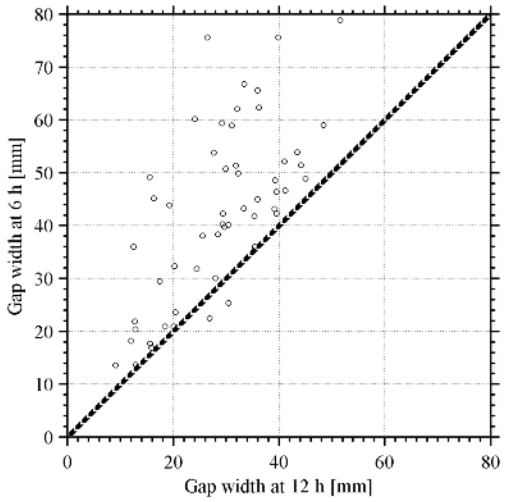

Figure 4
Joint gap at invert (6h) vs the joint gap at crown (12h). An open marker represents one inspected joint. The dashed line represents x=y.

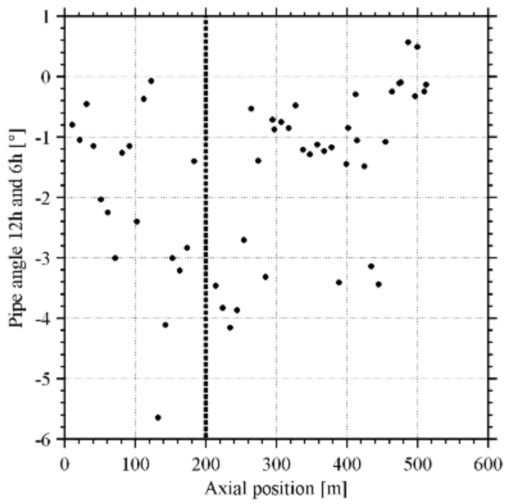

Figure 5
Values of pipe angle as a function of axial position – inside pipe's location. A filled marker represents one inspected joint.