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UK water sector shares rise as Southern goes up for sale again

Interest in the water sector in England and Wales has been reignited by the news that the Royal Bank of Scotland has put Southern Water up for sale again with a £4 billion ($7.9 billion) price tag.

Water stocks shot up amid City speculation that there would be no British-listed companies left by the end of next year. Kelda (which owns Yorkshire Water), Pennon (which owns South West Water), Severn Trent, Northumbrian and United Utilities are all seen as possible targets.

The speculation has been fuelled by the Competition Commission's go-ahead for the merger of Mid Kent and South East Water against economic regulator Ofwat's wishes. Ofwat is opposed to any more inter-company mergers because it fears the loss of comparators vital to its price and service determinations.

RBS (the Royal Bank of Scotland), which owns 49% of the much-sold Southern Water's shares and 94% of the company's economic interest under a complex ownership system, has appointed Deutsche Bank to oversee the sale.

It has been part-owner of Southern for four years, and bought its share for £2.1 billion ($4.1 billion). Vivendi Environmental (now Veolia) was supposed to be lead owner, but objections to its ownership (because of other UK water interests) caused it to take a back seat and bow out altogether last year.

The other large shareholders are two US hedge funds, Perry Capital and DE Shaw. A spokeswoman for RBS said: 'Our ownership of Southern Water is under review as part of the normal course of business.'

Southern employs around 2000 staff and supplies water to a million households, and treats wastewater for around two million customers. Its assets are worth around £3 billion ($5.9 billion).

However, speculation that the Mid Kent-South East merger might herald a new era of consolidation might be premature. An attempt several years ago by Wessex Water and Severn Trent Water to buy Pennon, South West Water's parent, was firmly rebuffed in a judgment that enshrined what is assumed to be an unbreakable principle that none of the 'big ten' water service companies can be merged.

Lis Stedman

EC urges compulsory water metering

The European Commission has issued a communication on moving the EU towards a water-efficient and water-saving economy that sets out initial policy options including compulsory metering and a water efficiency drive.

Environment Commissioner Stavros Dimas said: 'Access to water in sufficient quantity is fundamental to the daily lives of human beings and many economic activities. The major impacts of water scarcity and droughts are expected to be made worse by climate change.

'We thus need an integrated approach on water because sustainable water use is absolutely vital if we are to ensure that enough water is available to all European citizens and economic activities.'

EU member states must take an integrated approach, which is likely to deliver better results than targeting a single issue, the paper notes. States must put the right price on water, with the 'user pays' principle becoming the rule.

They should also promote water savings and water efficiency and adapt economic activities to the amount of water available locally, it added.

Over the past 30 years droughts have dramatically increased in number and intensity, and have cost the European economy at least 100 billion ($137 billion). If temperatures keep rising and no clear mitigation strategy is adopted, the water situation may deteriorate further, the EC experts warned.

Europe is currently wasting some 20% of available water, with recent data indicating this figure is likely to rise to 40%, the commission said.

Commission experts have said that a water saving policy needs to be created, like the one created for energy, and accused member states of dragging their feet in implementing EU rules on water pricing.

'Substantial changes' are therefore needed, which should include 'essential' efforts to introduce compulsory metering programmes as well as the promotion of water-saving devices on taps, shower heads and toilets, the EC added.

On a larger scale, a proper allocation of water use between economic sectors needs to be considered. Policy-making should be based on a clear 'water hierarchy', meaning that water saving must become the priority.

Effective water pricing and cost-effective measures for improving water demand management should also be considered before opting for additional water infrastructures.

This means that the integration of water sustainability and sustainable land use must become an integral part of policy making in areas such as agriculture and tourism. All activities should be adapted to the amount of water available locally. **LS**

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EDITORIAL

Editors
Steve Allbee
allbee.steve@epamail.epa.gov

Andrew Foley
afoley@goldcoastwater.com.au

Andrew Smith
andrew.smith@yorkshirewater.co.uk
Water Asset Management International is an international newsletter on asset management in water and wastewater utilities. The focus of the newsletter is on the strategic aspects of this developing field, providing utilities with international perspectives on infrastructure planning and maintenance as they seek to deliver cost-effective services to their customers.

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Papers for consideration should be submitted to the editors or to:

Oisin Sands
Publishing Assistant
osands@iwap.co.uk

PUBLISHING

Associate Publisher
Keith Hayward
khayward@iwap.co.uk

Publisher
Michael Dunn

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IWA Publishing
Alliance House,
12, Caxton Street,
London SW1H 0QS, UK
Tel: +44 (0)20 7654 5500
Fax: +44 (0)20 7654 5555
Email: publications@iwap.co.uk
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Fax: +44 (0)1206 79331
Email: sales@portlandpress.com

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PAC slams Environment Agency over flooding

The Commons Public Accounts Committee has condemned the Environment Agency for not doing enough to mitigate flooding, following major floods in Wales, the Midlands, Lincolnshire and Yorkshire that left seven dead.

Edward Leigh MP, the chairman of the Committee, issued a statement saying: ‘Flooding is an ever present risk to millions of homes and businesses in this country but the Environment Agency has not done enough to improve the condition of our flood defences. No less than six years have passed since our Committee asked for remedial action to be carried out as swiftly as possible.

‘That fewer than half of the country’s high risk flood defences were at target condition at the time of the National Audit Office’s review demands an explanation from the Agency. We simply cannot say, if there is a flood, whether these defences would stand up.

‘Flood defences are critical to the protection of towns, cities and people’s homes. There were significant variations on the amount spent on defences, with only small change going to the North East compared with the Midlands and Thames.

‘I welcome those areas of improvement in how the Environment Agency manages its floods defences – especially that an additional 100,000 households have been better protected from floods in the past three years. But the Agency now needs to get its priorities right.

‘The Environment Agency should put more of its efforts in to protecting towns and cities, rather than empty fields.’

The Environment Agency swiftly issued a statement rebutting the claims. Chief executive Baroness Young said: ‘We reject the charge that the Environment Agency has massively failed, as alleged in the Commons Public Accounts Committee hearing today. In the last seven years, we have created defences that protect 100,000 homes in floodplains, as well as dramatically increased those receiving flood warnings and greatly improved flood mapping and forecasting.

‘The current floods result from extreme weather events with flooding mostly from surface water drainage and defences being overtopped by the sheer amount of water – which has been more than a 1-in-150 year events in many places.

‘Our flooding warnings were out on time. We would urge the community to go onto our website, or phone Floodline, to check their flood status and what they can do to protect themselves.

‘We continue to make hard choices, with limited funds between building new defences for unprotected communities and maintaining existing defences. However, in many situations in the current floods no amount of defences would have protected communities against the overwhelming weight of water that fell in an incredibly short period on already saturated catchments.

‘We have done a lot and made significant achievements over the last five years, as the National Audit Report states. More people and property are protected and forecasting, mapping and warnings are much more effective.

‘I am proud of what we have achieved. If there is one major problem, it’s that there is much more that we could do if we had adequate funding.’

The Baroness had faced a grilling before the PAC at the height of the flooding. Uncorrected PAC transcripts show the Committee accused the EA, among other things, of failing to fulfill targets for catchment flood management plans for the river Don, which overtopped and flooded Sheffield.

She explained that the flooding in Sheffield was an ‘extreme weather event’ caused by a combination of surface water overwhelming drains and river over-topping rather than a failure of defences.

The Baroness also had to defend the EA against accusations of ‘shortcomings in your management systems…shortcomings in your allocation of funds between areas…shortcomings in terms of budgeting for cost and maintenance staff…shortcomings in terms of the lifespan of assets and…shortcomings in terms of construction costs.’

She told the Committee: ‘We have exceeded all of the targets set to us by Defra in terms of our mapping, our warning and our construction of flood defences.’ She was also asked about the impact on capital expenditure of Defra’s cuts in the EA’s budget for last year, of £15 million ($30.2 million), of which £6 million had been reinstated.

She noted: ‘The theory was that we were to protect capital and simply take it from revenue, but in reality it did mean that some of the precursors to capital expenditure had to slow down, things like the catchment flood management plans and some of the work-up of schemes for the pipeline. That is no hardship because we have so many schemes in the pipeline that we cannot fund them anyway.’

She emphasised the unusual nature of the recent flooding, saying ‘It would have been unwise of us to reserve funding for a very unusual event like the one we have had in the last two weeks, because we would simply be leaving money fallow.’

Lis Stedman

RUSSIA: PUTIN BANS PRIVATISION OF RESERVOIRS

Russian president Vladimir Putin has enacted a law banning the privatisation of some water and land assets related to the public water supply, the Kremlin has announced. The legislation amends Russia’s current Water and Land Codes, and bans privatisation of reservoirs used as drinking water sources as well as surrounding land.

AUSTRALIA: SYDNEY AWARDS RO DESAL CONTRACT

Sydney Water Corporation has awarded a contract for the construction and operation of a 250,000m^3/day seawater reverse osmosis desalination plant to Veolia Water and its construction partner John Holland. The plant is due to begin operation by late 2009.

UK: THAMES MEETS LEAKAGE TARGETS

The economic regulator for England and Wales, Ofwat, has announced that Thames Water has met its leakage targets for the first time in seven years, reducing it to 810MLD. Thames has announced it will spend £900 million ($1813 million) next year on improving and replacing its pipe network.

PANAMA: JAPAN BANK TO FINANCE WWT SYSTEM

Assistance equivalent to around $160 million is to be provided to Panama by the Japan Bank for International Cooperation to support a project that will include construction of the country’s first full-scale wastewater treatment system. The project will improve the environment of Panama City and Panama Bay.

Government water policy must be better informed, warns Australian commission report

Australia's water issues continue to make headlines, with a national report on water resources warning that state governments are making important decisions without adequate data.

The National Water Commission report stresses the need for governments to cooperate in the water reform process and points to continued management failures across the sector and throughout the country.

The chairman of the National Water Commission, Ken Matthews, denied that the federal government should have waited for the report before setting targets for the $10 billion Murray-Darling plan, saying: 'The report also highlights the need for nationally consistent methods for measuring river and wetland health – only Victoria and Tasmania could provide such data.'

The report recommends a nationally-agreed measurement for sustainable water use, and a framework for assessing river and wetland health.

Queensland and New South Wales are seeking to solve their water shortages by altering border river laws to allow irrigators to trade water, either selling or leasing their water allocations or buying more from either side of the state borders.

Inter-state water trading should be available by September, according to Queensland water minister Craig Wallace. He said the scheme would ensure more efficient use.

Melbourne Water managing director Rob Skinner added to the debate about how to solve water shortages by warning the city's water demand could outstrip the quantity that the state government plans to deliver by 2012.

The government has announced plans for a 150Gl/year desalination plant by 2011, a major pipeline over the Great Dividing Range and a recycling plant. Recently, following a series of protests by farmers against the proposed pipeline from the Murray-Goulburn region, irrigators agreed a deal to allow the scheme to be implemented.

The project will involve improving the water infrastructure in the area, which is expected to save up to 225 billion litres of water a year, one third of which will be diverted via the pipeline to Melbourne.

Sydney has been forced onto a subsidiary water supply after heavy rains caused its main drinking water supply canal to collapse. The problem with the 60km open channel, which feeds water from surrounding dams to the city's main treatment plant, was said not to be serious and officials were predicting that it would be repaired within a few days. Flooding was also blamed for a large plume of contaminated water at the city's largest reservoir, the Warragamba Dam.

OECD urges New Zealand to act on water

The Organisation for Economic Cooperation and Development (OECD) has issued an environmental performance review for New Zealand that notes that despite improving its environmental performance over the past decade the country needs to reinforce its water and wastewater management.

Among 37 other recommendations, the report calls on New Zealand to protect its ground and surface waters. It reveals that the water quality of streams, rivers and lakes has suffered a 'notable decline' due to diffuse pollution from livestock and other sources, although point source pollution has reduced.

Implementation of coastal management plans has helped reduce pollutant loading to coastal waters, the report notes, but adds that there is still 'considerable need' for progress in water management.

It notes: 'The absence of a national policy statement and legally-binding national environmental standards for ambient waters has made it difficult for regional authorities to design regulatory or economic measures to limit diffuse pollution of surface waters.'

Water quality in rivers and lakes has declined in regions dominated by pastoral farming, where high nutrient inputs and microbiological contamination destabilise natural ecosystems and pose risks to human health, the report warns.

In lowland areas, surface waters regularly exceed national water quality guidelines, and consequent damage to aquatic ecosystems is widespread, mainly due to runoff and leaching from pastoral farming and rural septic tanks.

Water allocation also needs to be revised, the report suggests. As demand for water for irrigation and domestic use rises, the 'first come, first served approach' will have to be refined.

Incentives to conserve water are weak, it continues, as pricing is generally not linked to the amount abstracted or consumed.

The OECD recommends introducing national environmental standards for drinking water sources and strengthening national approaches to protect receiving water quality. It also suggests introducing market-based instruments to internalise the costs of diffuse agricultural pollution (the polluter pays principle) and strengthening and expanding demand management measures such as metering.

It also suggests more research is needed into sustainable abstraction levels from key aquifers. **LS**

US EPA decision on contaminant regulation

The US EPA has made a preliminary determination not to regulate 11 contaminants on the second drinking water contaminant candidate list (CCL).

The agency's decision was based on a wide-ranging review of health effects and occurrence data, and concluded that these particular contaminants do not occur in public water systems at levels that cause concerns for public health.

The contaminants include herbicides, pesticides and chemicals used, or once used, in industry. Two other contaminants – rocket fuel component perchlorate and fuel oxygenator MTBE – require additional investigation to determine total human exposure and health risks, it has decided.

For those contaminants, EPA is providing a summary of current health, occurrence and exposure information and is looking for comment and additional information to help it reach a decision.

The announcement displeased Democrat Senator Barbara Boxer, chair of the Senate Environment and Public Works Committee, who said: 'It is simply unacceptable that EPA would postpone, yet again, a decision on whether to protect our children and families from the dangerous chemical perchlorate.

'Just last December EPA discontinued testing for perchlorate in tap water. I am outraged that EPA has yet again refused to do its duty to protect the health of our families and communities from perchlorate pollution.

'I have introduced two bills on perchlorate – one to require testing and public disclosure of contamination, the other ordering EPA to quickly set a standard. It is clear that action is needed.'

She added: 'I am also outraged that they are still refusing to set a standard to protect our tap water from the gasoline additive MTBE, which contaminates drinking water wells across the country. EPA is failing to do its job.' **LS**

World Bank approves $230M water funding for Azerbaijan

The World Bank has approved a $230 million national water supply and sanitation project for Azerbaijan, aimed at improving the quality of water supply and sanitation services for 700,000 people in regions across the country.

The quality of water and sanitation infrastructure and services in many secondary and small towns in Azerbaijan has deteriorated severely over the years as a result of age, limited capital investment, and poor maintenance of facilities. 'These conditions pose a threat to public health and increase the risk of environmental degradation,' the bank says.

The project builds on the recently-completed Greater Baku water supply project and continues the bank's long-term support for the improvement of Azerbaijan's water and sanitation sector.

The Rayon investment component finances the rehabilitation and extension of water supply and sewerage systems as well as wastewater and septic sludge treatment facilities in at least 20 regional centres. **LS**

An innovative model for sustainable cost effective management of stormwater drainage assets

Stormwater drainage system is one of the important infrastructures of any modern urban city. A well planned, operated and maintained stormwater system should drain stormwater runoff effectively during normal periods and during floods. However, with rapidly expanding cities, unanticipated problems from changing land usage, system overloading, pollution and deteriorating environment cause problems to stormwater assets and contribute to its failure. These issues are more problematic in larger and older cities where replacement is costly. Kogarah Council, a local government authority in Sydney, Australia, is anticipated to face many of the challenges this problem poses as it manages the urban water cycle system in an integrated manner to protect, restore and enhance the stormwater assets. The council owns a significant part of these assets, that were constructed back in 1930s.

There are a large number of physical and environmental factors which are significant in affecting the asset life of the stormwater system. The council possess a large database of information pertaining to its infrastructure. Most of the data is available in a subjective form, and does not favour a typical engineering analysis. In this regard, a more practical and scientific approach using fuzzy logic was identified as suitable for modelling the deterioration of assets. This method is more powerful when used in conjunction with engineering judgement and reasoning. This paper explains an overview of a rule-based fuzzy approach, and applies this technique to a stormwater network. Expert opinions and the experience of the council are among the inputs to the model. An asset condition index was derived between input factors and output targets to give more insight of the present and future conditions. The findings show that the application of fuzzy-based modelling techniques provides a more pragmatic tool for the present problem.

Arasu Kannapiran, Amit Chanan, Gurmeet Singh, Photios Tambosis
Assets and Services, Kogarah Council
Kogarah
Australia

Jeku Jeyakumaran, Jaya Kandasamy
Faculty of Engineering
University of Technology, Sydney
Australia

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Pipes associated with storm water systems drain the rainwater runoff from most urban areas. In Australia, local councils have the responsibility of installing and maintaining stormwater infrastructures. Kogarah Council, a local government authority in Sydney, owns a significant part of the stormwater infrastructures.

The council is committed to maintain an effective stormwater collection and removal from its catchments and waterways area. Stormwater assets comprise a series of floodways, drains, channels, and pipes and associated structures needed to form a complete collection and disposal of urban stormwater. The total length of council's drainage network is about 100 km. There are about 2400 stormwater pits, mostly constructed of concrete and the others are made of clay, PVC and terracotta. The majority of the pipe sizes vary between 300-475 mm in diameter while the maximum diameter is 2400 mm. The recent valuation of the drainage network is estimated to be around A$60 million. The average age of the Kogarah's drainage system is over 60 years, and this factor alone means a higher maintenance costs that is a burden to council. The traditional approach of 'replacing a pipe with a pipe' is no longer necessarily a viable and sensible management option. Hence the council is exploring all other avenues in redeveloping its old drainage system through an asset management programme.

The Austroad's (Association of Australian and New Zealand road transport and traffic authorities) definition of Asset management is worth considering here to evaluate the condition status of public assets. The Asset management may be defined as a comprehensive and structured approach to the long term management of assets as tools for the efficient and effective delivery of community benefits. The emphasis is on the assets being a means to an end, not an end in itself. The World Road Association's definition of asset management is also relevant. Their definition of asset management: 'a systematic process of effectively maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing the tools to facilitate a more organised and flexible approach to making decisions necessary to achieve the public's expectations.'

In light of these broad definitions, stormwater asset management means managing a drainage network for the benefit of the stake holders or the community at large, at the lowest possible cost over a sustained period of time. The main streams in asset management are the identification of the components of the asset, and the service of the asset including ongoing operation and maintenance. Asset management comprises the elements of facilitating the delivery of community benefits such as comfort, mobility, economic development and social justice. This paper discusses the current issues facing Kogarah Council, the deterioration process of stormwater assets and the applicability of a knowledge-based fuzzy logic technique. The superiority of this technique is demonstrated using a case study of an actual stormwater network in Kogarah Council.

Current issues with Kogarah council

The Kogarah council is currently facing several challenges in the life cycle management of its stormwater system. The aging of the assets causes the deterioration of stormwater structures and hence the performance. Blockage in the piping occurs due to penetration of tree roots, sediments, and the accidental intrusion of other service lines (Figure 1). In recent years, the concept of stormwater quality and its effect on the environment has become a major concern. Occasional sewerage overloading flows, pose another threat that significantly impact on storm-water runoff quality. Sydney has a separate sewerage and drainage system. In times of heavy rainfall the sewage system has inbuilt overflows into the drainage system to cope with overloading in the former system. This together with catchment runoff is a major source of pollution to the environment and waterways. In addition to the above conditions, there are other factors such as external traffic loads, loss of pipe bedding support, intrusion of tree roots, pipe material properties, corrosion and erosion that lead to the failure of pipes.

New developments and redevelopments create greater impervious surfaces, which leads to an increase in stormwater runoff volume and subsequently add to the pollutant load. This scenario is not unique to Kogarah Council and similar situations exist in many urban areas worldwide (Fwa and Shanmugam 1998; Davies *et al.* 2001; Yan and Vairavamoorthy 2003; Rajani and Tesfamariam 2005). Replacement of older buried infrastructures in a developed area is a huge task, time consuming and a major economic burden. The Council is currently seeking solutions towards addressing these issues as this problem is well understood and can be managed through innovative assessment methods. There are opportunities to apply the best management principles, and the following are the major steps necessary to achieve these:

- A more detailed understanding of the needs of the community, and the ability to correlate the stakeholders' aspirations with a quality of sustained service
- Development of predictive tools for cost effective maintenance standards
- Development of deterioration models for different scenarios of traffic volumes and environmental changes
- Development of tools that predict the remaining service life of major components.

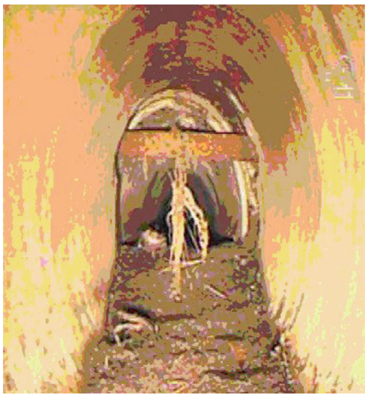


Figure 1 **Tree root and sediments inside a Kogarah stormwater pipe.**

Deterioration of infrastructures and modelling approach

There are many factors that directly and indirectly affect the performance of a stormwater pipe network. The factors contributing to the deterioration in performance include operational conditions, design parameters, external traffic loads, internal loads from operating and surge pressures, temperature changes, loss of bedding support, pipe properties and pipe condition. In stormwater systems, it is very difficult to ascertain the exact cause of pipe failures as they are rarely recorded.

To compile the drainage asset information to meet twenty-first century requirements, information such as age, grade, material, depth, hydraulic capacity and location of all drainage assets including pits, pipes and channel data are made available electronically at Kogarah. The extensive Geographic Information System (GIS) based data provides spatial information that includes the location of each inlet pit as well as details on drainage easements within the entire council. However, the information available is in discrete subjective or linguistic form, and is not connected by mathematical means suitable for a systematic analysis. Any attempt to predict the condition or state of the asset would involve considerable uncertainty due to large spatial and temporal variability that is inherent in the data (Tesfamariam and Rajani 2004).

In order to process the uncertainty associated with a piece of information, the probability theory or the fuzzy inference models are proposed (Karnib *et al.* 2002). Probability theory is more efficient when the exact probabilities of the behaviour are known. When it is too hard to assign probabilities to all possible events, or where there is not enough information about the likelihood of an event, application of probability theory becomes meaningless.

Techniques like artificial neural network, belief networks, fuzzy sets, and fuzzy based techniques are found to be suitable for problems where the cause-effect knowledge is imprecise (Kleiner *et al.* 2006). In recent years, fuzzy theory has been applied as a viable tool for combining new theories called soft computing such as neural networks to get knowledge from real data (Mukaidono 2001). The guiding principle of soft computing is to exploit the tolerance for imprecision, uncertainty, and partial truth to achieve tractability. Fuzzy based approach can be formulated with the specific purpose of mathematically describing imprecise information and interpreting concepts defined by linguistic expressions, into a mathematical model (Revelli and Ridolfi 2002). This approach enables the capture of qualitative and highly uncertain knowledge, forming them into the rules, and subsequently creating a complete inference system (Kleiner *et al.* 2004).

The important requirement in the evaluation of the deterioration process is that the subjective description of data be encoded into numerical form. Two important steps have been suggested for the condition evaluation of a deteriorating system (Kleiner *et al.* 2004). The first step involves the acquisition of distress indicators through observation

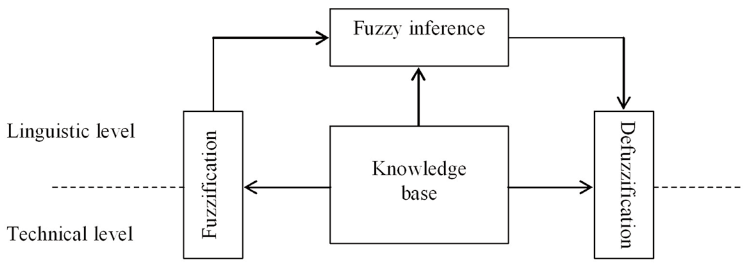


Figure 2
Structure of a fuzzy logic system.

or measurements and the second step involves the interpretation of the acquired indicators. Fuzzy based logic technique that has an inbuilt encoding process is well suited for modelling the deterioration of buried pipes. The basic ingredient of fuzzy logic is the fuzzy set, whose boundary is not clear. Fuzzy set plays an important role in human reasoning. Several researchers have explored the mathematical technique of fuzzy sets to deal with the subjectivity associated with human judgment of distress indicators (Bandara and Gunaratne 2001; Yan and Vairavamoorthy 2003; Adriaenssens *et al.* 2004). In addition, the relative importance of each distress type with respect to the maintenance needs was also utilized (Fwa and Shanmugam 1998; Al-Najjar and Alsyouf 2003). The fuzzy logic expert system is even capable of establishing a specific physical criterion for predicting the deterioration of say cast iron pipes using soil properties (Homayoun *et al.* 2004). The fuzzy logic output is used in many cases as a feedback device to control plant parameters (Von Altrock 1995; Mendi *et al.* 2002). The fuzzy procedure has the potential, together with the application of engineering principles, for a numerical analysis of subjective information.

Rule-based fuzzy model

The original idea of linguistic fuzzy models imitating the human way of thinking was elaborated by Zadeh (1994) in his pioneering works. Based on this concept, Mamdani and Sugeno (Abonyi, 2002) developed fuzzy model utilising human expert knowledge. Fuzzy logic is a methodology for computing with words rather than numbers and effectively employs modes of reasoning that are approximate rather than exact. The centre stage of most of fuzzy logic is that of if-then rules, or fuzzy rules. They act as a mechanism for dealing with fuzzy inputs or antecedents and fuzzy consequents. The advantages of using fuzzy logic are that they are simple, flexible, and tolerant of imprecise data. It can be built on top of the experience of experts, blended with conventional control techniques and modelling complex nonlinear functions. Figure 2 shows the structure of fuzzy logic system, and the following sections describe an overview of building a fuzzy logic problem.

Fuzzy sets and membership functions

Fuzzy logic starts with the concept of fuzzy set which is a set without a crisp, clearly defined boundary. Fuzzy sets are applied for qualitative evaluation of physical quantities and the truth (or accuracy) of any statement is a matter of degree. Membership value of a fuzzy set expresses the degree to which an element belongs to a fuzzy set. The degree of membership is represented subjectively by a continuous function between 0 and 1. Small values represent a low degree and high values represent a high degree of membership. The function can be an arbitrary curve whose shape is defined to suit simplicity, convenience, and efficiency. The simplest membership functions are formed using straight lines. A triangular membership function is a collection of three points forming a triangle. For the present investigation triangular, trapezoidal and Gaussian membership functions are used.

The primary building block of a fuzzy logic system is the 'linguistic variable'. The multiple subjective categories describing the same context are combined. As an example, the diameter of a pipe can be categorised as very small, small, medium and large. These are called linguistic variables and are linked to membership functions of various pipe diameters as shown in Figure 3. This linguistic function allows the translation of a measured pipe diameter in mm, into linguistic description.

Logical operations and fuzzy rules

The system behaviour is defined by the if-then rule which is the centre stage of a fuzzy model. In rule-based fuzzy systems, the relationships between variables are represented by means of if-then rules of the following general form:

If an *antecedent* proposition **then** a *consequent* proposition (1)

Among the many models, fuzzy linguistic models or Mamdani models are both the antecedent and consequent are fuzzy propositions. In a system having two inputs (x_1 and x_2) and one output (y), the general rule of a linguistic of Mamdani fuzzy model is given by:

If (x_1 is small) AND (x_2 is medium) THEN (y is large) (2)

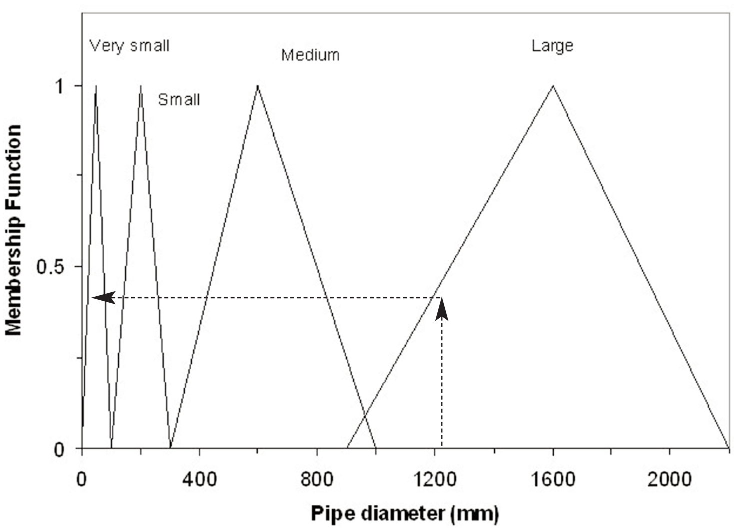


Figure 3
Linguistic variable for pipe diameter.

where, small and medium are fuzzy sets. The logical connectives determine the qualitative relationship between the input and output states by joining fragments of a rule to get a whole. The logical connectives used are AND, OR and NOT operations. To process information in a real system, any number of well defined methods can fill in for the logical connectives. The accuracy of a fuzzy model depends on the number, shape and parameters of membership function and the logical connectives used (Piegat 2001). In order to preserve the results of logical connectives, appropriate operators are to be identified and also it must be extendable to all real numbers between 0 and 1. The following are the three operators used in the majority of fuzzy logic applications:

$$\left.\begin{array}{ll} \text{AND} & :\mu_{a \wedge b} = \min\{\mu_a, \mu_b\} \\ \text{OR} & :\mu_{a \vee b} = \max\{\mu_a, \mu_b\} \\ \text{NOT} & :\mu_{\neg a} = 1 - \mu_a \end{array}\right\} \quad (3)$$

where μ_a and μ_b are membership functions of variables a and b respectively. The fuzzy operation is applied for a given rule to obtain one number that represents the result of the antecedent for that rule. This number is then applied to the output function. Figures 4a and 4b illustrate the fuzzy logic operations of AND and OR respectively. The input for this implication process is a single number and the output is a fuzzy set as seen in Figure 4. Two or more rules are needed for effective results. The implication process is implemented for each rule.

Figure 4a
Logic operation of AND rule.

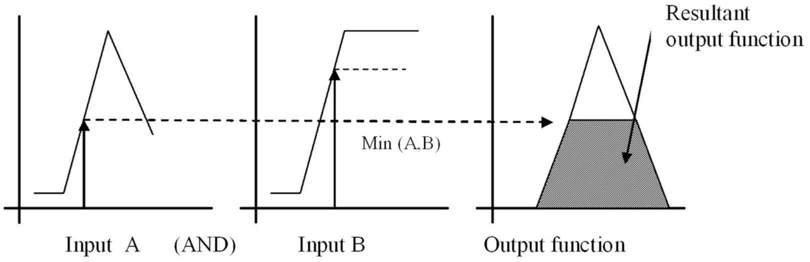
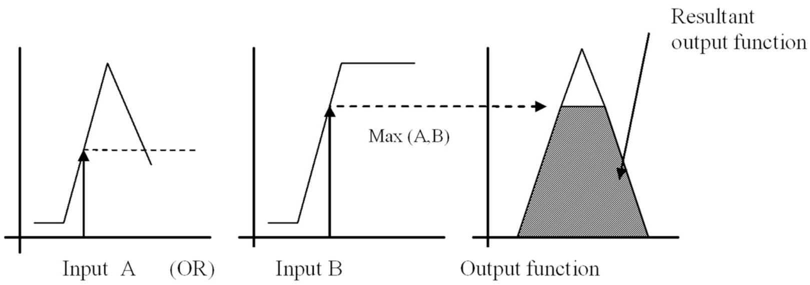


Figure 4b
Logic operation of OR rule.



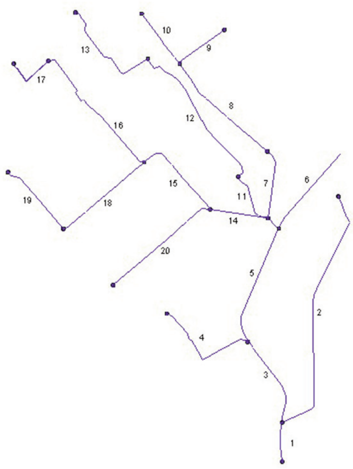


Figure 6
Representative stormwater system of Kogarah network.

Figure 5
Kogarah Council's entire stormwater drainage network.

Defuzzification

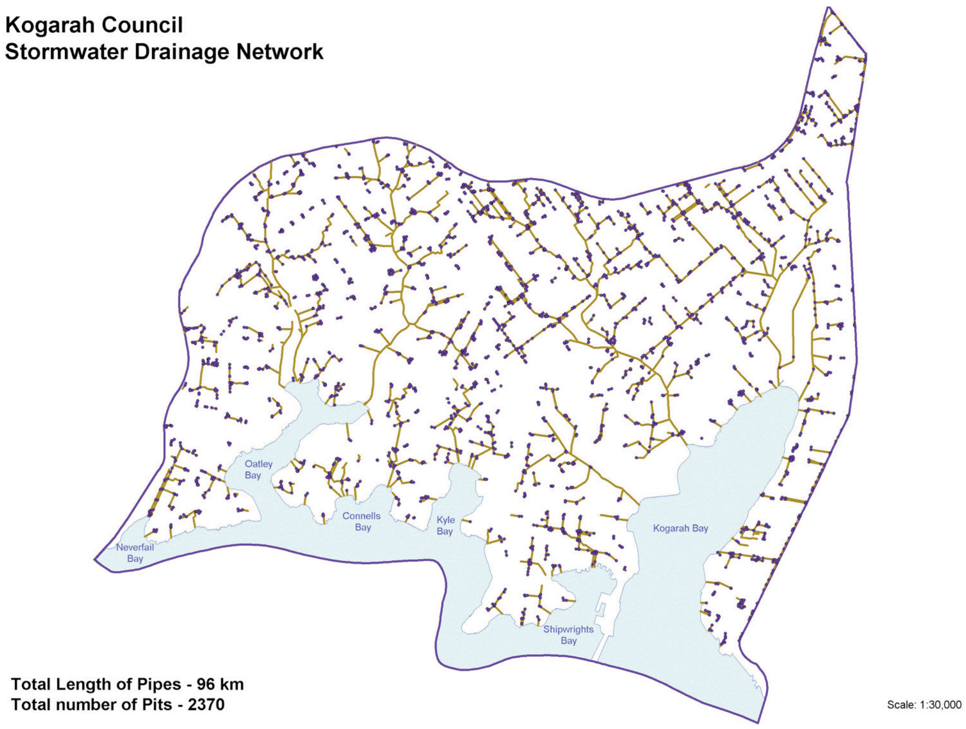
In order to make the final decision, the fuzzy rules must be combined. Through an aggregation process, the outputs of each rule are combined into a single fuzzy set. The outcome of the fuzzy inference process is a fuzzy set, specifying a fuzzy distribution of a conclusion. However, a single point that reflects the best value of the set needs to be selected. This process of reducing a fuzzy set to a single point is known as defuzzification. A defuzzifier compiles the information provided by each of the rules and makes decision from this basis.

A case study

Network description

Kogarah Council was established in 1885 and is bounded by a railway line, highways and the Georges River. The present-day population of about 50,000 lives in an area of about 20 square km, (Figure 5). Rainwater that runs off roofs, driveways, footpaths and roads drains into stormwater systems. Stormwater ultimately drains into bays, creeks and rivers comprising the 18 kilometres of river foreshore along the Georges River adding to whatever pollution the river already holds. In this way the city and its various land uses affects the quality of local waterways.

The underground stormwater network traverses the city's residential area, road ways and other facilities. It is affected by a range of environmental and operational factors. The condition assessment of the entire 100 km network of inter-connected pipes and structures is a difficult task on a 'point by point basis' in the absence of necessary data. The characteristics of the network shown in Figure 5 are complex, widespread in areal reach and yet interconnected in a cluster of segments. A preliminary assessment was conducted using a portion of the council stormwater system consisting of most of the features of the whole council network. This includes residential, business and park areas and other road ways. All data available from this representative stormwater system was focused in establishing a fuzzy based model to assess its conditional status. Figure 6 shows the council's representative stormwater drainage system and Table 1 shows the relevant data for each pipe. It is proposed to expand the assessment to the entire council stormwater system later from the knowledge gained from the condition assessment of the representative network.



Pipe No.	Age (years)	Diameter (mm)	Length (m)	Material	Traffic	Maintenance	Land use
1	60	+	60	Concrete	L	M	L
2	60	915	810	Concrete	L	L	O
3	60	+	390	Concrete	L	L	O
4	50	800	338	Concrete	L	M	L
5	50	+	466	Concrete	L	L	L
6	60	+	52	Concrete	L	L	O
7	60	1200	238	Terracotta	M	M	L
8	70	900	427	Terracotta	M	H	O
9	70	300	180	Concrete	M	M	L
10	70	450	173	Terracotta	M	H	M
11	60	1200	152	Terracotta	H	H	L
12	70	1100	430	Terracotta	M	M	L
13	70	750	358	Concrete	M	L	H
14	70	1200	30	Terracotta	M	L	L
15	70	1050	190	Terracotta	M	L	L
16	70	750	429	Terracotta	M	H	M
17	70	375	196	Concrete	L	L	M
18	70	1050	277	Terracotta	M	M	L
19	70	600	294	Concrete	L	M	L
20	70	650	378	Concrete	H	H	H

+ Refers to Channel, dimension: 5.5 m x 1.4 m L= Low; M= Medium/Moderate; H= High; O= Open space

Table 1
Pipe data.

Variables for fuzzy model
The infrastructure deterioration is a highly complex phenomenon and related to various structural and environmental factors. The modelling strategy incorporates those variables that are considered important and are inter-related. The purpose is to integrate different types of information into a single indicator that can give a deeper understanding of the interrelationships between numerous pipe condition indicators (Yan and Vairavamoorthy 2003). In this study, the principal factors considered to influence the deterioration are the age of the pipe, pipe diameter, traffic conditions, maintenance level and the land use. The pipe length and pipe material were not considered in the present study since these were assumed to be influenced indirectly by the pipe diameter and environment. As the first step these factors are expressed in linguistic form. The linguistic values for the selected variables are shown in Table 2. For computational purposes the linguistic indicators in each variable are decoded into fuzzy numbers. The decoded fuzzy numbers and the degree of memberships are derived from engineering judgement of Council staff and maintenance personnel.

This is a better way of representing subjective factors as it has the ability to handle the uncertainty involved in expert's assessments. Often, the condition assessment of infrastructure distress by different experts appears to be different. This is because there is an element of uncertainty concerning the true value of the severity levels (Fwa and Shanmugam 1998). This difference of opinion is incorporated in the fuzzy approach where each distress variable is represented by the spread membership function instead of a discrete value. The membership function allows the capture of much more information than a discrete value.

Rule-based reasoning
Evaluation of sensitive information requires the knowledge of the operational behaviour of the network. An expert system consists of information data base, knowledge from experts and an inference engine for problem solving. The simplest way to extract knowledge is from queries formed out of rules. The information available in the knowledge base for the most part is either imprecise or uncertain. In this situation two types of uncertainties are visualised, the first uncertainty is imperfect information and the second is related to imperfection of the rules (Karnib *et al.* 2002).

The first type of uncertainty is expressed in the fuzzy sets themselves. For example, the pipe diameters are indicated as very small, small, medium and large as shown in Figure 3. They are different 'levels' of diameter of the pipe. The originally thought-of imprecise and subjective indicators are in fact expressed in quantitative form. The uncertainty connected to rules of fuzzy system is processed by fuzzy inference tool. In modelling the fuzzy system, the knowledge base consists of fuzzy sets and the definition of rules that define relationships between variables. The relationships are expressed in a form given in Equation (1) by identifying the antecedents and consequents. An example of an actual rule is expressed as:

IF {*age* is *too old* and the *pipe diameter* is *large*} **THEN** {*condition indicator* is *very bad*} (4)

The rule base determines the relationships that exist between fuzzy sets of inputs and outputs. The inputs in the above example are age and pipe diameter and the output is condition indicator. The inference mechanism of fuzzy model gets the crisp membership value for the particular fuzzy set that falls within the indicator category. This is explained in Figure 3. Here the pipe diameter of 1200mm which is large by definition has a crisp value of about 0.48 as its membership function. A similar crisp value is obtained for the variable age.

A rule base is built by creating many rules connecting the different sensitive variables. The rule base consists of logical rules determining the relationships between fuzzy sets of its inputs and output. A typical rule base is written as follows:

$$\left.\begin{array}{l}\text{Rule 1: }\textbf{IF}\ (x_1 = A_1)\ \text{AND}\ (x_2 = B_1)\ \text{THEN}\ (y = C_1)\\ \text{Rule 2: }\textbf{IF}\ (x_1 = A_1)\ \text{AND}\ (x_2 = B_2)\ \text{THEN}\ (y = C2)\\ \ldots\ldots\quad \ldots\ldots\quad \ldots..\quad \ldots\ldots\quad \ldots\ldots\end{array}\right\} \quad (5)$$

The definition of fuzzy sets of inputs A's and B's are explained by values given in Table 1. For multiple components in the antecedents, fuzzy logic connective rules of AND, OR and NOT (Equation 3) are applied to get the degree of support for that rule. To weigh one rule relative to the others, suitable weight value between 0 and 1 is applied. This adds sensitivity in the result.

For the current model a rule base was built out of 24 rules. They are framed by taking no more than two

Combination	Pipe age	Pipe diameter	Traffic	Maintenance	Land use
1			-	-	-
2		-	-		-
3	-			-	-
4	-		-	-	-
5	-	-		-	-

Table 2
Variables and their linguistic indicators.

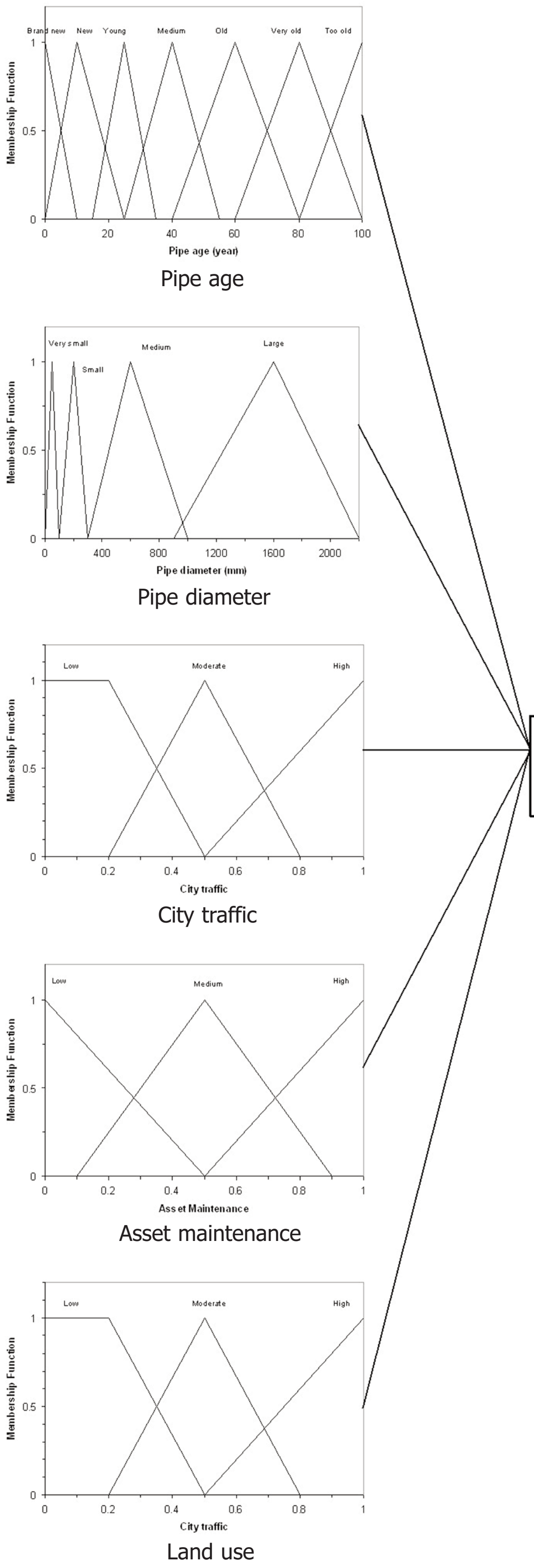
input variables for any one rule. More than two variables in the ruling are avoided at this stage due to lack of in-depth knowledge between system variables. Table 3 shows the combination of sensitive variables that have been combined in the ruling. On these variables, appropriate indicators (like very small, small, medium and large for pipe diameter) were chosen in the representation. The rulings are applied in a holistic manner collectively to the small network shown in Figure 6. No specific node by node analysis of inference was attempted, however all the relevant data, expert knowledge and engineering judgement were represented in the modelling.

Figure 7 demonstrates for a two rule, two input variables with one output variable for each rule. Results from each output are aggregated to evaluate the degree of sensitivity of the whole problem. The next section describes the application of rules to evaluate the system condition.

Evaluation of condition index

The objective of the condition evaluation is to identify the condition index for the pipe system using the components of the fuzzy model shown in Figure 8. The condition index refers to the status or condition of the system. The status is expressed through an index scale of 1-100, the lowest value corresponds to worst condition and the highest value refers to an ideal or excellent condition. The definition of fuzzy sets of the outputs is given in Figure 9. The output indicator values of *very bad*, *bad*, *good*, *very good* and *excellent* are assigned subjectively. This is a yardstick parameter to asses the condition status of the whole problem.

The fuzzy logic operation gives the degree of support for each rule, and this is assigned to shape the output in the implication process. The shape of the



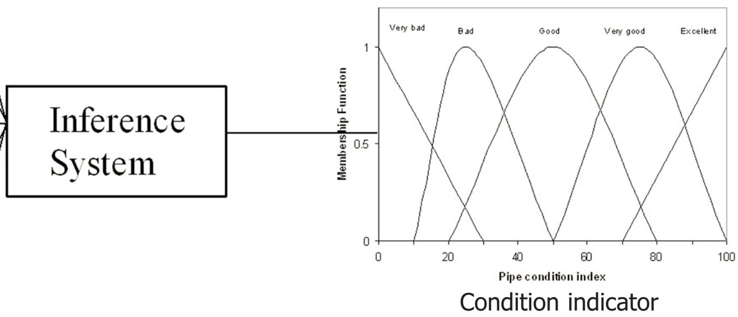


Table 3
Combinations of strategic variables.

No.	Variable	Linguistic indicators
1	Pipe age	Brand new, new, young, medium, old, very old, too old
2	Pipe diameter	Very small, small, medium, large
3	Traffic load	Low, moderate, high
4	Maintenance	Low, medium, high
5	Land use	Low, medium, high

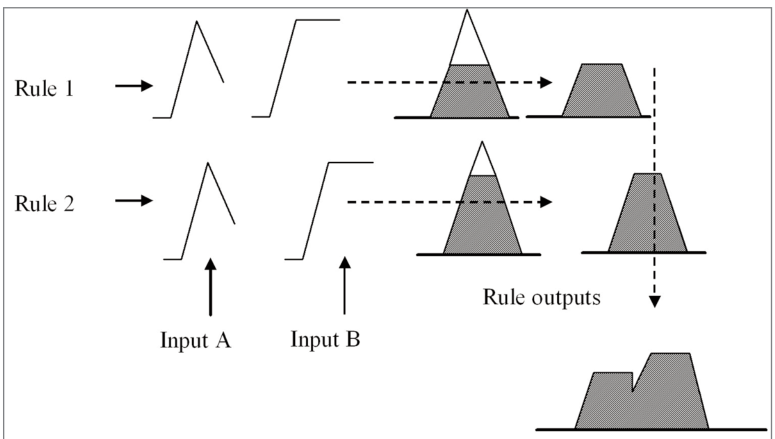


Figure 7
Fuzzy inference model.

Figure 8
Components of the fuzzy system.

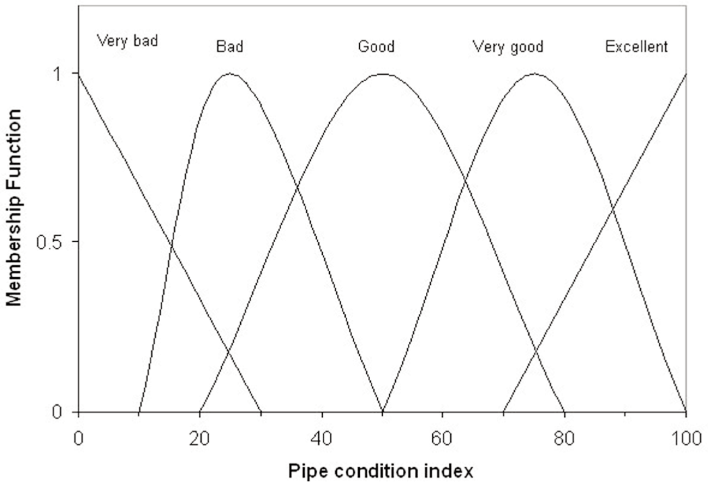


Figure 9
Fuzzy sets of the output for condition index values.

output function is mostly a complicated function as the calculations are accomplished by rule base, inference mechanics and membership function of the model output. This output process gives one fuzzy set for each output variable. The final decisions are made based on testing of all the rules in the fuzzy inference engine. The resulting list of changed output functions are combined into a single aggregated fuzzy set. This is pre-processing operation that is required before defuzzifying the aggregated result.

The defuzzification converts the output of the model to a standard crisp signal which is the condition index for the current asset condition. There are numerous types of defuzzifications such as centre of gravity, centre-of-sums, first-of-maxima, middle-of maxima and mean-of-maxima (Abonyi 2002), each one of which has advantages and disadvantages. The criteria that should be considered in choosing a defuzzification scheme are plausibility, computational simplicity and continuity (Wang 1997). The plausibility scheme represents the crisp value in the centre or that lies in a high degree of membership of the fuzzy set. In this study, a method which has been widely adopted is to take the centre of gravity or moment of the whole set. This has the advantage producing smoothly varying output. The resulting conclusion fuzzy set A has the membership function $\mu_A(y)$ as shown in Figure 10. The centre of gravity is calculated as the quotient of the moment of the surface under the curve $\mu_A(y)$. The crisp value y_c is determined by the following equation:

$$y_c = \frac{\int y\mu_A(y)dy}{\int \mu_A(y)dy} \qquad (6)$$

It can be seen that the centroid method of defuzzification takes weighted sum of the designated consequences of the rules according to the firing strengths of the rules (Figure 10).

Predictive condition assessment results

The results of pipe condition indices for age, traffic, maintenance and environment are shown in Figures 11a-11d. The results presented here are typical for the mid-values of the above parameters, however the results for any chosen parameter of the variables are observable. The prediction of the index for these variables presented are in the expected trend, however the actual interpretation of the values must be used with caution. Referring to Figure 11a, condition of the pipe is clearly declining with age, initially very slowly from the current year of 50 years and then rapidly after 20 years. The index value for the current year is about 53. The current condition of the infrastructure is usually known, and hence the index value of future years from the current asset condition gives an indication of the asset condition in the future. The relative variation with pipe age may be used for comparison purpose only and should not to be used as an absolute value. Through the result, the influence of a variable over another variable can also be visualised.

In Figures 11b and 11c, the indices for the traffic and maintenance show relatively steady change. The increased traffic condition deteriorates the situation, while the increased maintenance improves the condition. In Figure 11d, environment index of more than 0.5 represents an industrial environment and the land use associated with this area causes a very rapid decline in the pipe condition index. A more detailed description of the asset condition could be achieved by including more variables in the fuzzy modelling and by combining many influencing variables in the rule making process. It is also important that every possible rule is included from relevant knowledge, evidences and engineering judgements. This helps to choose many different alternatives to identify the best or optimum conditions.

Summary and Conclusion

An investigation of the asset condition of stormwater pipes associated with a larger network is complex. Deterioration of infrastructure is of primary concern for asset managers. In the absence of reliable data for statistical analysis of deteriorating assets, a simple, yet powerful technique of fuzzy logic can be applied to meet the objective of predicting the pipe conditions of the stormwater system. The fundamental principles involved with the rule based fuzzy logic technique are presented with the focus on its application to stormwater pipe systems. The existing database of the council is well suited to provide the input to the developed models. The linguistic descriptions of the stormwater assets are converted into appropriate numerical form. In this case study, a small sample area of the stormwater system consisting of the main features of the whole council network is analysed. The characteristics of most influential physical parameters of the network are identified and their relative behaviours are integrated by the model. A pipe condition index that defines the current and future trends is presented. The trends of the result are found to be very useful in the asset management decisions. The proposed modelling scheme has scope for further improvements, however, the methodology will assist the asset managers effectively maintain and rehabilitate their assets.

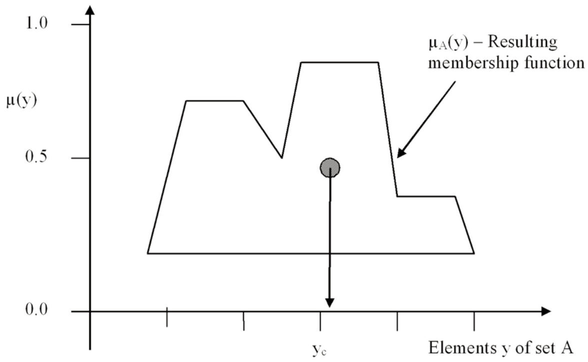


Figure 10
Defuzzification of aggregated output.

Acknowledgements

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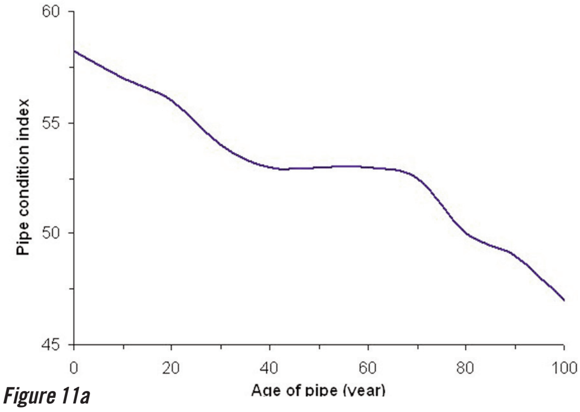

Figure 11a
Index for age.

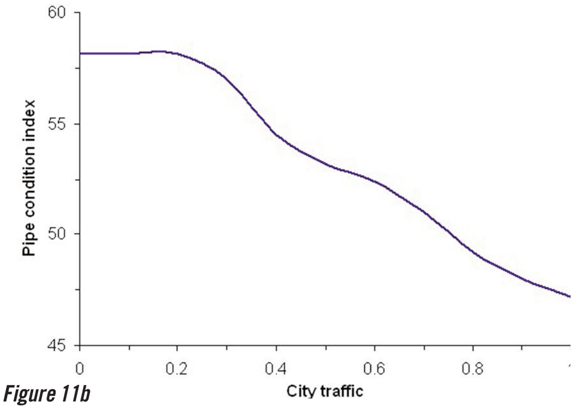

Figure 11b
Index for city traffic.

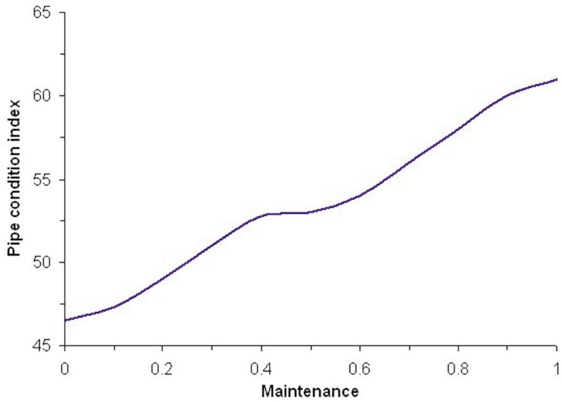

Figure 11c
Index for maintenance.

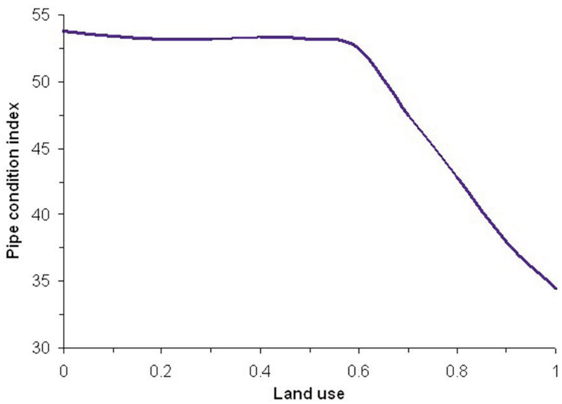

Figure 11d
Index for land use.

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Asset management for water infrastructure

Asset management aims to provide an appropriate and sustainable level of service at a cost that is considered valid for the community concerned. It is, however, still a developing discipline, which has only recently started to be undertaken as a distinct business function within the water sectors of many developed countries. It is useful to think of asset management as being a risk-based framework within which various tools and techniques are applied. In this context, planning models have been developed worldwide that allow the implications of different management and operational strategies on long-term costs, customer service levels, and network performance to be assessed by water authorities. This paper discusses the context within which asset management in the water sector is developing, and the need to embrace management practices with a wider scope. An overall asset management strategy using a risk-based approach is also outlined, including the application of this approach to both proactive and reactive assets. In the area of reticulation networks, the paper reviews the development and role of planning tools that allow the selection and targeting of pipeline replacement or rehabilitation options.

Stewart Burn, David Marlow and Magnus Moglia
CSIRO Land and Water
Australia

Peter Buckland
Hunter Water Corporation
Australia

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Worldwide annual expenditure on maintenance and rehabilitation of water reticulation pipe assets is currently calculated to be over $33,000M (US$/year), and this is expected to rise significantly over time as we move from an expansion phase (where capital investment was made in new assets) to a replacement phase (where existing assets increasingly come to the end of their life and thus need to be replaced). The long-term cost implications for a water sector (or individual authority) with a poorly structured replacement/renewal regime can be dramatic. For example, the American-based Water Infrastructure Network estimates that the gap between spending levels and the investment required to meet the national environmental and public health priorities embodied in their Clean Water Act and Safe Drinking Water Act will reach US$23 billion a year over the next 20 years (Water Infrastructure Network 2000), while the American Water Works Association estimates that US$250 billion over 30 years might be required nationwide for the replacement of only reticulation water pipes and their associated valves and fittings (AWWA 2001).

This situation is, to a greater or lesser degree, common to the water sectors of many countries, and has largely come about through pipes reaching the end of their life expectancy (many were installed in the 1950s), in combination with a poor record in replacing these pipes. This in turn can be related to the adoption of management practices with a short-term and narrow focus, which has lead to deferral of the necessary investment in asset renewals. The challenge for many water authorities is thus to determine how best to manage asset stocks with limited replacement funds, while maintaining a satisfactory level of service in the long-term.

This paper discusses the role that asset management can play in helping the water sector to meet these challenges, and the need to embrace management practices with a wider scope. The types of risk-based strategies being developed and applied to the management of water infrastructure assets are also considered, along with the tools that are required to support strategic and tactical planning at the network level.

The development of asset management

In the past, water authorities in developed countries concentrated on delivering good quality water to customers, with other service issues being relegated to the background in comparison. Assets were often over-engineered in an attempt to reduce the risk of failure, with little formal attention being given to the assessment of different operational and maintenance strategies. More recently, the water sectors of countries such as Australia, the United Kingdom, and increasingly the United States, have shifted focus. Water authorities now have to deliver against a wider range of service mandates, and give increasing emphasis to cost-effectiveness and/or 'added value'. This has required a more economic view of service provision to be taken, with explicit consideration of the tradeoffs between cost, performance, and risk. To facilitate this, asset management is being developed and adopted as a distinct business function within many water authorities.

Asset management is still an ill-defined term, and there are many definitions in use in the literature. The following definition, modified from that given in the International Infrastructure Management Manual (IPWEA, 2006), is considered by the authors to encapsulate the main features of this emerging discipline:

'The combination of management, financial, engineering and other practices applied to physical assets with the objective of providing the required levels of service to customers, communities, and the environment at acceptable levels of risk and in the most efficient manner.'

The development of asset management within the water sector correlates directly with changing business drivers linked to higher customer expectations, greater regulatory demands, requirements for cost-efficiency coupled with increasing budgetary constraints in conjunction with ageing infrastructure. If there were no such drivers, then the informal asset management systems used by water authorities in the past would remain in place, since these are the cheapest to implement. In fact, it can be asserted that now affordable technology is available to facilitate data and information management, the level of asset management sophistication adopted depends wholly on the business and regulatory environment within which a water authority operates. For example, the more exacting the service mandates are in relation to budgetary constraints, the more sophisticated the asset management capabilities need to be.

Various tools and approaches are available that facilitate effective 'asset management', and these will be discussed in the remainder of this paper, within the context of water infrastructure management. However, it is worth bearing in mind that these tools are not asset management per se. Instead, it is useful to consider asset management as a risk-based framework within which various tools and approaches are applied (see for example, asset management frameworks presented in the International Infrastructure Management Manual, IPWEA 2006, and the UK's Publicly Available Standard for asset management; PAS 55, 2004).

The role of risk in asset management

Over the life of an asset, various strategies are used in an attempt to derive value from asset ownership; the asset is first designed and built, then operated, maintained, renovated and eventually decommissioned and (potentially) replaced. All of these activities are undertaken to derive value; if this were not the case, the asset would not be created or continue to be maintained. Value is generally expressed in terms of benefits net of costs. The benefit an asset delivers is derived from the service it provides, considered either in isolation or in conjunction with the other assets that make up the system to which it belongs. These benefits are offset by the cost of creating, managing and disposing of the asset during its service life, including the costs associated with asset failures.

Since all assets are constructed, maintained and operated to deliver value, a common risk associated with asset ownership is that insufficient benefit will be realised or costs will be too high (i.e. that the direct and indirect costs associated with the asset will outweigh the benefits accrued over its life cycle). At a fundamental level, asset management is undertaken to manage this risk. Formalised risk-based approaches thus provide a natural framework for the context of asset management, and this is reflected in the definition of asset management given above, which explicitly refers to 'acceptable levels of risk'. Often, the issue of concern is not risk as it pertains to an individual asset, but the risk associated with the economic context within which service is required and delivered, and business risks associated with asset ownership and operation. Nevertheless, the specific assessment of asset-related risks remains an important aspect of asset management as it is practiced today.

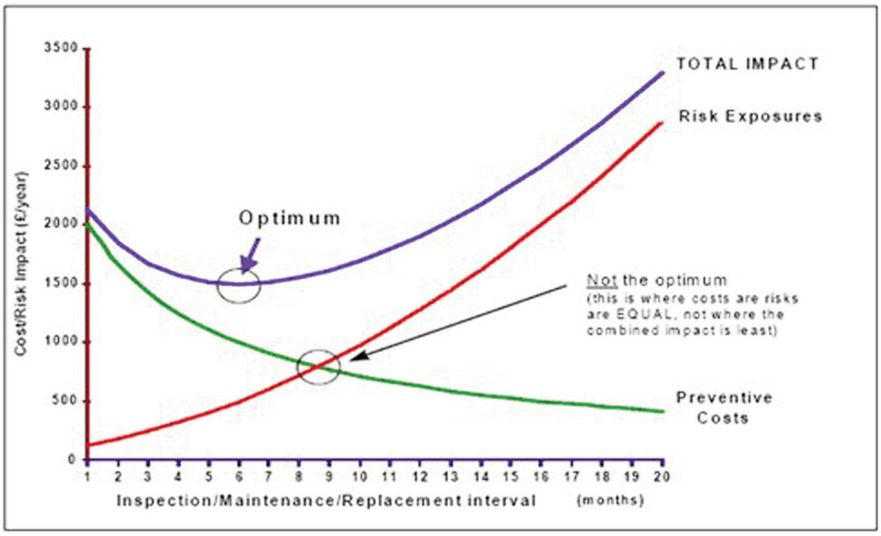

Figure 1
The relationship between maintenance expenditure and risk-costs for process equipment (after Woodhouse, 1999).

Risk assessment of water infrastructure assets

Risk is generally considered to be the product of probability and consequence. In the case of water infrastructure assets, the probability side of risk depends on the environmental conditions (e.g. soil type), operational and maintenance practices, the asset's inherent design, capacity-load relationships, human factors, etc. Similarly, the consequence side of risk will depend on various environmental, ecological, socio-political, and economic factors (including service mandates imposed by regulators), as well as the operating context of the asset. Variations in these factors mean that risk also varies along individual assets and across the overall network. For example, the section of a cast iron main under a busy arterial roadway represents a higher risk compared to the same main in a park (due to higher consequences of asset failure, and higher probability due to greater surface loads), as does the same main running through anaerobic sulphate clay compared to sand (due to higher degradation rates and therefore a higher probability of failure).

Ideally, the analysis of asset-related risk will consider the asset location, material, soil conditions, traffic loading etc., and give a quantitative measure of risk that incorporates both the likelihood and consequence of failure, including whole-life costing factors. The detail (and thus cost) of the risk analysis should, however, be in proportion to the potential risks, and such quantification is not always justified. In particular, subjective approaches such as rapid ranking (e.g. using a 5x5 or similar risk matrix) can be used as a 'first-pass' screening tool to identify those risks that should be considered in more detail. More detailed risk assessments can then be undertaken, as deemed appropriate, to determine the impact of different failure scenarios, as well as to assess operational and alternative water supply strategies and their effects on customers. These assessments can be facilitated by adopting a systematic methodology such as HACCP (Hazard Analysis and Critical Control Point). Once risks have been assessed, intervention analysis is then required to determine which risk management strategy to adopt. This requires economic analysis of the various risk mitigation options available, e.g. operational management strategies, replacement, or rehabilitation of assets.

The importance of externalities

At present, the level of detail involved in the analysis of asset-related risk varies between water authorities. In particular, the consequence calculations often do not include a methodology for factoring in costs external to the water authority (indirect/intangible costs) called externalities (e.g. environmental damage and social costs). The analysis can thus greatly underestimate the economic value of asset replacement and lead to insufficient levels of capital maintenance (renewals spend).

This issue can be illustrated by

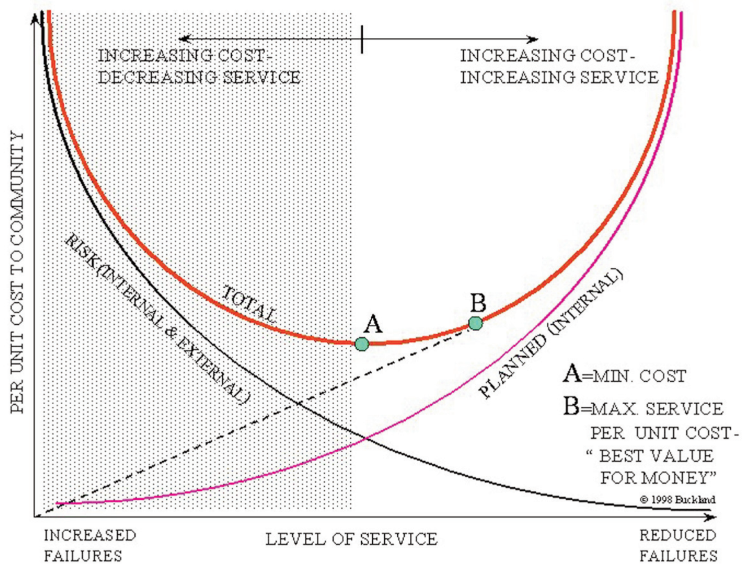

Figure 2
Cost to communities versus level of service. From 'Risk Based Economic Life Cycle Management of Infrastructure Assets and its Regulatory Implications' – P Buckland – Proc. International Conference of Maintenance Societies ICOMS 2000, Wollongong, May 2000)

considering the theoretical balance between total maintenance costs (inspection, maintenance, and renewal) and risk-costs associated with asset failure. In the literature relating to the maintenance of manufacturing and process equipment, plots such as that shown in Figure 1 are often used to demonstrate the a trade-off between the levels of maintenance, the corresponding risk-costs associated with equipment failures, and total cost. Since the impacts of any failures, and thus risk-costs, are borne directly by the asset owner/operator, it is possible to balance maintenance expenditure against risk-cost such that overall costs are minimised, as shown in Figure 1. Importantly, increased reliability (reduced risk-costs) can be achieved through higher maintenance expenditure, but only by accepting an increase in overall costs. In purely financial terms, the increase in expenditure to achieve this level of asset performance would not be justified.

For water infrastructure, the distributed nature of the asset stock means that not all risk-costs are carried by the asset owner/operator. Instead, some risk-costs are borne by customers (e.g. loss of business associated with the lack of service provision), whilst others are economic externalities; i.e. costs imposed on society (e.g. as traffic disruption) and/or the environment (e.g. as pollution incidents and environmental degradation). External risk-costs borne by customers will often influence the authority's decision making due to the imposition of fines, compensation payments and PR (public relations) considerations. This issue aside, if these external risk-costs, and especially externalities (which by definition do not have a direct impact on the activity from which they arise) are not given due consideration by the water authority, the economic arguments for selecting an appropriate level of maintenance are distorted, and reduce to a balance between the level of maintenance and risk-costs borne by the authority, a situation analogous to that illustrated in Figure 1. In contrast, the inclusion of externalities in the analysis reflects the true cost of service failures to the community.

The requirement to consider external costs in infrastructure management has been addressed previously in some detail by Buckland (2000), who developed the conceptual relationship between level of service (which for water infrastructure can be taken to be inversely related to the number of asset failures) and unit cost to the community, as shown in Figure 2. This diagram is based on the recognition that a community ultimately carries all costs associated with water service provision, whether they be costs internal to the water authority, incurred during service provision and funded by the community in the purchase of that service, or the risk-costs incurred by the community as a result of asset/service failure events. As noted by Buckland (2000), the left side of the diagram is a 'no go' area since levels of service and total costs are inversely related (total costs go up, even though service levels fall). Water authorities that do not consider externalities in their economic analysis run the risk of operating in this area, at least when total costs are viewed from those borne by the community, rather than the authority. As discussed previously, this is especially important in the context within which asset management is being undertaken today; i.e. moving into the replacement phase where assets are increasingly coming to the end of their lives.

Deferral of renewals as an undesirable business strategy

Given limits to available budgets and increasingly stringent quality targets that require significant investment, authorities may be tempted to defer investment for renewals into the future. The driver behind the adoption of such a strategy can be illustrated through reference to Figure 3, which shows the relationship between maintenance and total costs for a range of service levels generated using the strategic planning tool PARMS-PLANNING (Burn 2003). Figure 3 has been generated using a version of PARMS-PLANNING calibrated for the assets and operational context of an Australian water authority. The level of service provided is represented by the number of interruptions (failures) that must occur to trigger asset renewal.

For the purposes of the current discussion, this analysis represents the view of asset replacement when only internal authority costs are considered (i.e. risk-costs borne by the utility, including customer compensation).

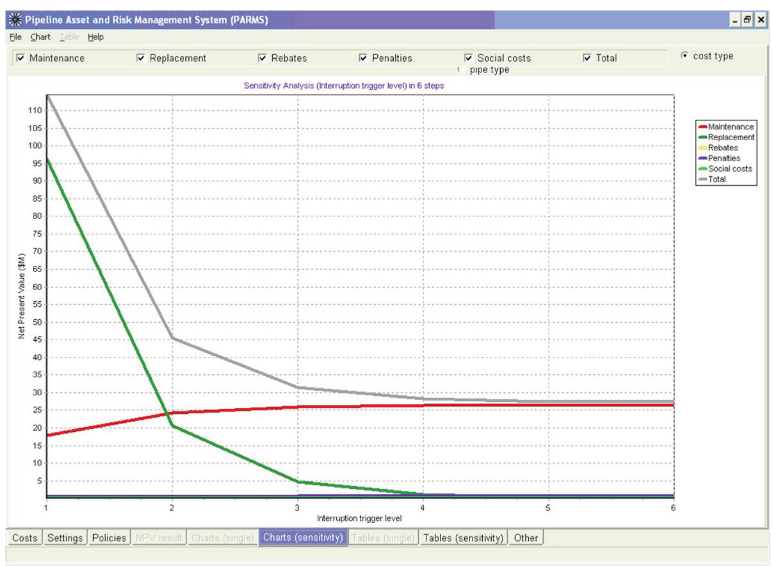

Figure 3
Predicted costs associated with improving level of service without externality costs.

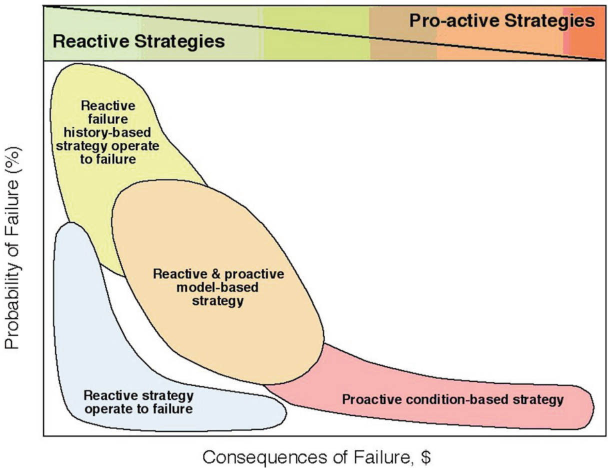

Figure 4
Asset management strategies for assets with different failure probabilities (adopted from Buckland (2000).

Figure 3 demonstrates that, under these conditions, as service levels decrease there is no marked increase in the total cost borne by the water authority. Instead, the total cost reaches a plateau that is independent of the (relatively poor) service provided. In essence, this is because, for the majority of assets, the cost of repair is small relative to the cost of replacement. As a result, if the authority ignores externalities imposed by service failures, then costs do not increase markedly with decreasing levels of service because the cost of the additional repairs is relatively low. With such an approach, the deferral of investment in asset renewal becomes a rational business decision that minimises the direct cost to the authority. Service level mandates and asset stewardship requirements are imposed by regulators to combat this tendency, but these do not necessarily result in an economic balance between the level of expenditure and service provided.

The view of asset replacement is often different when externalities are considered. As illustrated previously in Figure 2, higher levels of failure associated with poor service levels will eventually impose a disproportionate total cost on a community. However, it should be noted that for this to occur, the asset stock must be in such a poor state that failures occur frequently enough to have wide spread impacts on service provision. Furthermore, for externalities to be significant, the failures must occur frequently in areas that impose high levels of externality costs, such as busy roads, central business districts, or shopping strips. Nevertheless, these considerations show that a longer term and broader view of asset replacement must be taken with appropriate consideration of externalities (this is especially true for publicly owned authorities who should ideally have a core focus on serving the needs of communities). This can allow a higher expenditure in asset renewal to be justified, though willingness to pay and affordability issues must still be considered.

Asset management strategies for individual pipe assets

As discussed above, consideration of risk informs the overall approach taken to the management of assets and service provision. Risk also informs the management approach adopted for individual water mains. In this respect, a major factor to consider is what maintenance strategy to adopt, i.e. whether assets are to be replaced before failure occurs, whether they will be left to operate to failure, or whether condition monitoring or active protection techniques such as cathodic protection will be used.

Figure 4 shows a scheme that is applied in Australia, where the assets are divided into proactive and reactive assets on the basis of assessed risk, and different practices are applied to these asset classes. It should be noted that whilst proactive strategies tend to be more justifiable at the high consequence end of the spectrum, they may also apply to the lower consequence assets if the economics of this are favourable; e.g. if low-cost condition assessment is available. The converse is also true for reactive strategies, whereby even though the consequence of failure of an asset may be relatively high, if the cost of failure prevention is prohibitive, that asset may be operated to failure.

Reactive management strategies

As discussed by Buckland (2000), under the strategy illustrated in Figure 4, a reactive pipe with low consequence of failure is generally left to operate until failures start to occur. A decision is then made to maintain or replace this and similar assets. Such a decision would include consideration of budget constraints, the economics of continuing to operate the existing asset, the levels of customer service needed, and operational strategies such as pressure reduction, shut-off block reduction etc. that can be economically implemented to reduce the impact of retaining a failing asset.

When the decision is made to replace an asset, a risk-based strategy is increasingly being applied in the prioritisation process, where the probability and consequence of failure are calculated, and this is used along with the whole of life replacement costs to determine the priority/ranking for replacement. Pipes ranked highly for replacement would normally be grouped with other pipes in a clustering exercise that considers adjacent assets, and develops a replacement work package that can be costed (for in-house replacement) or sent to tender (for outsourced replacement).

Proactive management strategies

A more proactive strategy is adopted for some assets, as shown in Figure 4. Proactive assets are generally defined by some measure of failure consequence, the number and type of customers they feed and their role in the water supply system. However, the exact parameters for their definition depend on the respective water authority. In principle, they are independent of pipe size, whilst in practice they tend to comprise larger diameter pipes, typically with DN>300 mm, and are made of specific pipe materials. Mains in this category generally represent only a small proportion of the assets of any water authority (D'Agata 2003). The economics warrant monitoring of condition and replacement before failure, and/or the use of active protection strategies to control degradation.

In Australia, mains qualifying for proactive management are mainly metallic pipes: cast, wrought, ductile iron or mild steel (Cooper *et al* 2000). For most authorities cast iron pipes predominate, with other metallic materials such as mild steel having a low representation, generally because the mode of failure is not catastrophic and thus does not lead to large consequences. For mild steel mains, proactive management would be generally limited to larger size mains (DN>600) (Heathcote & Nicholas 1998). Pipe materials such as asbestos cement and pre-stressed concrete are either used in smaller reactive mains or are used in only very minor instances and thus represent a minor proportion of the proactively managed assets.

When considering proactive management options for large diameter cast iron mains, the strategy is again often selected using risk-based concepts. As noted above, the consequence associated with failure of these assets is very large, and there is thus the potential for incurring very high costs to water authorities, municipalities, and other segments of society, but the probability of failure is low. Effort is therefore often expended to determine the probability of failure and understand how this is changing with time. In most cases, there will only be no or very limited failure data available for analysis.

Non-destructive condition assessment techniques can be used to determine the level of degradation that a pipe has experienced. This is a costly activity and the application of different techniques has to be carefully planned to allow valid conclusions to be drawn. Fortunately, the reliability of condition

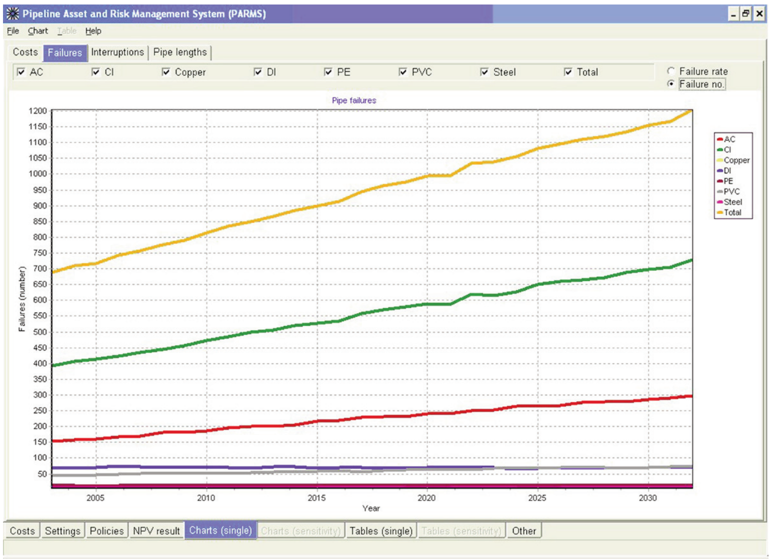

Figure 5
Long term prediction of asset failure rates derived from PARMS-PLANNING.

assessment has advanced significantly, with techniques becoming less intrusive, and with confidence limits of 80% and greater being reported for water pipe assessment (DeSilva *et al.* 2002; Sadler *et al.* 2003, Davis, Burn and Allan 2003; Davis *et al.* 2004a, Davis *et al.* 2004b).

A range of inspection and survey techniques are now available for supporting condition assessment, e.g. soil analysis techniques, linear polarisation resistance, broadband electromagnetics, pipe sampling and intelligent pigging. Their role in asset management strategies has been identified (Burn, Eiswirth, DeSilva and Davis 2001; Eiswirth & Burn 2001), however, each technique carries a range of limitations and advantages for each pipe material. Any limitations, such as poor accuracy, need to be considered when carrying out or interpreting condition assessment results. Unfortunately, these limitations are not well publicised, nor well documented in the literature.

As condition assessment can be expensive, sophisticated statistical techniques in conjunction with GIS and terrain mapping can be used to identify those assets most at risk, with explicit condition assessment being undertaken on these assets. Physical/probabilistic failure models are also being developed to enable relatively limited condition data to be utilised in predicting the change in probability of failure over time, and these have the potential for substantially reducing the cost of ongoing condition monitoring (Moglia *et al.* 2006). In some cases, the analysis may show that techniques such as cathodic protection should be applied to mitigate further degradation.

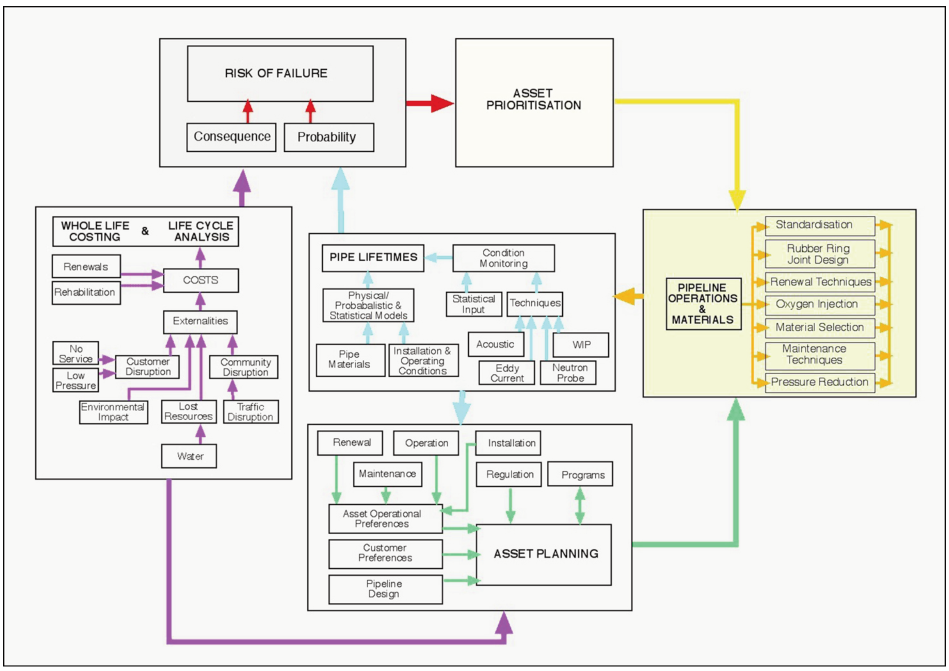

Figure 6
Critical components in the development of planning and risk assessment models for reactively managed mains.

Asset management strategies for reticulation networks

Though proactive assets are more important individually (because of the scale of potential consequences associated with their failure), reactive assets still comprise the majority of assets in any water supply system and, overall, cost the most to maintain and replace. Because of this high overall cost, and the distributed and heterogeneous nature of the asset stock, the production of a strategic asset management plan for reactive assets is essential if water authorities are to maintain service provision in a cost-effective manner. In essence, this means that whilst the individual assets are reactive, planning the approach to management of the reticulation network should be undertaken in a proactive manner to minimise the overall cost of service provision.

In producing a proactive asset management plan, a water utility needs to understand risk and determine an appropriate balance between operational and capital expenditure into the future. The long-term implications of different management and operational strategies on customer service levels also need to be assessed. A budget can then be allocated to meet the year-to-year maintenance/rehabilitation needs of the water utility. Planning approaches are therefore needed to provide information for decision making for three distinct purposes, *viz*:

Understanding risk (assessing costs and conditions to limit risk).

Budgeting (setting limits on available funds and setting overall strategies).

Scheduling (specifying mitigative actions and their timing).

Whilst these three requirements are common to all, individual water authorities can manage their assets in significantly different ways. For example, authorities vary in the formulation of Key Performance Indicators – in particular indicators concerning customer water supply interruptions and the types and levels of customer service delivered. The operational characteristics of authorities also vary significantly in terms of the ratio between number of customers and length of pipes; varying proportions of pipe materials; varying operating pressure; varying age of pipe assets; different rebate schedules to customers for water supply interruptions; varying pipe performance; different methods of treating externalities etc.

This heterogeneity means that, at the detail level at least, standardisation of the planning processes is difficult.

Nevertheless, the central component of the required analysis is consistent; the need to forecast the performance of the pipe network into the future. Often this takes the form of predicting the expected annual number of failures for each type and size of pipe for a set number of years under different operational and management scenarios; for example the long term predictions shown in Figure 5 produced using a calibrated version of the PARMS-PLANNING model (Burn *et al.* 2003).

Failure models and network planning tools

The bases for many network performance models are failure models that forecast the probabilities of failure in various kinds of pipe assets. Failure modelling is often accomplished by utilising a series of customised failure curves for pipes within a water authority's network, determined through analysis of the asset data and including the effects of soil, rainfall, pressure, etc. Where failure data are limited, physical/probabilistic models can be used instead. Significant effort has gone into the development of such statistical and physical/probabilistic lifetime models for traditional materials, as described by Davis and Burn (2002), Davis, Burn and Allan (2003), and Jarrett, van der Touw and Hussain (2001), with additional effort being applied to the development of valid models for newer materials such as polyvinylchloride (Burn *et al.* 2005; Davis *et al.* 2004a), polyethylene (Davis *et al.* 2007) and ductile iron by the American Water Works Association Research Foundation (AwwaRF) and CSIRO.

The calibration of these models depends on accurate, standardised and as extensive as possible information on the types and occurrences of failure modes, as well as information on the assets, including installation and operational conditions. With suitably calibrated failure models, the expected failure rates for each pipe segment or cohort of pipes can be estimated for each year in the forecast period, based on the relevant installation and operational factors and the previous failure history. Calculated failure rates are then combined with the lengths of corresponding pipe to determine the number of failures for each pipe asset or cohort. The total number of failures in the system in any one year is then the aggregate of these failures. Once the performance of the network is established, various scenarios can be analysed to see what effect they have on network performance and also the resulting total costs. As a measure of renewal urgency, it is also desirable to calculate the relative costs for a number of different management scenarios.

A number of planning tools have been developed that analyse the long-term cost implications of different operational strategies or repair/renewal strategies in this way. In general, all of these tools consider the deterioration and failure of assets in one way or another. The more recent tools implemented in Australia analyse the failures of individual pipe assets, whilst others follow the more traditional practice of predicting failure of pipe cohorts. The capacity to analyse the effect of management and operational strategies on customer service levels in these tools is, however, more varied. As indicated previously, models will ideally allow a range of 'what-if' scenarios to be analysed to determine the effects of providing different levels of service on water authorities' long-term costs, and should include integrated analysis of whole-of-life costs, externalities and customer impact.

The available planning tools provide guidance for setting pipe renewal budgets and selecting general strategies, but tactical prioritisation tools are also required to determine those assets on which maintenance/rehabilitation budget should be spent. Any replacement prioritisation tool should provide a methodology for managing asset prioritisation in terms of the predicted failure scenarios of a water reticulation system. There is also a need for more detailed analysis in order to efficiently target renewal efforts to those pipe assets where the benefits are the greatest.

Examples of strategic planning tools include KANEW (Herz 1998), PARMS-PLANNING (Burn *et al.* 2003) and CARE-W (Sægrov 2003); a recent example of a tactical prioritisation tool is PARMS-PRIORITY (Moglia *et al.* 2006). Each of these tools involves a different strategy that may or may not meet the exact needs of a water authority and, if their use is contemplated, the relative benefits of each need to be compared. For example PARMS-PLANNING allows the comparison of a significant number of operational scenarios and allows analysis of long term costs, including those externalities that have a significant impact on the analysis. As noted previously, the exclusion of externalities from the analysis can significantly underestimate the benefits associated with pipe renewal.

The value of good data

As detailed in Figure 6, all of the planning, prioritisation and risk management procedures discussed above require significant pipe lifetime and cost data, as well as input from operational practices, such as pressure reduction and valve insertion practices (shut-off block reduction) that affect pipe lifetimes and operational costs. In fact, the usefulness of a management tool often depends on the quality of the data available, both to validate the models and to describe the assets for which the models predict failure performance and consequences. Additionally, to allow a valid risk-based approach to be implemented, these data requirements need to be extended to include customer impact, externalities (such as traffic disruption), social and environmental impacts.

While it is a considerable undertaking to collect, clean and analyse the required data, it is worthwhile because of the potential savings via better failure predictions. Savings arise from the ability to identify the 'bad' pipes (with predicted high frequency of failure), and keep the 'good' pipes (with predicted low frequency of failure). It may be argued that this can be achieved using only experience and engineering judgment, but, as described by Jarrett, van der Touw and Hussain (2003), sometimes this is insufficient. To illustrate the merits of using better failure prediction within the renewal prioritisation process, imagine, for example, that it is possible via better failure predictions for the water authority to increase the average life in the ground for 90% of their pipe assets from 80 years to 90 years, and that 10% of the bad pipes (relating to 50% of future predicted failures) were replaced earlier. A calculation of annual savings would show an approximate 10% decrease in required annual pipe renewal costs (based on lifecycle costs) and up to 50% decrease in annual pipe repair costs.

Conclusions

Asset management of water infrastructure assets is becoming a critical issue worldwide, with expenditure levels forecast to increase rapidly due to ageing infrastructure. Formalised asset management implemented as a defined business function will allow water authorities to use available budgets more effectively. In this respect, consideration of risk provides a natural framework for decision support in asset management. Analysis is required to understand the levels of service that are appropriate for a given community, and this should include consideration of externalities such as traffic disruption, social implications and environmental degradation. If these costs are not included, there is a tendency to adopt short term management strategies that could result in lower levels of service in the future, which increase the overall level of cost imposed on a community.

At the asset level, a range of management strategies are available; one such approach used in Australia is to divide the assets into reactively and proactively managed assets. Reactive management will tend to apply to those assets with low consequences of failure, and which are generally operated to failure. Failure history can therefore be used to project future failure frequency, and determine which pipes should be replaced using available budgets. For proactive assets, a different approach can be justified in which renewal, maintenance, operational and condition monitoring strategies are combined. Determining a cost-efficient strategy still requires consideration of risk (probability and consequence of pipeline failure), along with the required customer service levels and proactive operational costs. However, unlike those reactive assets which can justifiably be operated to failure, risk must be determined in the absence of a failure history. In this case, failure probability must be established by condition monitoring and/or degradation modelling.

Although proactive assets are more important individually due to the scale of potential consequences, reactive assets still comprise the majority of assets in any water reticulation system and, overall, cost the most to maintain and replace. Because of this high cost, planning models are essential to allow the prediction of the future costs associated with different management and operational procedures.

To be useful, planning models must allow water authorities to model long-term operational strategies, and provide them with the ability to assess how their actions will impact on service provision and budgets, and thus provide the information needed for long-term strategic planning. A risk-based strategy again provides a systematic and flexible approach that can account for the specific operational environments, and thus be tailored to the context of a particular water authority.

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Benchmarking mechanical and electrical maintenance:
key perspectives and emerging challenges

Benchmarking work undertaken by the Water Services Association of Australia (WSAA) has attracted international interest and participation. In the March 2006 issue of *WAMI* the authors described the findings of the 2005 civil maintenance benchmarking programme; here, they report on the latest round of mechanical and electrical maintenance benchmarking carried out in 2006.

Paul Harris
Managing Director - Asia Pacific
UMS Group Australia

Tony Saker
Director of Consulting
UMS Group Australia

Don Vincent
Asset Management Service Line Leader
GHD Australia

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In 2006, eighteen urban water utilities from Australia, New Zealand, and the US, 14 of which are WSAA members, embarked on a comprehensive process benchmarking study. The study was designed to measure the efficiency (cost) and effectiveness (service level) performance of, and identify leading practices in, several key mechanical and electrical activities.

The benchmarked activities were classified as breakdown, scheduled and renewal (capital) maintenance, and included activities relating to water and wastewater assets and operations. Table 2 shows the fifteen activities benchmarked on facility by facility basis, generally for the 2004/05 reporting period.

Due to its varying year-on-year nature, renewals maintenance was not quantitatively benchmarked on a cost versus service level basis (as per breakdown and scheduled maintenance), but cost and practices information was gathered for this area.

Results of the study threw into focus utilities that are leading and those that are lagging in performance, and the key drivers of such performance. All utilities, and the industry as a whole, were presented with perspectives, insights, and challenges that were immediate and likely to last well into the long term the next round of mechanical and electrical maintenance benchmarking, expected to be in 2010.

Project details and deliverables

UMS, with its alliance partner GHD, won the bid to carry out the contract, with the project overseen by a WSAA steering committee initially comprising representatives from six member utilities: Brisbane Water, City West Water, Hunter Water, Melbourne Water, Sydney Water, and the Water Corporation of Western Australia. Subsequently the committee was extended to include international representation from Seattle Public Utilities in the US, and Watercare Services of New Zealand.

All data and performance information was blind coded on an activity-by-activity basis to ensure that no utility was able to directly compare its performance to another utility. Utilities are able use their results in public or show them to their respective economic regulators.

Key project deliverables included individual data validation reports and teleconferences, one- to two-day on-site interviews, detailed individual utility reports and teleconferences, including customised improvement roadmaps, and a major industry report. The project concluded with a best practice workshop that was extremely well received, and which presented key leading mechanical and electrical maintenance practices, particularly in areas found to be of interest and priority to the industry.

Australia	New Zealand
ActewAGL Hunter Water Sydney Water Power & Water Corporation Brisbane Water SA Water Hobart Water Central Highlands Water City West Water Gippsland Water Melbourne Water Water Corporation of Western Australia	Christchurch City Council North Shore City Council Watercare Services Ltd **United States** Portland Water Bureau (Oregon) San Francisco Public Utilities Commission Seattle Public Utilities

Table 1
The benchmarked peer group.

Breakdown maintenance	Scheduled maintenance	Renewal maintenance
Water Pumping Stations	Water Pumping Stations	Water Pumping Stations
Wastewater Pumping Stations	Wastewater Pumping Stations	Wastewater Pumping Stations
Water Treatment Plants	Water Treatment Plants	Water Treatment Plants
Wastewater Treatment Plants	Wastewater Treatment Plants	Wastewater Treatment Plants
Water Disinfection Plants	Water Disinfection Plants	Water Disinfection Plants

Table 2
Benchmarked mechanical and electrical maintenance activities.

Comparison of 2001 and 2006 mechanical and electrical maintenance benchmarking programmes

A number of enhancements and changes to measures were made in 2006 compared to the 2001 study, making detailed quantitative comparisons difficult. An overall

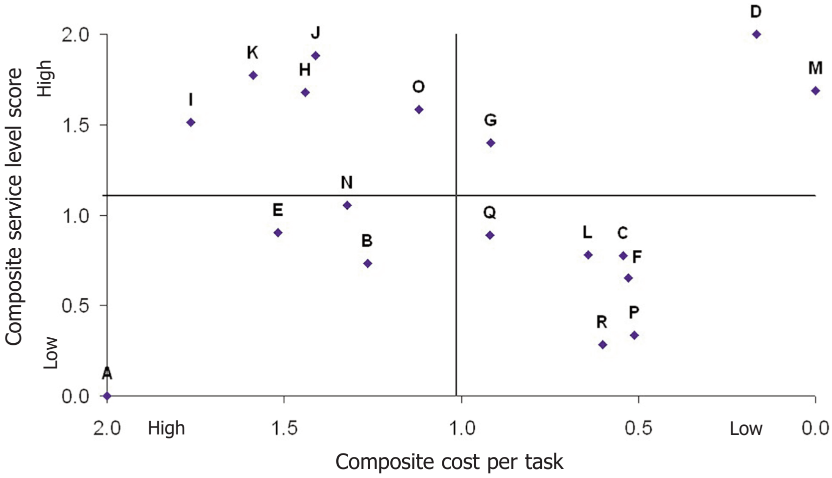


Figure 1
Overall cost and service level performance.

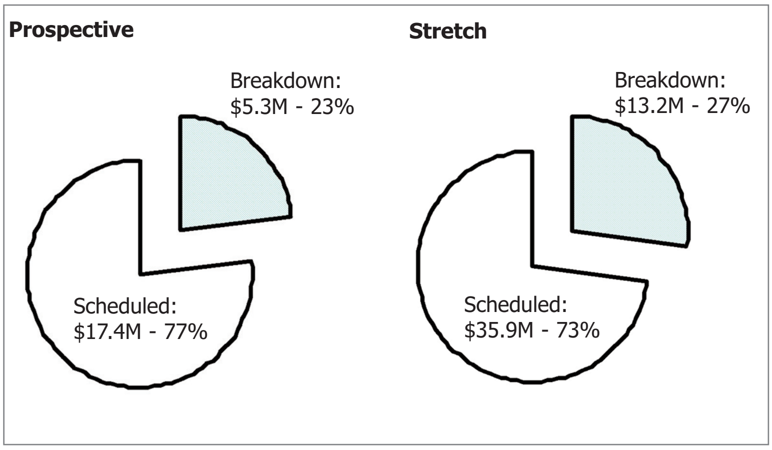


Figure 2
Potential savings range: prospective to stretch target levels.

comparison, however, was able to be made showing the relative movement in cost and service performance of the ANZ utilities that participated in both 2001 and 2006, when compared to each respective year's industry average. Overall, the industry appears to have improved its cost performance by 9%, with some 5% apparent decline in maintenance delivery service level. Some utilities continue to improve whilst others have lagged this cost service trend.

From a qualitative perspective, since 2001 the industry has identified and made fundamental changes in a number of key strategic and operational areas relating to mechanical and electrical (M&E) maintenance in two domains: asset management and service delivery. These include:

1. Asset management domains

Asset management structures: Low-cost asset management utilities have matured and gained greater sophistication in key asset management processes, have a greater scrutiny on costs, strong links to asset owner expectations, cultural development and alignment, and so on. However, a number of utilities have still to embrace and effectively apply asset management structures to their M&E operations, and as such the gulf between leading and lagging utilities is likely to widen.

Asset plans: Detailed asset plans are now commonplace, particularly as regulators and key stakeholders are demanding them for monitoring purposes. Dynamic M&E asset plans will be required to keep pace with and stay ahead of regulatory demands in prudently demonstrating effective management of cost and service levels.

Maintenance optimisation and planning: Low-cost utilities are increasingly improving their sophistication in applying maintenance optimisation techniques on a regular and formalised basis and incorporating them into their day-to-day decision making processes. A key factor will be understanding the cost and service level impacts of scheduled and other proactive maintenance, and developing appropriate maintenance regimes based on asset criticality, redundancy and availability requirements.

Risk management: Risk-based decision making is continuing to improve among better performing utilities, particularly as regulatory and environmental risks are increasingly transparent. Many lagging utilities have yet to implement effective risk management frameworks.

Service level agreements: Service level agreements (SLAs) have been increasingly scrutinised for value. Trends are to remove the internal costs of managing such agreements and simplify them to a point that allows consistent delivery and quality between internal and external workforces

Performance management: Performance measures are well established in the industry but effective application of measures still varies significantly among the M&E utilities. Better performers are updating and translating measures down to the field level to better influence and incentivise behaviour

Data capture and systems: Effective data management is becoming a strong challenge for many utilities as they seek to cope with increasing demands for accountability and information, and particularly M&E data where assets

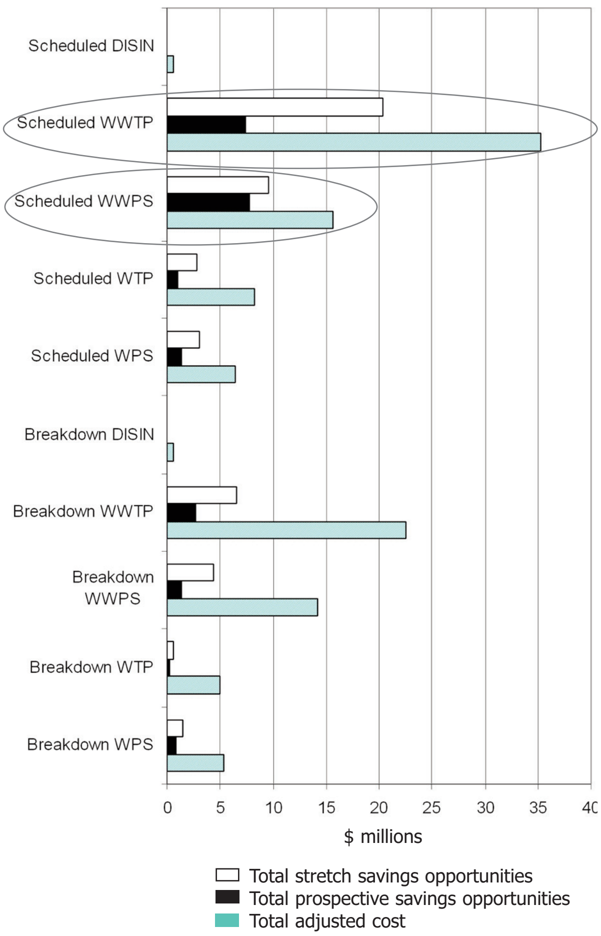


Figure 3
Spend levels and potential prospective stretch savings by benchmarked activity.

are complex and varied. Maintenance management and asset management systems continue to be widely deployed in the industry with some utilities now moving to newer technologies and IT platforms, and developing better data management and systems integration models.

2. Service delivery domains

Resource planning: Various mixes of internal and external workforces have been adopted, with no 'one size fits all' solution. Low-cost utilities are tailoring their M&E resource strategies to the strategic needs of the business.

Crew sizing: Many within the industry have moved towards adopting single person crews on several M&E maintenance tasks, with an emphasis on multi-skilling and better balancing specialisation needs between internal and external workforces.

Partnering: The use of contractors has grown appreciably. Some utilities have established alliance contracts for the delivery of the full range of M&E maintenance services. Best practice suggests fully leveraging the capability of contractors to maximise the value from their experience and expertise in areas such as innovation and asset management.

Direct overheads and supervisory: With the reduction of staff, increased use of contractors, more complex information and asset systems and so on, there has been a trend for supervisory and clerical M&E overheads to increase.

Succession planning: Succession planning has become a significant issue as the average age and years of service increase and the decision making and service delivery skills are becoming a premium. Apprenticeship and graduate programmes have proliferated, and proactive human resources and knowledge management planning and implementation will be key for a successful future.

Industry performance: cost, service level and safety analysis

Cost and service level performance

Cost and service level performance highlighted key differences in the industry. Based on water and wastewater composite mechanical and electrical service level and cost performance, there are two clear groups of performers: those with better than average cost per task, with varying service levels depending on how they treat task definition and scope (particularly for scheduled maintenance); and those with worse than average cost, who are generally clustered around average to high service level (suggesting their higher service level comes at a higher cost) – see Figure 1.

In terms of quantifying overall cost saving opportunities, one reference utility was identified as the 'prospective' target, that being Utility G as the highest cost performer in the group that exists to the right of the vertical line in Figure 1. 'Stretch' performance was based on the cost average of this peer group.

This group also represents those utilities exhibiting an overall lower than peer group average cost per task, and contained a wide set of utilities from small retailers to the larger wholesalers. Figure 2 highlights the significant opportunities that may be on offer for the industry. The largest prospective and stretch opportunities lie in the scheduled maintenance area, which constitutes $17.4 million (77%) and $35.9 million (73%) of the total prospective and stretch savings respectively.

Figure 3 breaks down the savings into their constituent benchmarked activities for prospective and stretch savings respectively. Note that the high spend areas have also given rise to the high opportunity areas. Prospective and stretch savings are dominated by opportunities in scheduled wastewater treatment plants (savings estimated from $7.3 million to $20.4 million respectively), and scheduled wastewater pump stations (savings estimated from $7.7 million to $9.5 million respectively).

Safety

The overall safety performance of the industry is good, with nine of the eighteen utilities recording no lost time injuries. As shown in Figures 4a and 4b, there is also no correlation between lost time injuries and cost per task, or lost time injuries and typical training hours.

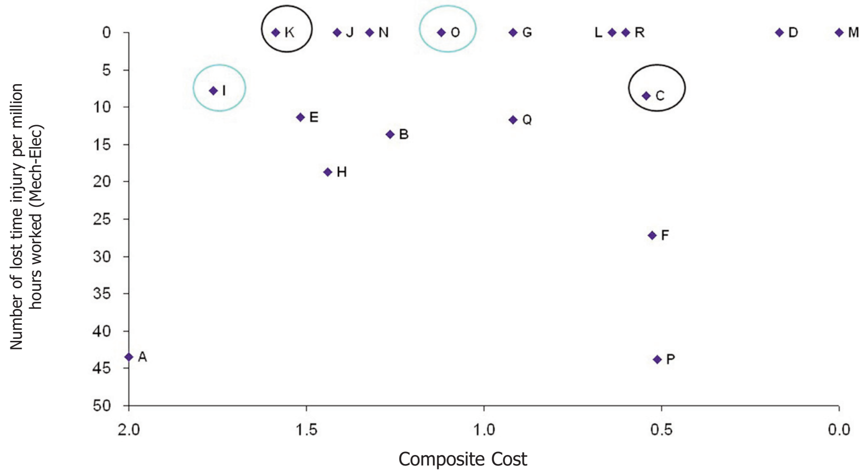
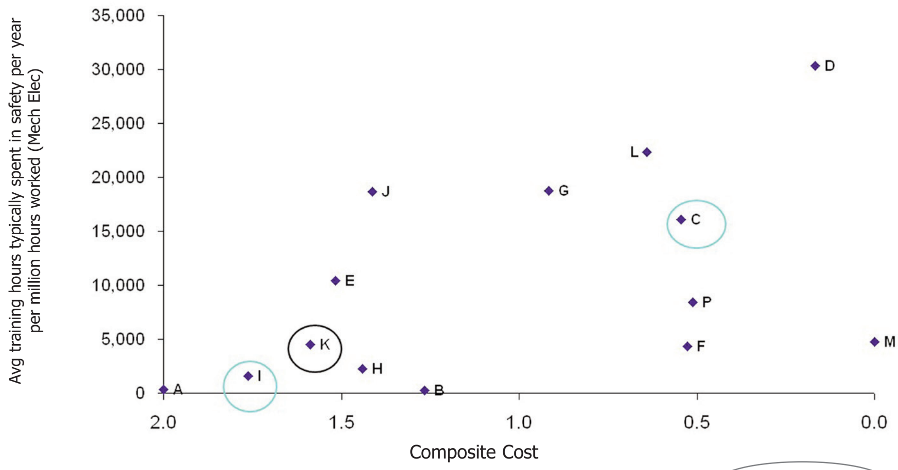


Figure 4a: **M&E internal and external staff - lost time injury frequency rate.**



Outliers: Co Q (0.92; 56, 936), N (1.32; 59, 796), R (0.6; 91, 335), O (1.12;5, 81, 823)

Figure 4b: **M&E internal and external staff - safety training hours per million hours worked.**

Key themes and leading practice attributes of high service and least cost

Based on overall and functional quantitative results and qualitative observations, there are five key industry themes that highlight the attributes of high service and low cost as found in

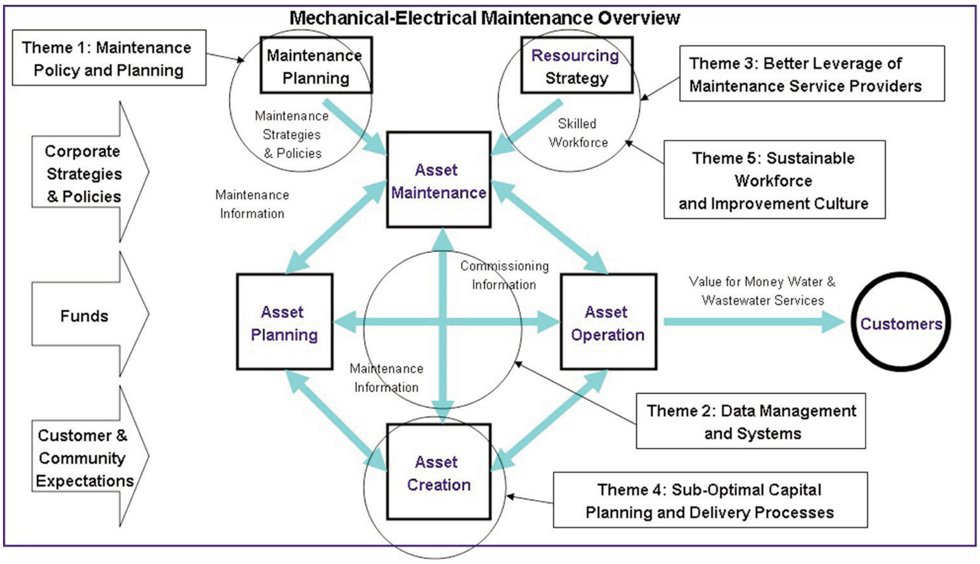


Figure 5
Asset management activities with other related maintenance activities.

low cost performing utilities:
1. Maintenance policy and planning
2. Data management and system integration
3. Better leverage of maintenance service providers
4. Sub-optimal capital planning and delivery processes
5. Sustainable workforce and improvement culture

The industry themes can be depicted in the context of a typical asset management model. The relationship of asset management activities with other related maintenance activities is shown in Figure 5.

1. Maintenance policy and planning, comprising the following sub themes.

Maintenance policy and strategy

Most utilities developed asset plans with varying degrees of centralisation and accountability, which had a strong link to corporate and service-level objectives. Most of the low cost performers are adopting risk based decision making at the corporate, asset, and project levels, with several low cost performers also using a risk based approach in developing maintenance policy through the use of asset condition based analysis techniques such as RCM.

Scheduled maintenance represents the largest savings opportunity in the industry. All water utilities need to conduct a rigorous review of their scheduled maintenance processes, noting that:

- Most utilities in the peer group used a moderate to large definition of task scope (centred on plant asset or facility), whereas some of the low cost performers used a small to moderate definition (centred on an asset component). This impacted their service level and cost per task, particularly for scheduled maintenance
- Water utilities do not have the asset condition information to vary their scheduled maintenance procedures, standards and policies
- The current maintenance arrangements are based on inconsistent application of procedures, standards and policies across scheduled activities, which can ultimately drive over-servicing and lead to increased costs and possibly lower service levels (that is, they can contribute to longer repair times)
- Many are unable to quantify the cost and service level impacts of scheduled activities, and therefore justify the current high expenditure levels

Most utilities within the peer group did not have formal cost-to-serve strategies based on assessments of regulatory and customer outcomes, cost and service level drivers, and business risk. In particular:

- In mechanical and electrical maintenance there tends to be a very strong focus on meeting service level imperatives (odour control, overflows and spillages, and so on)
- Many water utilities in the peer group did not have a sound understanding of their cost-to-serve strategy for mechanical and electrical maintenance at an aggregate water versus wastewater level, or breakdown versus scheduled level (that is, how much it would cost the organisation to meet increased service levels for certain asset classes or tasks, or how much the organisation could save by relaxing service levels for certain asset classes or tasks)

Several low cost performers have implemented or are attempting to standardise their equipment, particularly instrumentation and controls, but this is not practised extensively. Corporate procurement policies that used multiple design and construct contracts were cited by some utilities as leading to non-standardised plant and equipment, and consequently high maintenance costs. In general, this is an area that was poorly addressed across the peer group.

Maintenance planning techniques and tools

Some low cost performers increasingly use risk and condition-based assessment techniques and tools such as FMECA, RCM, RCA, LCA and CBM. They have carefully considered the application of sophisticated tools, trialed them on critical or major assets and/or facilities, and have found that careful application appeared to result in improved reliability and availability, amended maintenance schedules and reduced life cycle costs.

However, most utilities are not systematically using these tools and remain unclear about their maintenance strategies based on asset criticality, redundancy and availability requirements. Further, a shortage of skills exists within the industry in relation to knowledge of application of maintenance planning techniques.

Resourcing

All low-cost performers were adopting small crew sizes (see Figure 6a) for first response tasks with many attaching extra people as required, particularly for safety and confined space reasons. Low-cost performers are adopting multi-skilling to minimise crew size. Many utilities within the peer group adopted the resource strategy of an optimised mix of internal and external labour (see Figure 6b) supported by high degrees of specialisation for high volume and/or specialist tasks.

To minimise confined space impacts some utilities have critically re-evaluated their confined spaces against the regulations to ensure that only genuine confined spaces are classified as such, and proactively designed out as many confined spaces as possible by changing design requirements and standards.

2. Data management and system integration, comprising the following sub themes.

Data management

Most low cost performers, and indeed, many utilities in the peer group had asset management systems that did not meet the full range of maintenance management requirements. Typical issues include:

- Insufficient asset management, maintenance management and

performance management functionality
- Data hierarchies structured to meet financial or other corporate requirements, rather than operational
- An inconsistent approach to data management for different maintenance functions, particularly between treatment plants and pumping stations. This was particularly evident for asset condition data, with many different approaches utilised (different tools used for assessment and different approaches to the capture and storage of information)
- A lack of formal asset management systems strategies that linked with corporate IT strategies.

Whilst several low cost performers were generally collecting some cost and service level data, most utilities in the peer group had a predominant focus on cost data collection and management. Significantly less focus was afforded to service level and workload data collection and management (impacting on the ability of a water utility to develop cost-to-serve strategies).

The focus on cost data collection and management was further compounded by a general lack of formal data collection and management resources and processes in some parts of the industry. Most low cost performers were addressing this issue and making available analytical expertise and processes for the collection and utilisation of critical cost by function and service level data.

System integration

Most low-cost performers, and indeed the industry in general, had low levels of system integration across mechanical and electrical asset management, maintenance management and field-based activities. Many still adopt paper based processes and manual data entry of key maintenance information (for instance, a low level of use of field resource management systems existed in both treatment plants and pumping stations across the peer group, resulting in paper-based communication of work orders and schedules and manual data entry of maintenance information). System upgrades are now the norm for the industry, however, many are struggling with the associated data migration issues as follows:
- Loss of asset history
- Changed data definitions
- Reduced functionality
- Reduced reporting capabilities
- Reduced mechanical and electrical specific asset and maintenance management capabilities.

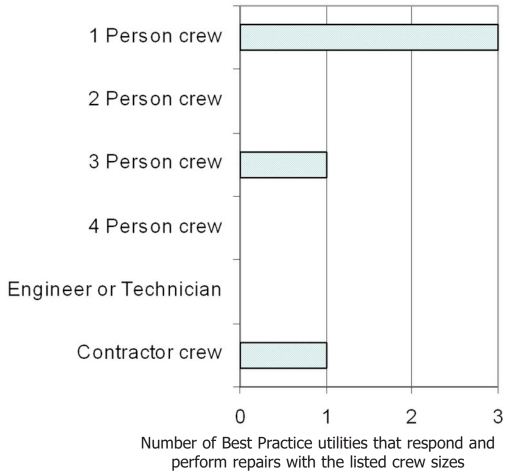


Figure 6a
Best practice crew sizes for scheduled maintenance at wastewater treatment plants.

The industry challenge is to select systems that support their business and facilitate effective and efficient asset management and maintenance management.

SCADA systems

A majority of utilities in the peer group had more than one SCADA system for pumping stations and treatment plants. The degree of implementation and use of SCADA systems varied across the water industry. All of the low cost performers have either fully or partially adopted SCADA systems on their pumping stations and treatment plant facilities that incorporate detailed fault advice capabilities.

3. Better leverage of maintenance service providers, comprising the following sub themes.

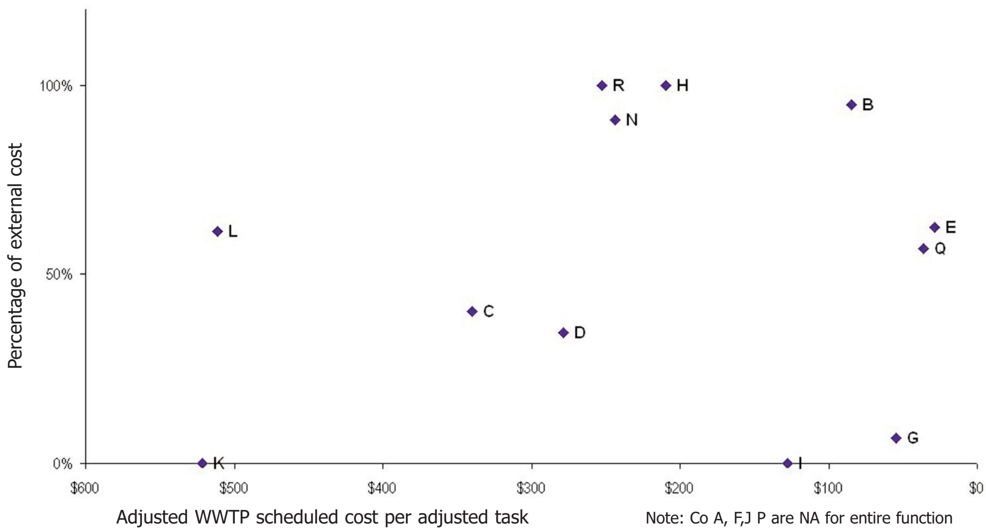
Asset management

Very few low-cost performers were leveraging the international, domestic and local skills and experience of their contractors to improve the management of their assets. Areas where contractor expertise could be better used by the utilities for asset management include:
- Asset management practices such as asset investment planning and spend optimisation
- Data management and systems (that is, advice on the efficient collection of cost, service level, productivity and asset condition data, the selection and integration of asset management, maintenance management and field based systems, and management of data quality)
- Effective use of advanced maintenance planning techniques such as FMECA, RCM, RCA, LCA and CBM
- Performance management (that is, implementation of productivity and utilisation measurement)
- Risk management

Service delivery

Few low cost performers leverage the skills and expertise of the contractors in service delivery areas, particularly as very few of the utilities had single contractors to extract benefits. Areas where contractor expertise could be better used by the utilities for service delivery include:
- Resource planning (that is, advice on crew strategy for breakdown, scheduled and renewal tasks, in order to optimise crew allocation and utilisation)
- Data management and use of field-based systems
- Knowledge management and training (that is, areas such as formal staff rotations or secondments, succession planning, ageing workforce, knowledge management and skills replacement, workforce retention and recruitment strategy, and professional and technical training)
- Improved design of plant and facility layouts

Figure 6b
Internal / external resource mix for scheduled maintenance at wastewater treatment plants.



Breakdown Maintenance	
Policies	**Practices and technology**
• Effective breakdown priority systems in place for customising breakdown response • Strong governance and policies designed to optimise and produce greater spend accountability • Leverage or bundling of orders when purchasing materials and/or services • Greater standardisation of equipment and procedures and reducing the costs associated with managing complexity (for instance, complex skill sets, documentation, contract negotiations, breakdown repair time and task standards and so on) • Detailed documentation and robust documentation control in critically understanding requirements, allowing ease of access to key information, effective knowledge transfer, and effective feedback processes (such as easy to use templates, electronic information flows and so on) • Intelligent and centralised alarming and SCADA systems linked to appropriate staff • Real or near real-time field computing and feedback • Use of lower-paid staff for extra person attendances in meeting confined space safety requirements • KPI-driven culture focusing on productivity and job cost as part of the KPI mix, and effective performance management of contractors. Incentives are formalised and based on key cost performance criteria.	**Mechanical** • Limited electrical qualification • Single (one) person crews (for instance, using cranes on trucks for removal of submersible pumps rather than two people using lifting chains and so on) • Ready access to containment (for example, to alleviate risk of overflow), emergency pumping station **Electrical** • Multi-skilled with instrumentation and control • Usually rostered for out of hours and can deal with most issues **Instrumentation and control** • Ability to multi-skill with electrician • Optimal standardisation of instrumentation and control equipment

Table 3a
Specific leading attributes for breakdown activities.

- Review of maintenance schedules

Most low-cost performers, and indeed most utilities in the peer group, did not have processes in place to support collaborative improvement efforts between internal and external resources in order to share knowledge, or enable process or practice improvements across both workforces. The internal and external workforces tended to work in geographically different areas and rarely interacted.

Contract form
Most utilities in the peer group have adopted lump sum, schedule of rates or time and materials type arrangements with their contractors. Few utilities in the peer group have alliance-style contracts in place. Some of the low-cost performers achieved better outcomes from their contractors if contracts were structured to include some of the alliance principles as follows:
- Reward for innovation
- Collaborative work arrangements such as staff rotations and secondments
- The development and implementation of formal knowledge-sharing processes and systems (particularly in the areas of asset management, maintenance management, FMECA, RCM, RCA, safety, training and so on)
- Risk-based performance incentives
- Performance drivers and measures that directly support the utilities' corporate outcomes.

4. Sub-optimal capital planning and delivery processes, comprising the following sub themes.

Capital planning process
The majority of utilities had formal capital planning, delivery and approval policies and processes in place. This process was generally sub-optimal due to poor procedures in relation to spend optimisation, equipment standardisation and project planning. Further observations include:
- Only low-cost performers focus on spend optimisation as it relates to the maintenance and capital trade-off
- For some high cost utilities, corporate procurement policies have driven competitive design and construct tenders for every project rather than bundling of like projects, which has resulted in a multitude of different plant, equipment and control systems that all require different parts, skills and knowledge to maintain
- Some high cost utilities have contracts for capital projects that do not have clear processes and requirements for the handover of documentation including as-built drawings, O&M manuals, commissioning results, plant information, and so on. This has resulted in receipt of incomplete information, commissioning delays, additional maintenance cost and difficulty in conducting appropriate staff training.

Key stakeholder involvement
The capital planning processes used by most utilities were typically either asset management or maintenance-centric and lacked collective input from asset planners, project managers, design staff and operational staff. This caused several issues including: lack of standardisation with respect to plant design and technology, an inconsistent view of project management responsibilities and approach, and a lack of streamlined handover and commissioning of new plant.

5. Sustainable workforce and improvement culture, comprising the following sub themes.

Training and skills availability
Staff training is focused on technical aspects, with a lesser emphasis on professional training and succession planning. Most utilities are using nationally recognised training programmes for their maintenance or field staff. Further observations include:
- There was a strong emphasis on technical training (safety, equipment usage, and so on) across the peer group
- There was a lesser emphasis on formal professional training (management training, asset management, analysis, presentation skills, communication skills, and so on)
- There were very low levels of formal succession planning conducted across the utilities in the peer group, with most limited to management levels
- Few utilities in the peer group had formal secondment or staff rotation programmes in place to support technical and professional training and development initiatives, either with their internal workforce or contractors
- Many utilities in the peer group are unable to attract high-calibre recruits and are also having problems retaining skilled resources (given competition for resources from IT, mining and so on)

Ageing workforce
A few better-than-average utilities are highly dependent on employees with considerable experience and knowledge. An ageing workforce and lack of formal knowledge management systems is presenting an immense sustainability challenge to the entire industry. These challenges are beginning to be addressed by most low cost performers. A high proportion of internal and external mechanical and electrical staff are in the 35 to 54 age

range, with those in the 45 to 54 age range representing approximately half the staff numbers. Furthermore, there was a limited application of formal knowledge management systems throughout the industry (for instance, documented details and records of assets, documented operational procedures and history for problematic assets, detailed descriptions of work policies and practices for complex tasks, and so on).

Specific policies, practices and technology: breakdown, scheduled and renewal maintenance

Tables 3a, 3b and 3c provide a summary of specific technical leading policies, practices and technologies as used by the leading performers in the peer group for breakdown, scheduled and renewals respectively.

Industry improvement initiatives

Based on the findings of the study there are four key improvement initiatives for the industry, briefly summarised as follows:

1. Improved data management and system integration review

Many utilities struggle to access accurate cost, workload, service level and asset condition data. Effective asset and maintenance management is being undermined by poor data management approaches, and as such there is a need to identify and develop cost, workload and service level data appropriate for breakdown, scheduled and renewal tasks. It is recommended that utilities use the 2006 WSAA mechanical and electrical benchmarking study and current regulatory requirements as a basis for identifying relevant cost, workload, service level and asset condition data for collection and analysis.

2. Rigorous scheduled maintenance review

There are different approaches to scheduled maintenance tasks, based on varying the scheduled task scope (that is, maintenance at an asset level versus a plant or facility level), and differing crew strategies (specialisation versus multi-skilling). Undisciplined asset management applications also exists in the industry, leading to inconsistent procedures, standards and policies across scheduled activities, which can ultimately drive over-servicing and lead to increased costs and possibly lower service levels. It is recommended that utilities implement a comparative review of all scheduled tasks, investigating the number and scope of tasks, the size of mechanical, electrical and I&C crews, people, processes and technology. This should be complemented with well-targeted visits to best-performing water utilities to understand how scheduled maintenance is managed in these organisations.

Scheduled Maintenance	
Policies	**Practices and technology**
• Identification of service level requirements for plants, critical assets, key stakeholders, etc. • Effective RCM maintenance policy in place (such as criteria for run to failure or time-based maintenance for critical assets, proactive policy on opportunistic repairs) • Strong governance and policies designed to optimise and produce greater spend accountability • Well-defined scheduled task definition based on plant complexity, knowledge of asset condition, application of a condition based or time based strategy and other key business criteria • Getting the right balance between scheduled work and the available breakdown resources who can conduct scheduled work as required • Leverage or bundling of orders when purchasing materials and/or services • Greater standardisation of equipment and procedures and reducing the costs associated with managing complexity (such as complex skill sets, documentation, contract negotiations, scheduled repair time and task standards and so on) • Detailed documentation and robust documentation control in critically understanding requirements, allowing ease of access to key information, effective knowledge transfer, and effective feedback processes (for instance easy to use templates, electronic information flows and so on) • Real or near real-time field computing and feedback • Use of lower-paid staff for extra person attendances in meeting confined space safety requirements • KPI-driven culture focusing on productivity and job cost as part of the KPI mix, and effective performance management of contractors. Incentives are formalised and based on key cost performance criteria	**Mechanical** • Planned refurbishment of critical pumps. • Online bearing monitoring, but with limited application to major critical assets • Efficiency testing of pumps, mixers and aerators • Noise and vibration monitoring of mechanical plant, but with limited application of fixed vibration monitoring to critical plant • Oil analysis, but with limited application and success or value in reducing maintenance costs • Containment testing • Limited electrical qualification **Electrical** • Battery replacement schedule • Generator testing. • Switchboard thermography (application on large switchboards). • Routine replacement of critical components • Megger (motor coil) testing, but with limited usefulness in some cases • Motor current analysis **Instrumentation and control** • Standardised PLC components • PLC monitoring • Standardised field devices • develop maintenance requirements with supplier partners • Regular alarm testing • Calibration of instrumentation given high priority, given increasing importance of criticality of plant, especially arising from application of HACCP processes to water quality and more recently wastewater treated effluent quality

Table 3b
Specific leading attributes for scheduled activities.

3. Developing a cost-to-serve strategy for mechanical and electrical maintenance

Many water utilities do not have a unique understanding of the relationship between mechanical and electrical cost and service level in their business and the possible trade-off options and implications. An agreed cost-to-serve strategy is the starting point for effective mechanical and electrical maintenance planning and delivery. It is recommended utilities take steps toward developing a cost to serve strategy for mechanical and electrical maintenance

4. Developing a sustainable workforce strategy

In both the 2005 civil maintenance programme and 2006 mechanical and electrical maintenance programme, issues were identified in relation to workforce strategy. It is recommended that the current workforce strategy should be reviewed in relation to sustainable workforce strategy, particularly in the areas of recruitment, staff development and training, the ageing workforce and knowledge management. Future strategies ought to include development of skills and competency matrices, clear succession plans, formal knowledge management processes, staff secondments and rotations, and so on.

The above four improvements coalesced from a wide range of improvement opportunities were seen to provide scope for major cost savings and business improvements across most of the utilities.

Further developments

A great deal of national and international interest continues to be generated as a result of the recent mechanical and electrical process benchmarking study. The reputation for developing keynote and incisive challenges for quantum business improvement also grows. Evidence of the increasing number of domestic and global enquiries could be seen by the interest shown at a recent presentation

Table 3c
Specific leading attributes for renewal activities.

Renewal Maintenance

Policies

- Effective renewal policies in place that are tied to financial and life cycle requirements of plant (such as trigger points for replacement based on economic as well as technical and regulatory drivers, spares policy and so on)
- Strong interaction between internal and external capital and maintenance stakeholders during design, capital delivery planning, implementation and post implementation phases
- Designing out costly confined space areas and other safety requirements like rails and ladders, and searching for credible alternatives
- Full commercial scrutiny and application of best technical options (such as balancing standardisation and adopting new technologies)
- Effective project management to allow delivery to budget and cost standards
- Renewals are programmed well in advance to minimise cost, and allow effective outage management and resource balancing between breakdown, scheduled and renewal work
- Effective use of highly skilled, dedicated capital workforces based on optimal internal and/or external workforce arrangements
- Effective use of contractors based on innovation, credible timeliness of delivery, quality, cost and safety records
- Robust commissioning and plant handover procedures where requirements are well identified and communicated in conjunction with an efficient process for receipt of key documentation (such as as-builts, operating manuals, commissioning details and records, on going support information, asset and cost information, and so on)
- Regular process in selection of appropriate renewals practices and techniques and encompassing – investigation, awareness and documentation, seeking peer experience and assessing benefits
- Encouraging innovation and development.
- KPI-driven focusing on service requirements, and the long term cost–benefits of reductions in breakdown and scheduled activity as part of the KPI mix. Incentives are formalised based on key service level performance criteria (such as timeliness of delivery, quality of works and so on)
- Identifying and understanding the service level components of renewal tasks for use in future forecasting and decision making in relation to renewals programmes

Practices and technology

Mechanical, electrical, and instrumentation and control

- Internal and external staff involved in the capital planning and delivery process
- Utilising theses renewals resources in breakdown and scheduled for resource balancing

on WSAA process benchmarking at the 2006 IWA World Congress in Beijing, China.

In addition, arrangements and protocols are in place for those seeking improvements to meet with utilities that did particularly well in certain areas. These protocols have already proved helpful, particularly to those now actively developing their mechanical and electrical maintenance business strategies.

WSAA is now planning for the 2007 customer services process benchmarking programme, a co-initiative between WSAA and the International Water Association (IWA). The IWA will therefore be a member of the steering committee for the 2007 programme. IWA's involvement is expected to raise the programme's international profile and increase the number of international participants.

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Integrated modelling, data warehousing and web publishing for water asset management

Zheng Yi Wu, Andres Gutierrez

Bentley Systems, Incorporated
Haestad Methods Solution Centre
Connecticut
USA

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Asset management has gradually become a holistic paradigm for the water industry, although only a limited number of utilities have undertaken the approach. Many factors may contribute to the lack of wide adoption. Good practice of asset management requires not only managerial change within a water utility organisation, but also the implementation of a comprehensive technical framework that enables water utilities to reach the essential target, that is to minimise the life-cycle costs of owning and operating infrastructure assets while maintaining required service levels and sustaining the infrastructure. To achieve the goal, utility engineers and managers must be equipped with the tools for information management, system analysis, and timely communication within and between organisations.

This paper presents the case study of a water system in USA. The system provides water service to a population of more than 300,000 through 31 reservoirs, 14 wells, 116 pumps and more than 800 miles of water distribution pipelines. An open software architecture is adopted for complete data management, integrated hydraulic, water quality, optimisation analysis, document management for technical and non-technical contents (CAD drawings, spreadsheets, correspondence, meeting minutes etc.) together with geo web publishing for information sharing. The approach is well under implementation. It is believed that the technology paradigm shift is going to significantly improve the information management integrity, decision-making intelligence and operation efficiency for the water company. This study exemplifies valuable lessons for adopting a technically sound asset management programme.

While the asset management is a well-understood and accepted concept of 'getting the best return from their investments', it is still relatively new practice for the water industry. With privatisation of the water industry and tight financial budgets, water utilities have recognised that, despite all their cost-cuttings, reorganisations, new technology, productivity and quality initiatives, the overall picture is fragmented. Inefficiency and conflicting objectives, lack of coordination and missed opportunities are still plentiful. Thus the water industry eventually turns to asset management to improve its performance-for-cost.

There are only a limited number of water companies adopting the asset management approach within their organisations, with the UK, Australia and New Zealand pioneering such a holistic approach (Smith 2005; Foley 2005; Harlow 2005; Lumbers & Kirby 2005). However, industrial and political imperatives have forced a radical re-think on how to get better cost performance. The commercial and safety impact of drinking water supply failure is high, so it is clearly vital to find the right combination of risk, performance and cost. Over the last four decades, the water industry has been provided with the most sophisticated information management, systematic simulation and optimisation tools.

However, an asset management programme also needs to be well managed. Like managing any other innovative programme, it is all about people – shared understanding, cross-functional collaboration and teamwork, problem-solving instead of repeated fire-fighting. This paper first gives a brief overview of the integrated technical framework for water asset management, then a case study example of a water system in California is presented to illustrate the application of the latest open architecture software platform for a typical water company to implement a sound asset management programme. The benefits and challenges are also outlined for the benefit of private and public water-related organisations.

Integrated Technology

Asset management is defined as an integrative programme that enables a utility to minimise the life-cycle costs of owning and operating infrastructure assets while maintaining required service levels and sustaining the infrastructure (Allbee 2005 and Causey 2005). By definition, asset management requires water utilities to:

1. Minimise the costs of asset ownership: asset ownership accounts for the bulk of all costs including the capital cost, management cost, operational cost, social cost and risk cost over a lifecycle;
2. Maintain required service levels: while asset management reduces costs, it also improves reliability because it emphasises detailed attention to assets
3. Sustain the infrastructure: this is ultimate goal of asset management.

A sound asset management programme is both near-term (maintenance-oriented) and long-term (refurbishment- and replacement-oriented). Its planning horizon is a long period – typically, 40 years or more. Planning within this time frame will yield the information required for utility governing bodies to understand infrastructure needs and to fund them properly. To achieve the goal, an integrated technique framework is essential for successful implementation of asset management programme. The author (Wu 2006a; 2006b) proposed the detailed requirements for implementing such a framework, which is briefly summarised below.

Framework Components

Effective asset management is to achieve the whole-life optimal impact of every asset, which may be contributed to by all areas of the business – maintenance, operations, projects, safety, engineering and compliance etc. It needs a set of disciplines, methods, procedures and technical tools to optimise the whole life business impact of costs, performance and risk exposure. The tools that pull these elements together within an organisation are classified into three categories, namely information management systems, hydraulic and water quality analysis tools and decision-making support systems. They must be interactively applied to facilitate all the stages and aspects of asset management from asset registering, condition monitoring, risk assessment, hydraulic and water quality analysis, performance evaluation and asset improvement decision-making.

Information Management

The asset information includes its identification system, historical and current condition data. Asset information requires the following information tools for effective management.

Asset register

This may range from a simple coded equipment list to a fully fledged technical information database with GIS diagrams, technical specifications and even video clips of the equipment and how it works. However simple or sophisticated, a comprehensive list of what the assets are, where they are and what they do is essential.

Condition assessment and monitoring

Core to the improvements of asset management is a shift towards condition-based activity – only doing work when the assets need it. Inspections, condition assessment and monitoring systems need to drive maintenance, renewals and modification decisions. There has been considerable overselling of online condition monitoring, however; the asset management approach considers the ‘crude but cheap’ options of operator monitoring or visual inspection quite objectively in comparison to the high technology (and high cost) approaches.

Performance and maintenance history data

In the past, data gathering has been a weak link in the chain. There is usually no real incentive to provide the data (‘nobody seems to use it’). To break this vicious circle, asset management methods address the decision-making steps first (why do we need the data, and how would we use it?), then identify what data is needed to support such decisions. Once the usage is clear, we have a much better chance of gathering the right data in the first place – and maintaining enthusiasm for its continued collection.

The other modules of asset information management may include:

Resource management
Resource management enables managers to systematically categorise the materials, contractors, tools and facilities used for the business.

Safety, risk and environmental management
This helps to meet the government and institutional compliance, and identify risk potential identification.

Project management
This facilitates project planning, logistics, document management and change control.

Financial management
This assists financial budgeting and reporting.

Modeling and Analysis

The important part of water asset management is to evaluate the system performance, supply service level and ‘what-if?’ scenarios. This calls for systematic analysis of the hydraulic and water quality characteristics. Hydraulic and water quality models play an essential role in the analysis.

Hydraulic model

This is a computer tool that allows engineers to replicate and predict the hydraulic behaviour of a water supply system. The results form the basis for asset improvement decision-making and further analysis of water quality conditions.

Water quality model

This is able to simulate the transport and fate of any constituent throughout a water supply system. With the help of a water quality model, engineers and decision-makers can undertake the analysis of water quality characteristics for current and future conditions. It improves the understanding and insights into the water supply performance.

Although the computer models provide a good tool for systematically analysing hydraulic and water quality behaviour, construction of accurate hydraulic and water quality models is not a hit-and-go task. It needs profound understanding of the system in the real world, and also insight into network hydraulics.

Decision-making Support System

It is business-based decision-making that really makes the difference. There are three key stages including:

Identify problems and opportunities

Potential system deficiencies or abnormalities can be uncovered by undertaking the evaluation of key performance indicators, trend analysis, suggestion schemes and quality management activities. This requires effective performance analysis at system level, and linking the results with an information management system: e.g. finding leakage areas and quantifying the unaccounted-for water, or discovering the shortage of water supply for the planning horizon.

Define feasible solutions

Various systematic techniques including failure modes, effects analysis and root cause analysis, are available for investigating problems and identifying feasible solutions or improvements. More importantly, careful analysis of current conditions, future demand and supply criteria will better prescribe the alternative solution space, which may often involve many conflicting decision objectives.

Search for tradeoff

Cost, risk, and performance evaluation of the possible options, and best optimisation of the possible solutions. This brings us back to the starting point – what comprises the best combination of costs, risks and

Figure 1
Service area of the case study water system.

performance, with a whole-life view of the infrastructure. Asset management decision-making is rapidly expanding to include 'what if?' analysis, system performance simulators, cost/risk trade-off optimisers, project life cycle costing and investment prioritisation tools. State-of-art decision-making technology is not the last word and does not replace human judgment – but enabling this decision-making support process to take off, understanding and correctly implementing it, will determine the degree of success that can be achieved.

Work scheduling

A systematic and consistent scheduling system improvement/expansion is vital to make sure that the right investment is made on the right assets at the right time with the right materials. This is the core of a work management system and another 'must-have' tool.

One of the practical examples is illustrated for using the integrated modelling, data warehousing and geo web publishing technology for sound water asset management.

Case Study

This case study describes a project that was implemented in a water supply company that provides water service to a population of more than 300,000 in a service area of 41 square miles. The area is covered by a water distribution system consisting of 31 reservoirs, 14 wells, 116 pumps and more than 800 miles of pipelines. The service area of the water system is shown in Figure 1.

Prior to adopting the integrated asset management framework, the company maintained a tiled base CAD system in DGN format that contained water system information of nodes and pipes, as well as separate land use information of parcels and addresses.

A Geograhics system was created, however, minimum function was being used, other than keeping records in an Access database. There are about 350 landbase and water facility tiles, each of which is 3000 x 2000 feet in size and named according to the 1000 grid values in the lower left corner. The system tracked some work information, but most of it was tracked outside of the Geographics environment, and some important data, like elevation data, was missing in the drawing or in the database.

In order to achieve a more comprehensive design system to manage the day to day activities, the company decided to move towards a more complete design and analytical water asset management system. An open software architecture (Figure 2) for advancing the water company's information infrastructure was proposed in order to improve management and operation efficiency. It integrates complete data management, comprehensive hydraulic and water quality simulation models, state-of-art optimisation analysis tools, document management for technical and non-technical contents, and web publishing.

The proposed solution essentially provided a sound technological framework for informed water asset management. There are various software technology components that are involved in this solution, as follows:

Bentley Water

Bentley Water is an engineering automation solution for water network design and management. It addresses all operations of a typical water supply network through an integrated geospatial environment. Bentley Water includes an integrated mapping and design environment, as well as support for operations, maintenance, and record keeping.

All data manipulations including entry, modifications and removal of the water facilities can be built upon Bentley Water's data maintenance capabilities in the following two aspects:

1. Modifications to the database structure or schema

Change existing tables to match the Bentley Water Schema.

Port the existing attribute tables over to the Bentley Water table definitions. This process ensures the data integrity by adding the additional columns being needed and retaining existing columns that are not even used in Bentley Water.

Add the additional to store and manage extra work information, such as adding the elevation data to the database. This data becomes available for the use by the other integrated components.

Align the database schema to match the needs of water system modeling and analysis.

Conduct additional QA/QC over the data porting progresses.

2. Modifications to the existing drawings

All drawing data are validated against the symbology standards. These standards are defined by the database table. For any items that are not receiving a feature linkage, the symbology standards are applied. These standards guidelines are agreed upon before the conversion is to begin.

All drawing items that have a database linkage or linkages are validated against the database records they refer to, ensuring 1) the drawing graphics and the database linkage are in synch. This means that the linkage on the drawing element coincides with a record, for the referenced table, in the database; (2) a drawing graphic has been orphaned if there is a database record but it points to a nonexistent graphical record.

Where appropriate, entity numbers for each linkage are corrected due to schema changes.

The features not having an attribute linkage are validated. For the situations where a graphical element does not have an attribute linkage, but does have a feature linkage, an entry will be placed in the error log file and nothing more will be done.

Attribute records are verified and updated. This includes:

1. XY coordinates. The original system does not keep track of any coordinate information in the database. It is assumed that nodes are placed in the correct location in the DGN files. The XY data will have to be retrieved from the graphics to populate the XY coordinates in the database. The elevation (or Z) data is provided from external sources.

2. Verifying that the to- and from-nodes numbering is correct in the main table.

3. Verifying that the hydrant and valve tables are correct – update where necessary.

4. For cross, tee or any other type of node that has more than one edge (main) tied to it, the number of mains attached to it needs to be

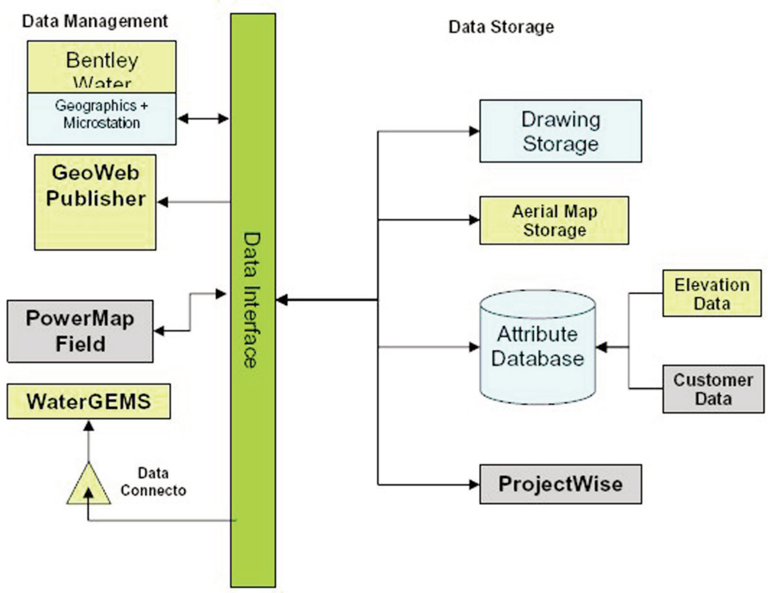

Figure 2
Integrated and open architecture for data management, modeling and geo web publishing.

verified. A scan for elements is performed to discover the pipes around the node. If the correct number of edges (mains) are not found then this node will be flagged for further investigation.

Features' symbology is validated, based on feature table attributes.

Each element with an attribute linkage is reviewed to ensure that the map id is correct in the maps table.

Any valid water feature whose map id can not be determined from the database is updated with the map reference for the drawing that the element currently resides in.

WaterGEMS

WaterGEMS is a hydraulic and water-quality modeling solution for water distribution systems with advanced interoperability, geospatial model building, optimisation, and asset management tools. In this solution, WaterGEMS is used as the design and analysis component. WaterGEMS and Bentley Water interact through the tabular data stored in the database.

Geo Web Publisher

Geo Web Publisher is a high-performance Internet server that supports distribution of information in both its original intended form and through dynamically created new representations to geographically dispersed workgroups or public audiences. Geo Web Publisher allows users outside of the engineering and mapping departments to review, query and print the water facilities information maintained by Bentley Water. In particular, Geo Web Publisher enables the water company in the following tasks:

Data integration

Geo Web Publisher facilitates the integration of multiple graphical and non-graphical data sources into one homogenous web interface. Native Oracle Spatial data can easily be published live. Geo-referenced tabular data, virtually any type of raster image files, DGN, DWG and MicroStation. GeoGraphics projects can also be combined into intelligent presentations. Multiple tabular data sources can also be integrated even if they are not directly related to maps. The structure is optimised for organisations like municipal environments where information is highly inter-related.

Building and maintaining geospatial websites

Website options include website layout and graphical presentation and configuration of geospatial building blocks such as querying, reporting, or map display. Websites can be efficiently updated as new needs arise with task oriented tools for adding or modifying queries and reports or adding new layers of information. Multiple links can be created to integrate the geospatial site with other pages of corporate websites or with documents such as metadata, customer support files, or other pertinent information.

Reporting and analysis

Powerful end-user functionality is delivered in Bentley Geo Web Publisher. Users can generate reports and perform spatial analysis from the Web browser. Various options are available to create efficient queries, both simple and complex. Open-ended questions as well as streamlined queries can be presented to your end-users, minimising the amount of time necessary to find information. Reports can generated from queries, spatial analysis, or other means such as multiple feature selection. These reports may include multi-tabbed views of textual data and multimedia information, as well as, downloadable files.

Map viewer

An end-user client optimised for enhancing the map experience and ease-of-use is delivered with Bentley Geo Web Publisher. Functions such as tooltips, measure, buffer, and scale are dependent on the data presented, that is, the Map Viewer is 'map aware'. Enhanced capabilities such as selectable features, scale-dependent display control, and analysis functions are provided with the Map Viewer.

High-performance Internet data server

Geo Web Publisher provides high-performance publishing of vector, raster, and database information. There is no need to simplify your data in order to view it over the Web. Full fidelity publishing including 3D hybrid displays of vector and raster information is readily available via a web browser.

PowerMap Field

PowerMap Field is a customisable mobile environment designed to enable rapid creation of field data collection, as-built reporting and other field based applications. PowerMap Field utilises the data in the drawings and database for use by field personnel in laptop or pen computers. PowerMap field uses the same base engine and data schemas as Bentley Water.

ProjectWise

ProjectWise is a full featured document management system that fully integrates with all Bentley products providing document and content management, content querying, distribution, lifecycle management, printing and publishing, digital security, change management, standards administration, customization, and workflow management. ProjectWise provides a document management system for drawings and other engineer and non-engineering content (Spreadsheets, correspondence, etc.). All the techniques components adopted in the project are designed to work in conjunction with ProjectWise.

With the implementation of the state-of-art information management, system modeling and analysis techniques, the water company is benefited from the expanded and up to date information, upon which the informed decision can be made for daily system operation and maintenance. The integration of different data sources also helps engineers to undertake the systematic approach for analysing a variety of system scenarios by using the intelligent water modeling technology. In the meantime, the information is better shared within the water company and with the local community by the high performance internet data server of Geo Web Publisher.

Summary

In summary, asset management is a classic concept for many industry sectors, but it is a relatively new practice for the water industry to bring the existing best practices together, and fill some of the remaining gaps. Water Utilities need to align all technical components to achieve business goals, and ensures that the component activities operate in harmony. It requires the sophisticated technical solutions, the shared understanding, motivation, trust and collaboration to reach the best outcome, rather than local and short-term self-interest. Implementing and executing such an overall change and reformation is not easy but ensures water organisations stay on the competitive edge in getting the best return of the investment while satisfying customer expectation.

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AM UPDATES

InfoWorks the automatic choice for Carolina network

Wallingford Software's InfoWorks WS has been chosen to play a key role in decision-making in the town of Cary, North Carolina, in the US. Engineers in Cary are in the process of introducing InfoWorks for both managing the water network and planning a capital improvement programme in line with the town's water system master plan.

Cary is in the heart of North Carolina´s Research Triangle area. It is the state's seventh largest municipality. One application that is expected to bring particular benefits involves making better use of the information about demand gathered by the town's water meters, through InfoWorks WS customer points.

'There is a straightforward function in InfoWorks that will let us take meter readings and assign them automatically to nodes in the model,' says engineering services manager Glen Harrell. 'I intend using it initially for our annual meter readings. Then, within the next few years, we will be getting automated meter infrastructure, which will give us real-time data. We will then be able to update our demand distribution information throughout the year.'

InfoWorks WS allows the user to integrate customer information with the hydraulic model. This allows the user to increase significantly the accuracy of the model without the need to increase model complexity. It also provides modeling results individually for each customer and allows direct customer notification in case of an emergency.

www.wallingfordsoftware.com

C+G unveil smart meter conversion kit

New technology which converts existing gas, water or electricity meters into 'smart' meters to enable businesses to better manage utility service usage, will be unveiled by C+G Management at the Energy Event 07, held at the UK's National Motorcycle Museum in September.

Meter-Mimic, a quad band GPRS wireless data logging system for non-invasive meter monitoring, features an advanced ferro-magnetic detection technology which senses the fluctuations in the Earth's magnetic field caused by the rotation of internal magnets in mechanical meters.

Using this technology, Meter-Mimic enables meters to be read without using any physical connection. The process is controlled by advanced software algorithms. The Meter-Mimic system is also able to collect readings from all types of electricity meters, including rotating disc meters and electronic meters via its optical input port.

The collected data is then transmitted via Meter-Mimic's internal GPRS modem to a central server database which then analyses and organises the data. Subscribers to the system can interrogate the data via a secure web-based system.

Meter-Mimic can transmit much more data than a conventional GSM/SMS text based system as it sends data as an email as opposed to an SMS text message, at a fraction of the cost of SMS messaging. As a consequence, much larger payloads of data can be sent for high resolution energy and water management purposes. Alternatively, data can be held on the Meter-Mimic's internal multimedia card and sent at less frequent periods, thus reducing the costs of the system even further but without loss of data resolution.

Mobile leak detection system passes pilot test

A mobile technology system delivering quicker and more accurate reporting of water leaks has been successfully piloted in the north west of the UK for United Utilities.

The 'Pinpoint' system, developed by software provider eSAY for RPS Water and United Utilities, allows engineers to file real-time reports of leaks and defects via GPS and GPRS-enabled hand-held devices, wherever they are.

Unique in the water industry, the system has changed working practices with quicker and more accurate reporting of leaks saving an estimated 175 hours a week in travel time for the 35 engineers using it.

Although not yet quantified, the associated water savings are also expected to be significant.

Following the success of the pilot, United Utilities is now considering rolling out the technology across the whole north west region, with potentially 100 new devices to be issued. Anglian Water has also signed up for an initial project with the technology.

The system has been upgraded for Anglian Water to include the ability to send a sketch of the defect with the report; an initial 20 units are live in the region.

www.esay-ltd.co.uk

New AwwaRF research reports from IWA Publishing

Estimating Health Risks from Infrastructure Failures

AwwaRF Report 91125F

Authors: Karen M.E. Emde, Daniel W. Smith, James A. Talbot, Les Gammie, Susan Ancel, Nelson Fok, Janet Mainiero

Health risks from infrastructure failures are not well understood, despite the potential widespread introduction of chemical, microbial, and physical contaminants, as well as service disruptions. Public health effects due to distribution infrastructure failures are the concern and responsibility of the local water utility, the health department, community medical care providers, and in special circumstances, emergency first response agencies.

While the water utility is responsible for safe water, including the operation and maintenance of distribution infrastructure, other agencies including public health regulators, medical practitioners, and first responders (e.g., police, fire, others) also play a pivotal and active role when dealing with the impacts of infrastructure failures on the community.

All agencies involved with some aspect of public health protection from infrastructure failures acknowledged that the true extent of health effects, while not yet well known or characterized, required a collaborative, interagency approach.

The study identified methods to develop future collaborative efforts, which included improved understanding of the relationships and outcomes between infrastructure failure events and measured health outcomes, as well as the need to develop improved tools for the detection and monitoring of these events and community effects.

The study identified ways to improve interagency communication as well as potential opportunities for cross-training to improve understanding between stakeholders and to develop better collaborative relationships and programmes.

Publication Date: June 2007; 176 pages
Paperback; ISBN: 1843399725
Price: £ 120.00 / US$ 240.00 / € 180.00
IWA members price: £ 78.00 / US$ 156.00 / € 117.00

Environmental Management Systems: a Tool to Help Water Utilities Manage More Effectively

AwwarF Report 91128

Author: James Ollerenshaw

Although water utilities are usually viewed as clean facilities, their operations can have both direct and indirect effects on the environment. From impacts on source water and land use, to energy consumption, chemical usage and residuals disposal, drinking water utilities may find that implementing an EMS that evaluates ongoing utility activities and includes performance measures, based on the Plan-Do-Check-Act cycle, the heart of an EMS, will demonstrate continually improving environmental stewardship.

The initial objective of this project was to investigate the potential benefits of developing a model environmental management system (EMS) specific to drinking water utilities.

Originally envisioned as a sector-specific EMS model for utilities to customize and implement, it was determined that a more useful product would be guidance on how to implement an EMS based on the existing International Organization for Standardization (ISO) 14001 voluntary standard, supported by examples from water utilities with established environmental management systems.

The initial work for the project included a review of available literature relevant to developing and evaluating EMS options for drinking water utilities, and a survey of industry professionals to (1) assess current views about key issues facing utilities and to (2) evaluate how an EMS might help manage these issues more effectively.

The project was guided by two workshops with participation from 13 utility representatives. The first workshop clarified the issues that are of prime importance to drinking water utilities and also explored the EMS structure that was favored by the participants. The second workshop focused on the elements of an EMS and their relationship to drinking water utilities.

Publication Date: June 2007; 255 pages
Paperback; ISBN: 1843398117
Price: £ 120.00 / US$ 240.00 / € 180.00
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AM DIARY

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

New Directions in Urban Water Management
12-14 September 2007, Paris, France
For more information, contact the event Secretariat:
Fax: +33 145 685 811
Email: symposiumUWM2007@unesco.org

Design, Operation and Economics of Large Wastewater Treatment Plants
9-13 September 2007, Vienna, Austria
For more information contact
Prof. Dr.-Ing. Harro Bode, Ruhrverband, Kronprinzenstrasse 37, 45128 Essen, Germany.
Tel: +49 (0)2011 781 020
Fax: +49 (0)2011 781 025
Email: bode@ruhrverband.de
Website: http://lwwtp07.tuwien.ac.at

2nd Leading-Edge Conference & Exhibition on Strategic Asset Management
17–19 October 2007
Lisbon, Portugal
The subject of LESAM 2007 is Strategic Asset Management of Water and Wastewater Infrastructure. Management of investment needs, while meeting regulatory and other goals, requires:

- A better understanding of what customers demand from the services they pay for, and the extent to which they are willing to pay for improvements or be compensated for a reduction in performance
- Development of models to predict asset failure and to identify and concentrate investment on critical assets
- Improved management systems
- Improved accounting for costs and benefits and their incorporation within an appropriate cost-benefit framework
- Incorporation of risk management techniques
- Utilisation of advanced maintenance techniques including new rehabilitation failure detection technologies
- Enhancements in pipeline materials, technologies and laying techniques.

LESAM 2007 will provide an opportunity to discuss developments at the leading-edge in these and other fields to an audience of utility operators and managers, regulators and consultants. It will be focused on the techniques, technologies and management approaches aiming at optimising the investment in infrastructure while achieving demanded customer service standards.

The topics within the subject tobe covered at the conference and exhibition are:

- Global approaches to asset management
- Target definition and assessment of performance
- Cost and benefit valuation
- Target definition and assessment of risks
- Asset data and information systems
- Engineering developments
- Institutional and organisational aspects
- Financial management
- Social and economical dimensions

For more information contact:
LESAM Secretariat (LNEC / DSLM / DIEAG), Av. Brasil, 101. 1700-066 Lisboa Portugal
Fax: +351 218 443 014
Email: lesam@lesam2007.org
Website: www.lesam2007.org