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PAPERS

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World Bank agrees loan for Morocco development plan

The World Bank has approved $300 million loan for Morocco to finance various programmes under phase two of the National Human Development Initiative (NHDI), a development plan launched in 2005 which includes increasing access to water supply and sanitation services for the urban and rural poor.

The four-year second phase of NHDI, launched by King Mohammed VI, will cost $2.1 billion and has five components to be implemented between 2012 and 2015. The water supply and sanitation programmes are included under the rural and urban sub-programmes components, which will cost $374 million and $410 million respectively by the end of the NHDI plan period.

Under the rural sub-programme, an estimated 702 poor communes will benefit from construction and rehabilitation of infrastructure and provision of services including water supply and sanitation while similar activities will be carried out in at least 532 selected urban neighbourhoods during the same period.

Just like in phase one of NHDI, water utilities will be provided with subsidies to cover costs for user fees as one way of increasing the number of people connected to water supply and accessible to sanitation services by the end of 2015.

Water supply in Morocco is dominated by private companies in four of the largest cities, including Casablanca and Rabat, municipal utilities in 13 cities and the National Water Company (ONEP) which, in addition to supplying bulk water for all utilities in the country, is also responsible for supplying 500 other smaller towns across the North African nation.

Among the private water service providers expected to implement the subsidy water supply and sanitation access programme with the World Bank funding is Lydec, a subsidiary of Suez Environment, which is the concession holder in Casablanca, and France's Veolia Environment subsidiaries Amendis and Radel, both holding concessionaires for the cities of Tetouan and Rabat respectively.

The bank's funding, part of the 20 percent expected from external donors, will also facilitate a full roll-out of the subsidy water supply and sanitation project that has been under implementation on a pilot basis in four cities through an output-based aid programme.

'The loan package approved today targets poor rural and urban Moroccan communities for improved services and economic opportunities and promotes the development of smaller enterprises,' the World Bank said in a statement on 29 June.● **Shem Oirere**

Ex-Im approves $64.9 million in financing for water supply system in Sri Lanka

For the first time since 2008, the Export-Import Bank of the United States (Ex-Im Bank) has authorized a sovereign transaction – a $64.9 million, 12-year direct loan – to the Democratic Socialist Republic of Sri Lanka to finance the design and construction of the Badulla, Haliela and Ella Integrated Water Supply System by US company Tetra Tech.

The water-supply project will integrate new and rehabilitated treatment plants, storage tanks, pumping stations, a new dam and impoundment reservoir, new and existing water intake structures, nearly 50km of transmission pipeline, and more than 100km of distribution pipeline. Once in place, the water-supply system will help the government of Sri Lanka to realize its objective of providing safe drinking water to 85 percent of the population, in line with the United Nations Millennium Development goals.

According to Sri Lankan government estimates in 2009, 79.5 percent of the population had access to water supplies, but only 37.5 percent of the population, or 8.06 million people, could access potable water through pipe-borne systems. In some regions, it was estimated that more than 80 percent of the water supply was contaminated. Much of the contamination was attributed to agrichemical runoff and saltwater intrusion, the latter of which resulted from the 2004 tsunami when four tidal waves inundated part of the island's freshwater aquifer and well network with seawater.

'This is the first full-scale, design-build water-supply project that Ex-Im Bank has financed for an international client,' said Dan Batrack, Tetra Tech's chairman and CEO. 'Tetra Tech is proud to support the government of Sri Lanka in this important effort to bring safe drinking water to its people.'

Sri Lanka accounted for approximately $20 million of the Bank's worldwide credit exposure as of the end of FY 2011.

The Bank's Environmental Export Program includes support for US goods and services to international water projects, and its enhanced financing includes repayment terms up to 18 years.

Ex-Im Bank's financing has supported the sale of approximately $270 million in water-related exports since FY 2009. ●

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EBRD agrees grant and loan for water supply works

The European Bank for Reconstruction and Development (EBRD) is providing a €2 million ($2.5 million) loan and a €3 million ($3.7 million) grant from its Shareholder Special Fund to help improve the water supply for around 40,000 people in the Kyrgyz Republic city of Kara-Balta, a major industrial and transport hub.

The works will include significant rehabilitation and modernization of the city's water and wastewater networks including pump upgrades, network rehabilitation, installing household and bulk meters, and chlorination equipment.

The project will help the country move towards achieving full compliance with EU standards. An additional grant of €1.3 million ($1.6 million) will support project implementation and provide technical assistance to strengthen the operational and financial sustainability of the Kara-Balta Water Company. Water wastage in the city was estimated in 2011 at 78%. ●

Leaky water pipes problem solved by UK engineers

A leak detection system that can identify damaged water pipes swiftly and accurately has been developed by engineers at the University of Sheffield, UK.

The system invented at Sheffield tests pipes by transmitting a pressure wave along them that sends back a signal if it passes any unexpected features, such as a leak or a crack in the pipe's surface.

The pressure wave is generated by a valve fitted to an ordinary water hydrant, which is opened and closed rapidly. The wave sends back a reflection, or a signal, if it encounters any anomalous features in the pipe. The strength of that signal can then be analysed to determine the location and the size of the leak.

Originally developed by a team led by Professor Stephen Beck in the University's Department of Mechanical Engineering, the invention was developed into a prototype device in partnership with colleagues in the Department of Civil and Structural Engineering and utility Yorkshire Water.

The device has now been trialled at Yorkshire Water's field operators training site in Bradford and results show that it offers a reliable and accurate method of leak testing. Leaks in cast iron pipes were located accurately to within one metre, while leaks in plastic pipes were located even more precisely, to within 20cm.

Existing leak detection techniques rely on acoustic sensing with microphones commonly used to identify noise generated by pressurised water escaping from the pipe. This method, however, is time consuming and prone to errors, says Sheffield University; the use of plastic pipes, for example, means that the sound can fall away quickly, making detection very difficult.

In contrast, the device invented by the Sheffield team uses a series of calculations based on the size of the pipe, the speed of the pressure wave, and the distance it has to travel. The device can be calibrated to get the most accurate results and all the data is analysed on site, delivering immediate results that can be prioritised for action.

Dr James Shucksmith, in the Department of Civil and Structural Engineering at the University of Sheffield, who led the trial, says: 'We are very excited by the results we've achieved so far: we are able to identify the location of leaks much more accurately and rapidly than existing systems are able to, meaning water companies will be able to save both time and money in carrying out repairs.

'The system has delivered some very promising results at Yorkshire Water. We hope now to find an industrial partner to develop the device to the point where it can be manufactured commercially.'

Dr Allyson Seth, Networks Analytics Manager at Yorkshire Water comments: 'Driving down leakage on our 31,000km network of water pipes is a high priority for us.

'Over the last 12 months alone, we've targeted leakage reduction and as a result we're currently recording our lowest ever levels of leakage.

'But we want to do more, which is why, in addition to the existing technologies we use, we're looking at new ways to help us to reduce leakage.

'Our work with engineers at the University of Sheffield is the latest example of this, and we look forward to working with them going forward to build on what has been achieved so far.' ●

NIB provides funds for municipal improvements in Lithuania

The Nordic Investment Bank and Vilnius, the capital of Lithuania, have signed an agreement providing the city with a new 20-year loan facility worth €8.5 million ($10.5 million) to finance a municipal investment programme.

The loan will be used to finance projects including street reconstruction, upgrading infrastructure for sludge and wastewater treatment, and improving energy efficiency in public buildings.

The sludge treatment project will help solve the problem of storing wastewater sludge. The sludge will be used to produce biogas, which will fuel a combined heat and power station.

Rehabilitation and extension of the Vilnius water supply and wastewater treatment infrastructure will connect newly developed residential areas to the municipal water networks. ●

Looking forward to asset management

This paper takes a look forward to the strategic issues facing water company asset managers and considers the extent to how issues have been addressed over the past few years. Paul J Conroy discusses whether or not there is a single approach or concept that describes the asset management philosophy and the issues of resilience, sustainability and the challenge of decision making in an uncertain world.

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In 2007, reflecting at IWA's LESAM conference in Portugal, I discussed areas that were driving research and developments and being delivered by consulting firms to asset management organisations, but are these still key issues and drivers? A general definition of asset management, taken from PAS 55, is still generally accepted by many as a good one:

'The systematic and coordinated activities and practices through which an organisation optimally manages its physical assets, and their associated performance, risks and expenditures over their lifecycle, for the purpose of achieving its organisational strategic plan' (Publicly Available Standard (PAS) 55: Asset Management – the specification for the optimised management of physical assets).

'Therefore, asset management in the water industry is the process through which utilities determine capital and operational investment needs to deliver acceptable levels of service to customers, balanced against wider stakeholder expectations' (Conroy PJ & Williams WD, 2007).

Perhaps this definition is best summed up by Figure 1. Showing a graph with unlabelled axes would usually invite plenty of criticism, however, perhaps this is the safest option and a discussion as to how best to generate the individual risk and cost curves could create even greater disagreement over the precise methodology.

The illustration is one of concept, not quantification. The graph attempts to show that whilst benefit increases (shown as a risk reduction) with increasing investment, the return is a diminishing one. This means that there is a theoretical optimum trade-off (compromise), where the rate of change of cost and risk is the same (note, this is not the cross-over in this particular illustration).

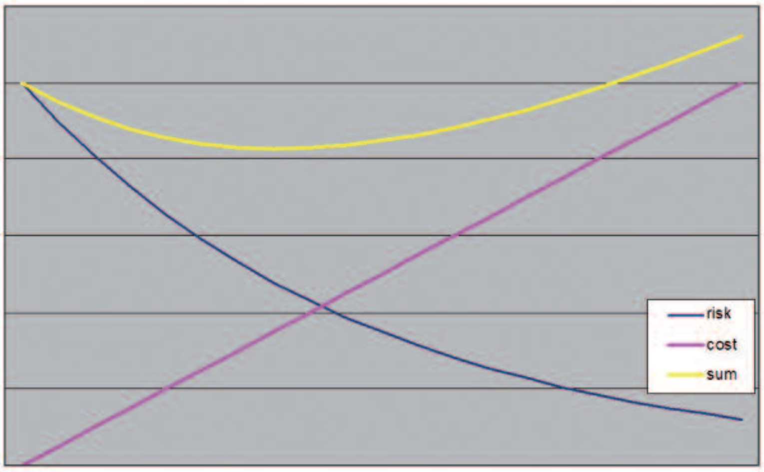
It is the concept of compromise that in fact unifies the various approaches to asset management. The optimisation approach involves a process of estimating costs and benefits and determining the value of the total benefit, i.e. what is valued and to what extent. Working within constrains of budget and time horizon has a profound impact on the strategy and the investment decisions that are made. For example, the level of investment tends to be a reflection of the perceived value of the service and stakeholder willingness to pay / avoid. Values and affordability vary from one region to the next and it is because of this that one company is able to justify 'gold plated' assets and another believes that a risk cost sum 'sticking plaster' approach is optimal. However, they should both, as effective asset management companies, be attempting to reach the optimum compromise between cost and benefit and assign value to benefits based on a process of stakeholder consultation.

At a more practical level, irrespective of the methodology for assigning value to the service delivered by the assets, there are a number of critical elements to the asset management process:

- Categorising the assets (what and where)
- Defining and measuring service levels and key performance indicators (KPIs)
- Deterioration and service forecasting
- Risk assessment and management
- WLC and CBA (whole life costing and cost benefit analysis)

These activities need to be supported

Figure 1
The theoretical trade-off between cost and risk



by the culture and organization, business processes and systems. There is also a need for innovation and the technology to deliver solutions. In 2007, when considering my own experiences in the water industry (UK, Europe, US and Australia) and where the industry was with these issues, there were a number of concerns.

The 'strategy'

At the time, many organisations were focused on the immediate problems, operational issues and 'tools-based' solutions; documented strategies were few and far between. Rarely were they linked to policy with clear objectives and the associated KPIs and measures defined. Even when these issues were addressed, invariably the issue of dissemination and wider corporate buy-in were still problematic.

The 'culture and organisation'

Good asset management requires the right leadership, an enabling culture and organisational structure to support it. The culture is about the desire and environment and instilling the passion for beneficial change into the organisation. Creating this culture requires the right messages from the top of the organisation and good communications of strategy throughout the organisation. Everyone needs visibility as to how their actions will support delivery of the strategy – from the person repairing a collapsed sewer at 3am in the morning, to the ultimate decision-maker in the board room, this is essential. It is especially important that top management buy-in is apparent to all. Needless to say, good intentions alone will not achieve effective asset management and the organisational structures, written procedures and authorities need to be in place to support it

The 'tools and systems'

Tools for integrated risk analysis and assessing the benefits of intervention are always high on the list of needs. These products are continually evolving and range greatly in terms of their degree of sophistication. In 2007, there was much debate as to the best way to measure risk and express benefits. Another issue faced by many was deficiencies in data to support effective investment planning; this was typically coupled with systems issues that made it difficult to access and the asset planners. This problem has been compounded, historically, by legacy systems and a culture focused on reactive and operational management.

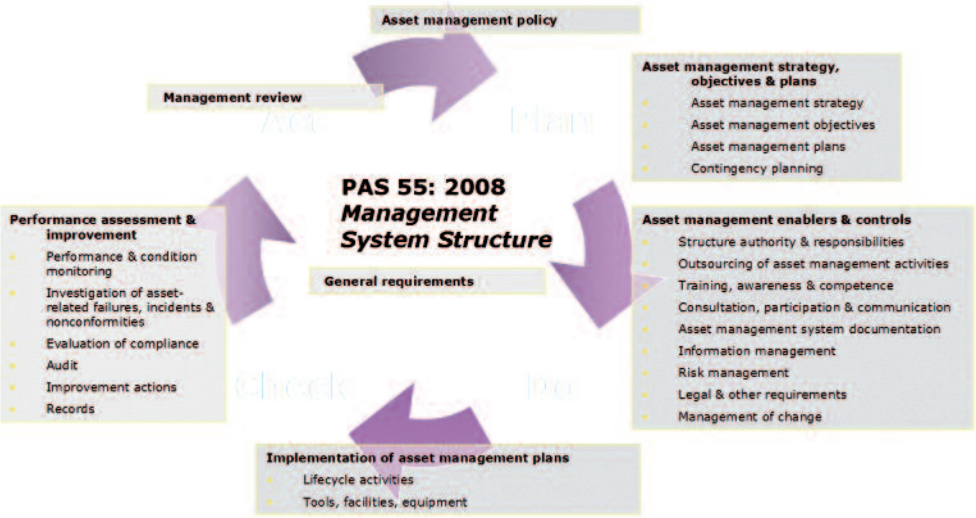


Figure 2

PAS 55 checklist of good practice

Where are we now?

So, are we moving forward, and if so in what direction? It was my hope to see significant progress against these challenges. Indeed, there have been significant steps taken to look at asset management planning in a more integrated and balanced way. In the UK, one such example is the process that was used by UK economic regulator Ofwat for the 2009 price review that drew on the use of the AMA (asset management assessment) process and scored the extent to which the water companies had addressed issues such as: stakeholder engagement, management, data, process, systems, analysis and reporting.

Looking through papers presented at the 2011 IWA LESAM conference, tools still feature quite highly, but strategy is coming through as a key focus. It is clear, not just from the papers in this conference, but also from wider contacts and working relationships with companies across the globe, that holistic and integrated asset management is an important concept. This is nicely highlighted in the work within the AWARE-P project (Alegre, H et al, 2011) and others. These themes are also being reinforced, by other international asset management standards, benchmarking and audit methodologies.

For example, Figure 1 highlights good practice components from PAS 55. This covers the issues of people, process, systems, data, strategy etc., as well as the feedback process that is an integral element of the plan, do, check, act cycle and which is aimed at driving continuous improvement.

In addition to real progress (at least amongst leading organizations) with respect to the more strategic and organizational elements of asset management, it is good to see that analytical tools are continuing to evolve and enable better insights into the assets and the risks that they present. Ongoing development in terms of risk assessment and asset deterioration modelling is apparent and a key theme in asset management and is complemented by continued developments in inspection technologies for both below ground (Vangdal et al, 2011) and above ground infrastructure. This is being complemented by improvements to IT systems that enable maintenance activity data to be captured and used to help optimize asset maintenance regimes (Kraft and Saathoff, 2011).

Key enablers

Whole life costing and cost benefit analysis

It is fascinating to see the debate on decision making and the application of cost benefit analysis. It is generally recognised that when asset managers look at quantifying cost and risk, they need to look at whole life or lifecycle techniques, but there is lively debate regarding monetization of risk and whether or not this is becoming a critical issue in support of making optimal decisions (Buckland, 2011). Personally, I am an advocate of monetization when companies are making a case to agree a budget, but once budgets have been set, then a weighting-based methodology could be a more pragmatic approach for many. However, this is a hot topic which will see further development.

Categorising the assets (what and where)

Technologies for inspecting assets continue to evolve and perhaps the only barriers that remain to achieving perfect asset deterioration data are ones of cost and access. Unfortunately, many utilities are still hindered by weak asset data, in terms of both accuracy and completeness. Filling data gaps is expensive and should be prioritized by the size of the risks associated with not having it. This is easier said than done as even a basic asset survey is a time consuming and costly exercise. However, if a company does not have a reasonable understanding of its assets and their risks, it cannot benefit from the implementation of asset management good practice. Therefore, identifying critical data gaps and filling them is a 'must do' priority.

Defining and measuring service levels and KPIs

Huge strides have been made in the area of KPI development. There are few reasons to prevent a company from being able to determine an appropriate set of KPIs and start to use them to support their business.

Deterioration and service forecasting

This is another area that has seen a lot of interest in recent years. There has been an excessive focus on water distribution and short life assets, where failure data lends itself to statistical modelling. There needs to be more research into understanding what happens to some of our longer life and more critical infrastructure and more consideration into how to determine their investment needs.

Looking forward

It is reassuring that the leading edge in the industry is moving forwards and competition and benchmarking is pushing the elite end of the industry to even greater heights. Perhaps what is concerning is who is being left behind and whether this means we are alienating the less capable and poorer end of the market. The specific situation of very small companies should also be thought about, and how they can be supported more effectively.

Whilst utilities demonstrate a vast range of asset management maturities, if we were to take what is best from what is out there, we would be able to get very close to a perfect asset management utility. The benchmarking and learning opportunities are tremendous, but there are perhaps a few long standing issues that are holding companies back and a few new challenges that have yet to be faced head on.

Some long-term challenges facing the industry and how we can best respond include carbon management, sustainability, climate change and asset resilience, which are becoming hot topics, and water companies are uncertain as to how best to integrate these newer drivers into their strategies.

The issues of climate chance and flooding resilience are exceedingly complex topics. Whilst we have some very sophisticated tools for assessing flooding probabilities (e.g. Figure 3 on pluvial flood hazard analysis for a water treatment works) the uncertainties in the analysis, especially when climate change projections are factored in, make decision making tremendously difficult. One of the big technical issues here is that the consequence of failure is typically very large, whilst the probabilities of the flood event are often very low (say 1 in 500 years or greater). So, should we invest in major flood protection measures now in order to provide 1 in 1000 year resilience, or wait a while to see if technology or analytical confidence improves and provides a more cost effective option? This is an open question and I leave it for the reader to consider.

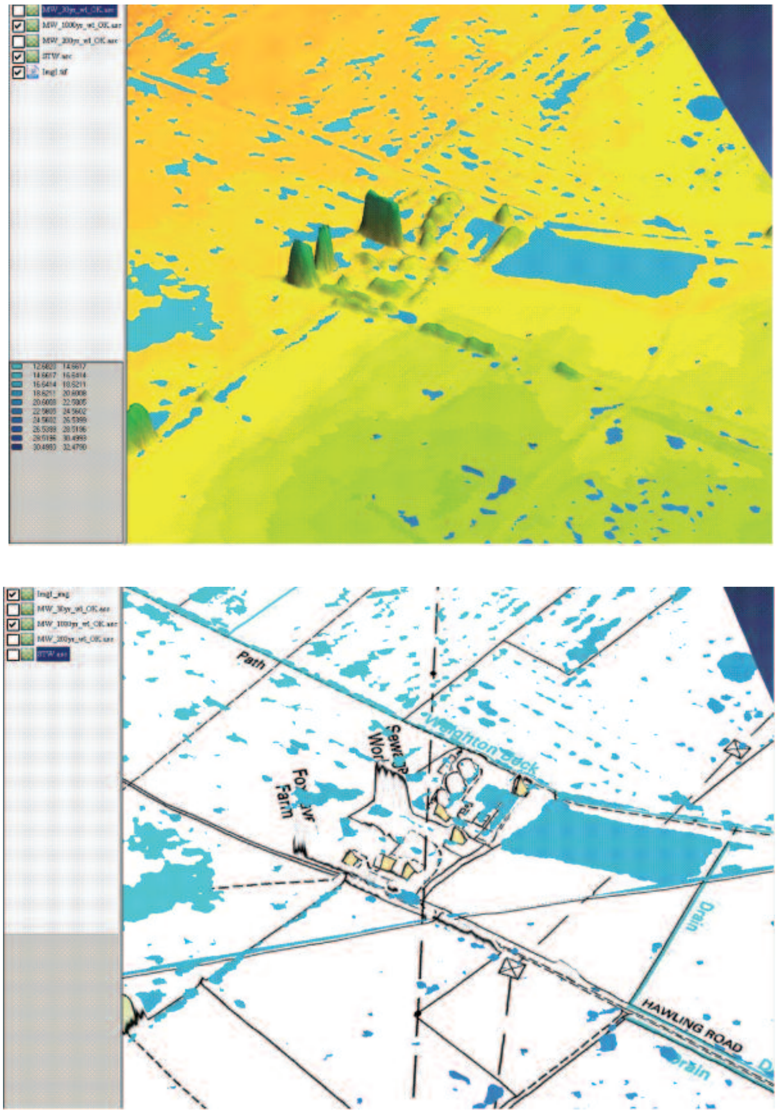
Carbon management has also surfaced as an issue for the asset manager to consider. Valuing carbon is problematic and if it is to be treated as a driver there needs to be a methodology for comparing its importance or value against other drivers, such as good river quality. Carbon is also closely correlated with energy and this makes it difficult for companies to see it as a factor in its own right. Nonetheless, these issues are being debated and many companies now undertake carbon footprinting of their assets and activities as a matter of routine. Some are also setting far reaching carbon reduction targets as aspirational elements in their company strategy. How carbon can be eventually included in the decision making process is yet to be seen and this is an issue that may be discussed for many years to come.

Conclusions

The final impressions are that the building blocks for good practice asset management are being put in place. Innovative companies are taking a far more holistic approach where asset management is no longer a standalone activity and is recognized as a way of working that needs to be ingrained throughout the business.

In addition to the strategic building blocks, tools and technologies are moving forwards and systems being introduced that help the asset manager to optimise their investment practices. To move forwards, there is a need also to think about how best to help those

Figure 3
Flood hazard assessment using digital terrain data (flood extents for 1/1000 year pluvial events)



companies that struggle with issues of affordability and to encourage more 'joining up' of best practice because many companies excel in one or two areas but far fewer demonstrate good practice across all their activities. There is still a lot to learn and a huge task to implement integrated asset management.

Furthermore, the nature of the challenge continues to evolve. Sustainability, carbon management and resilience are some of the issues and another is water scarcity – which has not even mentioned so far and deserves a focus in its own right, because it involves a far wider group of stakeholders. My final impression is one of cautious optimism and I look forward to seeing how we will meet the challenges of asset management decision making in an uncertain world. ●

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AM DIARY

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

Overcoming Barriers to Competition in Water
11 October 2012, London, UK
Web: www.marketforce.eu.com/beesley

Advanced course on pressure management and pressure transients in water distribution systems
31 October – 2 November 2012
Amsterdam, The Netherlands
Web:
www.deltares.nl/en/cursus/1533373/advanced-course-on-pressure-management-and-pressure-transients-in-water-distribu

5th Water Loss Reduction Conference
19-20 November 2012, Sofia, Bulgaria
Web: www.bwa-bg.com

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

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

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

Utility Management for Best Performance in the Balkan Region
14-16 May 2013, Tirana, Albania
Web: info@shukalb.org

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

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

Interconnections between water systems as an incentive for asset management

Interconnections are an increasingly popular water management strategy that allows water to be redistributed between neighbouring water systems, which builds up redundancy in the water system. Interconnection projects are expensive and their avocation presents an asset management opportunity. Not only do they comprise a large part of a utility's risk management plan, but they also create an incentive to perform more accurate asset mapping.

Here, Stacey Isaac Berahzer, Shadi Eskaf, Lauren Patterson and Jeff Hughes discuss a method for developing an asset management database for community water systems (CWS) and interconnections for North Carolina.

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Water partnerships are an increasingly popular avenue to explore for reducing risk to water supply systems. Large urban systems facing water supply challenges due to growth or drought are increasingly seeking partnerships with their neighbours to increase their water security (EFC, 2009). Small town systems that are struggling with the increased costs of managing their systems often look towards partnerships with other systems to spread out costs. Systems that find themselves with excess capacity due to the loss of large industrial customers realize that selling water to neighbouring communities may be the only way of both taking advantage of their capacity and filling revenue holes. Communities engaged in economic development activities often find that partnerships with other water suppliers are the most cost effective and sustainable means of providing water to support future development.

Water system interconnections are one form of water partnerships that provide a means of redistributing water from systems with excess supply or capacity to systems that need additional water (EFC, 2009). Interconnections are the focus of this paper.

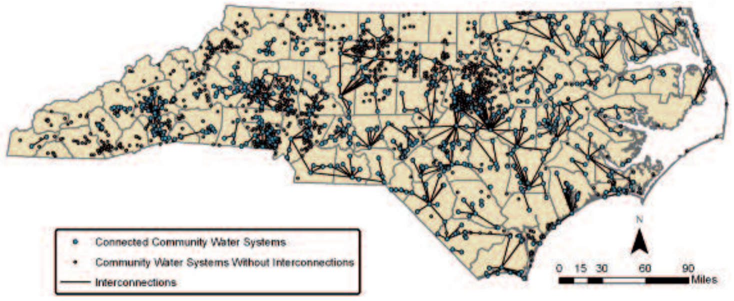


Figure 1
Community water systems and interconnection status as of September 2010

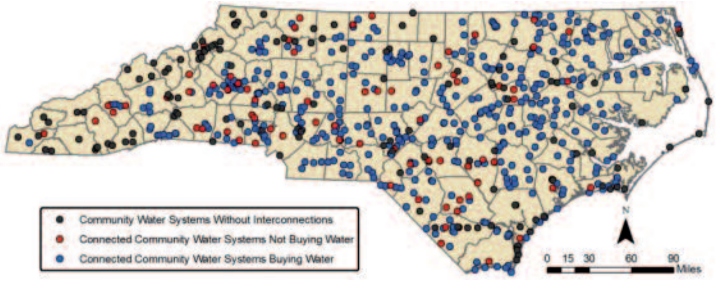


Figure 2
CWS in analysis that have no interconnections, sell but do not buy water, and buy water

The state of North Carolina in the US is interested in formulating a comprehensive, state-wide water resource management plan. However, prior to being able to create such a plan, the State first has to know what utilities and assets already exist. To address this need, the Environmental Finance Center (EFC) was funded in 2008 to create a comprehensive database of all community water systems (CWS) and interconnections with pipes six inches or greater. An interactive map was created (www.efc.unc.edu/projects/partnerships.htm) that allows a user to click on any interconnection to access data on water sales between those systems.

Further funding was provided in 2010 to find the most feasible location for future interconnections between neighbouring water systems that currently do not purchase water. Geographic feasibility is assessed using a standard straight line distance, as well as a path distance function that also takes into account slope and geographic barriers such as water bodies, protected areas, and infrastructure. Results from these methods are compared and should be interpreted as the most geographically feasible connection for utilities, disregarding political, economic, or supply needs.

Data on water system interconnections

EFC created a relational database combining data on water system interconnections from four areas. The first was the North Carolina

Table 1 - Attributes and weights included in the cost surface raster

	No barrier	Barrier	Weight	Description
Major water bodies	1	100	0.4	Includes lakes and estuaries. It is highly unlikely for an interconnection to cross a major water body.
Rivers	1	100	0.28	Includes major rivers such as the Neuse. It would be highly costly for an interconnection to be constructed.
Interstates	1	100	0.08	Passing through an interstate would be costly. However, technology makes it a more feasible possibility than rivers.
Highways	1	100	0.08	US and state highways. See interstate explanation.
Protected areas	1	100	0.08	Environmental impact assessments increase the cost of interconnections through protected lands.
Creeks	1	100	0.06	Creeks are smaller and more feasible for an interconnection with new technology.
Outside water system	1	100	0.01	Water infrastructure should already be present within a water system. Therefore interconnecting two adjacent water systems should reduce the cost. Inside the water system there is not a cost, but outside the cost increases.
Inside municipality	1	100	0.01	Land is developed and would not require environmental impact assessments; however, the cost of modifying pre-existing infrastructure is high.

Department of Environment and Natural Resources' (DENR) Public Water Supply Section (PWSS). Data on every public water system are collected in the Safe Drinking Water Information System (SDWIS). Data on interconnections include:

- The water system that receives water from the interconnection ('buying' system)
- The water system that provides water to the interconnection ('selling' system)
- Whether the interconnection is for regular use or emergency use
- The number of physical interconnections between the two systems

The second was the DENR Division of Water Resources' (DWR) Local Water Supply Plans (LWSP) for all local government-owned CWS and other large CWS. Water system interconnections are listed in these plans and, where available, the following data are included:

- The buying system and the selling system
- Whether the interconnection is for regular use or emergency use
- The size of the interconnection pipe(s)
- The contracted capacity of water flow between the systems
- The average water flow between the systems in the previous year

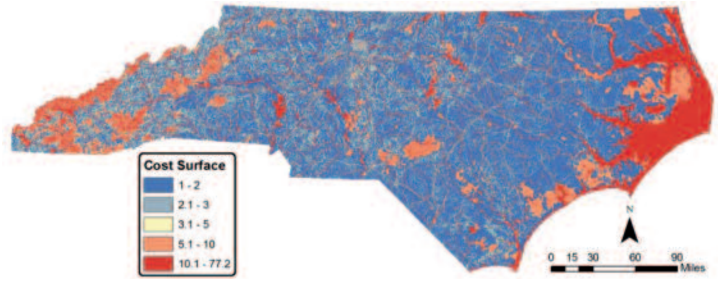


Figure 3
Cost surface raster used in path analysis

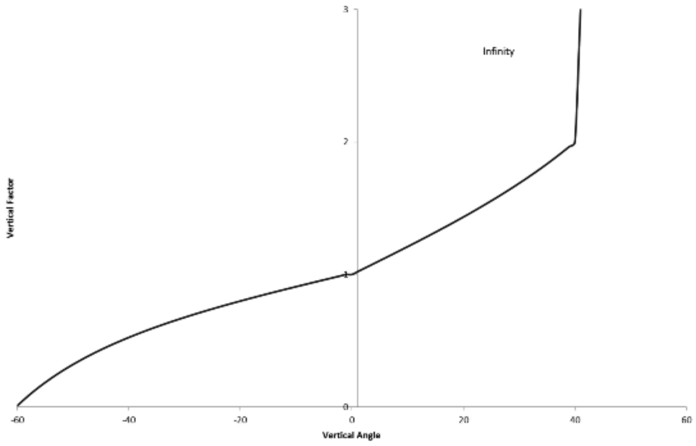


Figure 4
Vertical factors used in path analysis

The third was the Rural Economic Development Center's database on water systems that was compiled in 2005 for its Water 2030 report. Data on water system interconnections matched the fields described above.

Finally there was primary data. In 2009, EFC contacted several water system managers and asked questions about their interconnections with other systems.

There were 2124 identified active CWS in North Carolina. Of those CWS, 635 (30%) have an interconnection, meaning these systems either buy or sell water to other systems (Figure 1). Interconnections include both regular and emergency contracts.

CWS included in the interconnection analysis

Of the 2124 active CWS, the analysis was limited to those systems that have over 300 service connections or are owned by local governments regardless of their size. This removes many of the very small, private CWS that have a significantly lower probability of interconnecting. There were 645 CWS that met this definition and are hereafter referred to as 'CWS in analysis'. Of the CWS in analysis, 130 (20%) do not currently have any interconnections and 73 (11%) have an interconnection to only sell water (Figure 2). These systems are also considered in the analysis for potential interconnections, since buying water offers a means to increase the breadth of a water supply portfolio. There are 203 CWS (31%) in analysis that do not currently buy water and are assessed for the geographic feasibility of establishing a new interconnection.

Method to identify the most geographically feasible potential interconnection

Traditionally, most studies only use proximity to other systems to identify potential interconnections (Raucher et al., 2003). Proximity is an important factor to consider, but it requires making the assumption that topography is flat and that there are no physical barriers to the installation of waterlines between systems. In this study, the most geographically feasible potential interconnections between systems were determined using proximity and effective distance, which takes into account physical attributes such as:

- Topography: change of elevation and the direction of water flow
- Hydrology: crossing estuaries, lakes, rivers, major streams, and creeks
- Protected lands: crossing managed lands that would require an environmental impact assessment
- Existing infrastructure: crossing

Table 2 - Sample matrix of effective distances (km). Highlighted cells are the least costly for that destination.

Source	Destination					
	NC0100010	NC0100105	NC0102010	NC0102015	NC0102020	NC0103010
NC0100010	0	14	188	203	177	277
NC0100105	16	0	200	214	187	290
NC0102010	174	198	0	21	13	119
NC0102015	188	214	18	0	27	130
NC0102020	164	187	14	29	0	130
NC0103010	262	283	124	134	135	0

interstates and major highways, already developed land, and existing water system infrastructure.

It is important to note that this study only assesses the geographical feasibility of potential interconnections. It is beyond the scope of this study to include analysis on the actual cost of installing interconnections (which varies by waterline size and materials), the system capacity constraints of potential sellers of water, and the political feasibility of partnership between two specific water systems.

For each of the 203 potential buyers there were 644 potential sources of water (all remaining CWS in analysis; Figure 2). The analysis calculates both the actual (straight-line) and effective (geographic) distance between the buyer and the remaining water systems and ranks the potential sellers, or sources of water, from most to least geographically feasible. These are sometimes referred to as 'least costly' and 'most costly,' respectively.

Calculating actual proximity

The actual straight-line distance between CWS is based on the latitude and longitude of each community water system as determined from a combination of the following sources:

- The centroid of the water system service area as provided in the North Carolina Center for Geographic Information and Analysis (NCCGIA's) 'Public Water Systems – Current Service Areas 2004' shapefile.
- The centroid of the collection of water source intake points for each system as provided in NCCGIA's 'Public Water Supply Water Sources – 2004' shapefile.
- Manually locating physical plant locations and / or street addresses.

The straight-line distance was calculated between all CWS pairs (Equation 1).

Equation 1: *Actual distance =*

$$\sqrt{(From\_Y\_Lat_{km} - To\_Y\_Lat_{km})^2 +}$$

$$\overline{(From\_X\_Long_{km} - To\_X\_Long_{km})^2}$$

Calculate effective distance

ArcGIS has a path distance tool that enables the user to take into account distance, topography (moving uphill or downhill) and potential physical barriers such as lakes, rivers, and interstates. Path analysis is a path weighted distance model that is 'useful when seeking to minimize construction costs for routing pipelines' (Qi, 2007; McLaughlin, 2010). The path distance, or effective distance, takes into account the topography, distance, and barriers on moving water from one CWS to each of the remaining 644 CWS.

Equation 2:

*Path distance = Surface distance * Cost surface * Vertical factor*

Surface distance

Surface distance is similar to proximity except it is also a function of the vertical distance travelled (Equation 3).

Equation 3:

$$Surface\ Distance =$$

$$\sqrt{(\sqrt{((From\_Y\_Lat_{km} - To\_Y\_Lat_{km})^2 +}}$$

$$\overline{(From\_X\_Long_{km} - To\_X\_Long_{km})^2)^2 +}$$

$$\overline{(From\_Elevation_{km} - To\_Elevation_{km})^2)}$$

Cost surface

The cost surface raster (a grid of pixels, with each pixel containing a value representing information) shows the relative 'cost' of moving from Cell A to Cell B. Each cell (90 metre resolution) is given a weight proportional to the relative cost incurred by passing through it. The cost – not to be confused with financial cost – is a relative number indicating the difficulty of traversing the cell, and is a compilation of different static geographic features in the environment such as lakes, rivers, roads, and protected lands. A cost of one means there are no geographic barriers located in a cell. As the cost increases, the difficulty of moving through a cell increases. Since the costs are relative, the different spatial barriers have to be reclassified in relation to the difficulty of an interconnection passing through them and then combined together to create a single cost surface.

Two associates from PWSS were spoken to, to ascertain some of the major physical barriers to interconnections and the relative difficulty of passing an interconnection through those barriers (Table 1). The only physical attribute for the cost surface suggested by the PWSS associates that spatial data was unable to be obtained for were the right-of-ways for utilities. The presence of a right-of-way would likely facilitate construction of an interconnection. Additional data for future analysis could include the location of railroads and soil type.

Each physical barrier was transformed into a raster and given a value of 1 where barriers are absent and 100 where barriers are present. Weights were then applied to provide an assessment of the relative difficulty to traverse a specific barrier compared to another based on the conversation with PWSS and through sensitivity analysis (Table 1). For example, major water bodies are weighted 0.4 compared to an interstate or highway with a weight of 0.08. This implies that it would be five times more difficult to install an

Table 3 - Sample ranking the best potential option using effective distance for one buyer (NC0106107)

Source PWSID	Destination PWSID	Actual distance (km)	Effective distance (km)	Effective distance rank	Ratio to best option
NC0106117	NC0106107	2.19	5.94	1	1.00
NC0106015	NC0106107	4.02	8.93	2	1.50
NC0195118	NC0106107	5.58	13.58	3	2.28
NC0106025	NC0106107	6.97	18.19	4	3.06
NC0106104	NC0106107	9.48	20.33	5	3.42
NC0195104	NC0106107	9.70	20.42	6	3.43
NC3086055	NC0106107	9.74	21.21	7	3.57

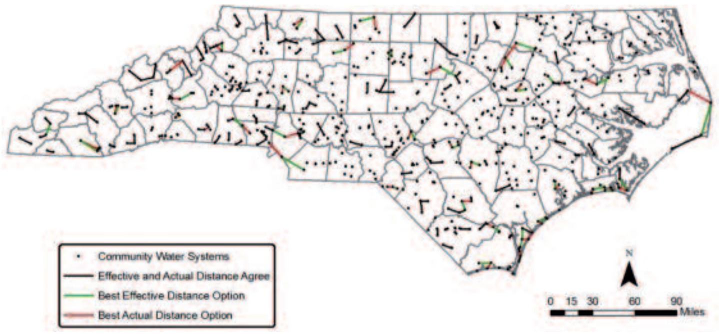


Figure 5
Best options for potential interconnections using actual and effective distances

interconnection that crosses a lake or estuary than one that crosses underneath an interstate or highway.

The rasters for each geographic barrier was combined to generate the final cost raster used in the path analysis (Equation 4 and Figure 3). Values ranged from 1 (no barrier) to 77.23.

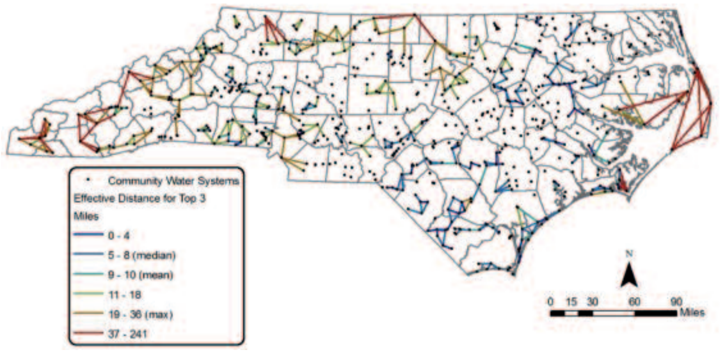


Figure 6
Three shortest effective distances for each potential buyer (4 mi (~6km), 8 mi (~13km), 10 mi (~16km), 18 mi (~29km), 36 mi (~58km), and 241 mi (~388km))

Equation 4:

*Cost surface = 0.06 * [creek] + 0.28 * [river] + 0.4 * [major water bodies] + 0.08 * [protected lands] + 0.01 * [municipality] + 0.08 * [highway] + 0.08 * [interstate] + 0.01 * [outside water system]*

Vertical factor

The vertical factor addresses the topographic component of pumping water. Water can move downhill cheaply, whereas it is costly to pump water uphill. The slope, or vertical angle, is first calculated between the elevations of cells moving from the source (seller) to the destination (buyer). The vertical slope is derived in Equation 5. The base of the triangle is the resolution, or cell size, of the Digital Elevation Model (DEM) raster.

Equation 5:

$$\text{Slope} = \tan\left(\frac{\text{Elevation}_{\text{To}} - \text{Elevation}_{\text{From}}}{\text{Cell Resolution (90 m)}}\right)$$

The slope angle is then related to a vertical factor. The vertical factor specifies the ease or difficulty of traversing a particular slope. For interconnections, downhill slopes are easily traversed and uphill slopes require an additional cost to pump the water. The slope is on the x-axis and ranges from -90 degrees (vertically downhill with no slope) to 90 degrees (vertically uphill). The vertical factor, which represents the degree of difficulty to traverse a slope, is on the y-axis. A vertical factor was created from the relative cost of pumping one unit of water (Ackermann, 1969).

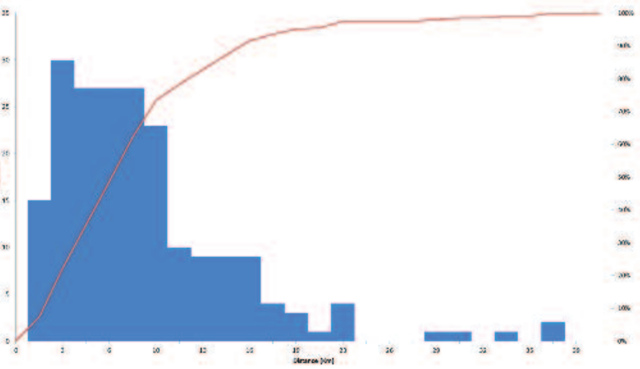


Figure 7
Histogram and cumulative distribution of current interconnection straight-line distances.

Equation 6:

hp = Qwh/550

where: hp = theoretical horsepower (1 hp = 550 ft-lb/sec),
Q = flow in cubic feet per second (cfs),
w = weight of water at 60 degree F (62.37 lb/cf) and
h = total pumping head in feet (ft).

A vertical factor value of 1 indicates there is no additional cost to move water (i.e. moving water on a horizontally flat surface). A value below 1 indicates that it is easier to move water (downhill slopes) and a value greater than 1 indicates it is harder to move water (pump uphill). The relative downhill costs are constrained between the values of 0 to 1. To maintain equity we constrained the 'cost to pump' uphill between the values of 1 and 2. After talking with staff at the Department of Water Quality (DWQ), we decided that it would not be cost effective to pump water up a slope greater than 40 degrees. This vertical factor is assigned to infinity, making it impossible to move through that cell (Figure 4).

Path distance

The path distance was calculated for the 645 CWS in analysis using Equation 2. Upon completion of the path distance analysis, a matrix of effective distances between each CWS was created (Table 2). The effective distance going from one water system to another might not be the same effective distance in reverse. For example, NC0102015 can connect and sell water to NC0102010 in a path that is effectively 18km long, but the reverse route has an effective distance of 21km. The difference is due to the fact that NC0102015 is uphill of NC0102010 and requires additional cost (measured as more distance) to pump water.

Rank and extract the 'least costly' interconnections for each potential buyer

The effective distances for the 203 potential buyers were ranked from lowest to highest. This process was repeated for actual distances. As shown in Table 3, NC0106107 has an interconnection possibility 5.94 effective km (2.19 actual km) away. The relative ease between these different options is calculated. For example, NC0106107 could three times more easily connect to NC0106117 than to NC0106025 in terms of effective distance.

The best options for potential interconnections including geographic barriers

There was agreement on the smallest

distance, and therefore relative cost, between actual and effective distances for 158 of the potential buyers (78% agreement). In other words, for 78% of the 203 CWS that currently do not purchase water, geographic barriers did not change the overall outcome. For the remaining 22% the effective distance calculation identified a different geographically optimal potential seller than the actual distance calculation (Figure 5). This result highlights the importance of using effective distance calculations when analyzing potential interconnections, and not relying solely on straight-line proximity analyses.

The best interconnection option, or closest option, for slightly over half (102 for effective distance and 106 for actual distance) of the potential buyers was to a CWS that is currently buying water. In these cases, the sellers act as intermediary systems, buying more water from their own sellers and selling water or passing it through to their potential buyer.

The basic assumption for determining the best potential interconnection using physical parameters only is that the shorter the distance, the easier it is to have an interconnection, ignoring political and water system capacity factors. The best potential interconnection is therefore the shortest effective distance. Figure 6 shows the three shortest ('best') potential interconnection options and the effective distance. The eight, ten and 36 mile (13, 16 and 58km) threshold correlate to the median, mean and maximum straight-line distance of current interconnections (Figure 7). Some potential buyers have three options that are approximately the same distance, while others have few ideal alternative options for new interconnections.

Figure 8 shows the relative increase in 'cost' of the alternative options compared to the best option for each potential buyer. The best option has a ratio of one, while the remaining options have a ratio equal to their effective distance divided by the effective distance of the best option. For example, a green line means that interconnection has an effective distance 1.6 to 2 times greater than the best potential option. This essentially means that this interconnection option would be 1.6 to 2 times geographically more difficult than the best interconnection option. A larger ratio means the other options are less appealing relative to the best option.

Figure 8
Ratio of alternative options to the lowest effective distance (best option)

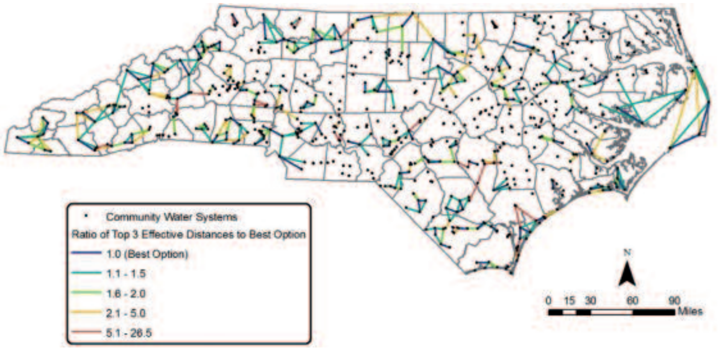


Table 4 - Number (percent) of CWS in analysis connected by effective distance

Distance	Best option	Top 2 options	Top 3 options
6 km	74 (36%)	105 (26%)	115 (19%)
13 km	138 (68%)	239 (59%)	312 (51%)
16 km	148 (73%)	266 (66%)	355 (58%)
29 km	181 (89%)	345 (85%)	486 (80%)
58 km	196 (97%)	387 (95%)	574 (94%)
Total	203	406	609

Equation 7:

$$Ratio = \frac{Effective\ Distance_{Option\ i}}{Effective\ Distance_{Option\ 1}},$$

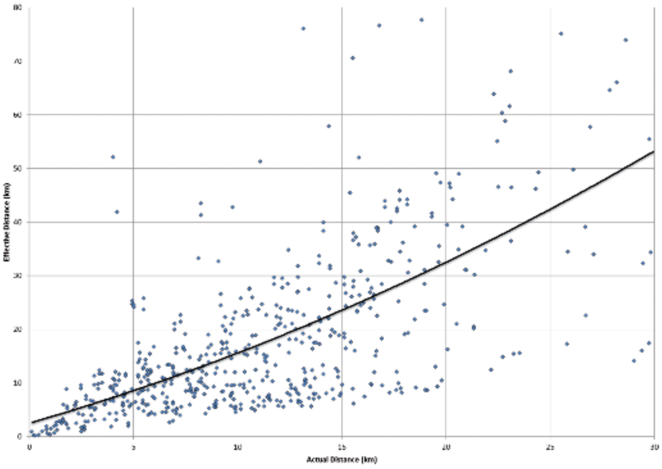
$$where\ i = rank\ from\ 1\ to\ 10$$

How does this output compare to the current interconnection network?

The average straight-line length of an interconnection is 15.4km (median = 13km), and the maximum length is 57.4km (Figure 7). Examining the best potential interconnections based solely on straight-line proximity (no geographic barriers), the distribution of interconnection lengths is more right skewed than for the current interconnections. This suggests that there are several CWS with nearby systems that do not currently buy water. It also indicates that geographic barriers are significant in determining the feasibility of interconnections. In other words, it might be easier to connect to a CWS that is physically located farther away than to connect to a closer system with geographic barriers in between.

In general, the difference between effective and actual distance tends to increase as the actual distance increases (Figure 9). Intuitively, this makes sense as the further two CWS are from each other the more likely it becomes for additional geographic barriers to exist between the two systems. However, the effective distance can be less than the actual distance in cases where the buying system is located downhill from a selling system. For example, where the actual distance is near 15km the effective distance ranges in value from 8km to 70km.

Figure 9
Effective versus actual distances for the best potential effective distance option



The effective distance had its best interconnection option within 6.4km for 74 (36%) of the 203 potential buyers (Table 4). Thus, there is potential for relatively 'easy' new interconnections from a geographic standpoint.

Conclusion

The objective of this research was to identify and describe the current interconnection status of community water systems in North Carolina. Of the 645 CWS included in the analysis, 69% currently purchase water. For the remaining 203 CWS, a methodology was developed to determine the most geographically feasible interconnection option. Path analysis was used to calculate the relative difficulty of moving water from one water system to another given distance, topography and physical barriers. The shortest effective distance was considered to be the best potential option for an interconnection for each of the 203 potential buyers. In many cases, the optimal effective distance interconnection was similar in length to existing water system interconnections. Future work should incorporate considerations of water system and resource supply capacities of potential selling systems, as well as the political feasibility of connecting two water systems.

As water providers seek to address issues related to risk management, interconnecting with neighbouring systems has significant potential. State proposal requests have included the goal to 'Integrate information about existing and / or ongoing water emergency planning and current and / or planned water system interconnections into emergency water supply plan' (US GAO, 2004). As states and other regional entities seek to form comprehensive development plans and form water partnerships, they must become more familiar with their current systems and strategically explore the potential for developing new water partnerships. ●

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Pipe fitters assist to predict investment needs for water main rehabilitation

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For planning of investment needs of water main rehabilitation, insight into the condition and deterioration of assets is required to estimate when their replacement is due. Maintenance and failure data can be useful sources of information to estimate failure frequencies or residual lifetime of asset populations.

Research has shown that by sharing the failure data of individual companies, the data became much more valuable in terms of directive outcomes for strategic asset management. Irene Vloerbergh, Rogier Schipdam, Peter van Thienen and Ralph Beuken describe the systemised process from 'on site' failure information registration to knowledge creation by means of statistical analysis of shared failure data. This knowledge, built on information provided by pipe fitters, can help to determine when replacement is due, thereby supporting replacement decisions of asset managers, policy makers and financial planners.

The Dutch drinking water industry is characterized by low failure frequencies, low leakage and high customer satisfaction (VEWIN, 2010). On average, households rarely suffer from unexpected supply interruptions due to failures in the network, caused by technical failures such as breaking mains or leaking joints. To maintain service provision at a high level, pipes are targeted for replacement based on the potential risk they pose to the supply quantity and the quality of the service provision. The average replacement rate in the Netherlands is approximately 0.5% per year (Senden et al, 2009).

Because resources are always limited, pipes which need to be replaced with priority have to be indicated. Externalities (including consumer perception) and failure rates are generally used as indicators for the need for replacement. For financial as well as technical calculations, key figures are used for material specific lifetime estimates (usually 50 or 75 years). It is known that these are rough estimates that do not take into account factors influencing the remaining lifetime such as the surrounding soil characteristics or various loads (see Kleiner & Rajani, 2001) for a comprehensive review of factors influencing deterioration of water mains. Failure data can help to understand network deterioration and may as such provide details about the behaviour of pipes over time, given different circumstances. When sufficient failure data are available, analyses can be performed with sufficient significance, resulting in knowledge about distinctive pipe cohorts. To enable the division of

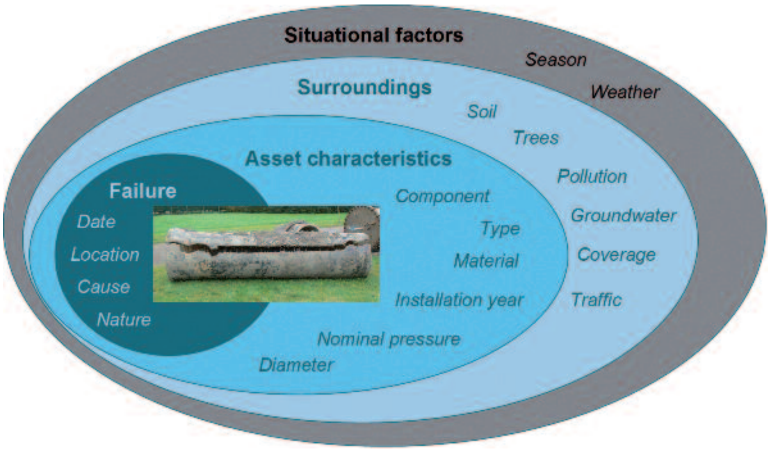


Figure 1
Aspects considered to have an influence on the occurrence of failures. By including these aspects in the registration as parameters it will become possible to prove or disprove the assumed influence.

cohorts it is essential that all potentially distinctive features of the pipe and its surroundings are registered for each failure. The extent to which detailed analysis will be performed determines the requirements of the failure registration form that pipe fitters have to complete.

A failure registration system has been set up that enables uniform exchange of failure data between companies while being flexible enough to be adjusted to the various needs for implementation at each of the participating water companies. Here, it will be discussed how the system was developed, what exactly it comprises and which processes it currently entails. The current dataset illustrates what the failure data can tell us now and in the future. The purpose is to motivate and guide other water companies or utilities worldwide to set up a registration system that meets the needs of the users and provides information for knowledge about deterioration of underground infrastructure for strategic asset management.

USTORE: Uniform failure registration, data exchange and analysis

The KWR Watercycle Research Institute serves the Dutch drinking water industry by creating knowledge and developing practically applicable solutions to water issues. In the Netherlands, a joint research programme of the drinking water companies exists in which nine out of the ten Dutch and two Flemish water companies participate. The companies cooperate to enable the research, for example by carrying out pilots and providing data for input. The research findings of the joint programme are for the benefit of the industry as a whole. Within the joint research programme, a system by the name of USTORE has been developed to uniformly register water mains failure data, and then to exchange and analyse the data to improve asset management.

Recognizing the need for uniform failure registration

Although several authors have previously recommended sets of parameters for uniform failure registration for water mains (a.o. LeGat and Eisenbeis, 2000; Trietsch, 2001; Deb et al, 2002; Wood and Lence, 2006) it was not until 2008 that seven out of ten Dutch water companies decided to design and implement a uniform failure registration system. The motivation to do so was found in a study (Vloerbergh & Blokker, 2007b) in which failure databases of individual water companies were scrutinized to understand their possibilities and limitations for statistical analysis. Statistical methods were considered that could help to determine which factors influence the occurrence of failures. The results showed that, until then, the returns of the various registration efforts at the participating companies were very limited. The quality, quantity and detail level of the registered parameters and values determine the possibilities for statistical analysis and thereby the potential of the data as a valuable input for management decisions. The seven water companies formed a project group that committed to jointly design and implement a uniform failure registration system.

Addressing the need behind the need (2008 / 2009)

Studying the failure registration databases of the individual water companies showed that failure data can provide insight in deterioration dynamics, but that the potential to predict remaining lifetimes of pipe sections is limited by what is registered, and how accurately and consistently this is done. The first step taken by the project group was therefore to search for the common information need to be fulfilled.

Each aspect of a failure that is to be investigated needs to be registered on the failure form that pipe fitters must complete. This list of aspects to be registered should be as concise as possible because completing forms is not the core interest of field workers and accurate completion is key for a useful failure database upon which asset management decisions can be based. Figure 1 shows the aspects that were considered essential by the project group for failure analysis. Besides the aspects to be registered, their possible values, or multiple-choice answers on the form were also jointly determined.

Commitment to participation means that the efforts are primarily aimed at the common benefits. As a tool to investigate predetermined relations, a uniform failure form was developed, designed to demand as little as possible from the companies. For individual water companies this may mean that what is asked in the uniform system does not cover the information or data required by the company management. Additional questions or adaptations of the form to the companies' needs are possible.

The USTORE system

Agreeing on the content of the forms to be completed by the fitters is the first step towards using the information registered with each failure. Before the information is shared and transformed

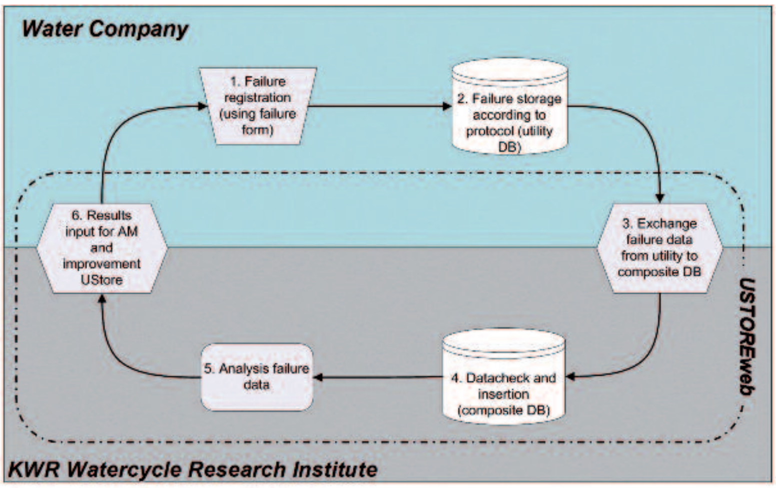


Figure 2
The USTORE system is broken down in six steps; 1) failure registration, 2) collection, 3) exchange, 4) controlled & composition, 5) analysis and 6) follow up. Steps 3 to 6 are automated in USTOREweb, an internet based application

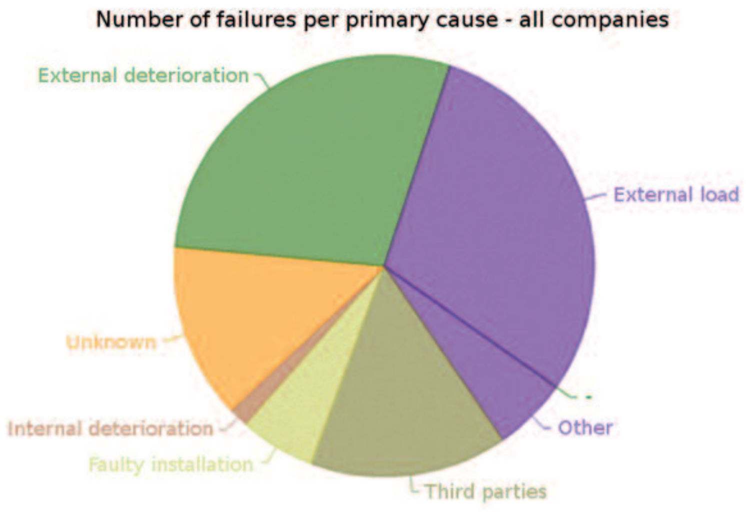


Figure 3a
Distribution of the number of failures of the composite database per parameter: primary cause

into knowledge for the support of asset management decisions however, further steps will have to be taken.

The complete system of failure registration, collection, exchange, analysis and follow-up is broken down in six steps. Figure 2 shows each step, which is explained in the following by describing the accompanying process.

Failure registration (using the failure form). When a failure occurs in the network, a work order is placed and one of the fitters receives the order. He or she will go to the failure location to carry out the work needed to repair the failure and to register on the form at least the mandatory questions. The form can be filled in manually (using paper) which then requires digital input into the system or digitally if the fitters are equipped with PDAs or laptops.

Each failure is recorded in the company failure database according to an agreed format. A protocol describes the parameters and pre-set values, or multiple-choice answers to be put in the table. All participating companies use either an Excel template or use their own system and convert the table in csv format according to the agreed format.

To exchange the failure data a secure database system with web access has been developed: USTOREweb. This internet application, only accessible to members, offers the latest versions of working documents such as the Excel template and the protocol. In addition to the failure databases, databases of network lengths must be provided by each water company to enable the calculation of failure frequencies (annual number of failures e.g. in a specified material / total length of that material installed).

USTOREweb combines the individual databases into a composite database. Before the failure data are entered into the central database, each record is checked for omissions and duplicates. Records that lack certain (mandatory) fields or are already in the database are excluded from the database and reported back to the company for checking. Improved or completed records can be uploaded again. All participants can download an anonymous composite database. This composite database contains all uploaded failures, but company name, address and coordinates are omitted. Asset managers can use the database to perform their own specific analyses or compare their data with the total dataset (next step).

USTOREweb offers the opportunity to generate statistics from the data. Companies can view metadata such as their response rate per parameter and start and end dates of registered failures.

Furthermore, the programme offers three basic variations of descriptive statistics:

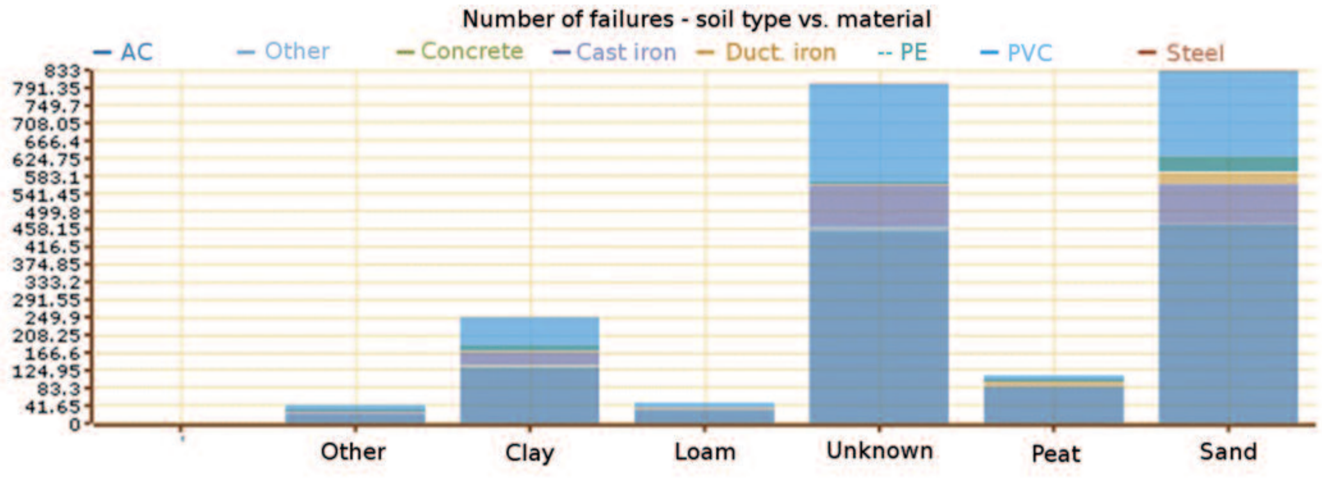
- Distribution of the number of failures per one or two parameters. Each company can plot its own database (in a graph or table) and also those of the composite database (see example in Figure 3a and 3b).
- Time sequences of the number of failures (optionally distributed per parameter, see example in Figure 4).
- Failure frequency, indicating the annual number of failures per km pipe (see example in Figure 5). To calculate the failure frequency, the pipe lengths per material, diameter and installation year are requested. Each year a 'snapshot' of the network is made on an agreed reference date.

The companies who have uploaded their failure data can at any time download their own datasets as well as the anonymous composite database to perform specific analyses in their preferred software.

Analyses of the failure data can be used to support various asset management decisions:

- Replacement strategies (short-term decisions): pipes which are at risk of failing in the short-term, for example based on the material and soil characteristics may be planned for immediate replacement. In areas where works on other underground infrastructures or road constructions are planned, it can be decided to combine the works if the failure frequencies of the assets indicate that replacement is due within a certain time frame (in some areas where road blocks cause high economic or societal costs, collaboration is

Figure 3b
The number of failures of the composite database distributed per two parameters: soil type vs. material



demanded by the municipality). Understanding the condition of the network is essential to make informed decisions.

- Investment strategies (long-term decisions): when sufficient data are available, lifetimes of pipe cohorts (groups with similar characteristics) can be estimated. Graphs illustrating the development of the failure frequencies of such cohorts over time help to understand the behaviour of the infrastructure under certain circumstances. This provides support for predicting when the probability of failures is likely to become unacceptable for a certain area. When the pipe cohort lifetime estimates are reliable (based on sufficient data) the same knowledge can also be applied in calculations of the economic lifetime and decision support methods such as cost-benefit, multi-criteria and risk analyses.

Analysis of USTORE data

The purpose of collecting failure data is to estimate when pipe replacement is due based on the occurrence of failures in the network. There are two types of models to predict failure potential: deterministic and probabilistic models (Wood and Lence, 2009). An implication of the design of USTORE is that the models which can be used to predict failure potential are those that do not require pipe specific data. Deterministic models estimate pipe breakage by fitting failure data to various time dependent equations (time-linear (Kettler and Goulter, 1985) or time-exponential functions (see, e.g., Kleiner and Rajani, 1999) are most commonly used). Prior to fitting these functions, pipes are partitioned into groups which have similar characteristics, known as pipe cohorts. The characteristics used to sort the pipes are based on the factors that are assumed to influence breaks such as pipe age, pipe material, diameter, or soil type. Probabilistic models do not only predict the failure potential, but also the distribution of failure. These models are more complex than deterministic models and require more data. Examples of these include cohort survival, such as KANEW (Deb et al., 2002), Bayesian diagnostics, break clustering, semi-Markov chain and data filtering methods. Based on the results discussed in the following paragraph, the data obtained so far are insufficient to apply probabilistic models.

Results of two years of USTORE

In approximately two years of collecting data according to the USTORE principles, more than 3500 failures have been registered and uploaded by five water companies. This corresponds roughly with three to seven times the number of failures water companies would have collected individually.

Approach

The USTORE registration system was set up in close collaboration with the water companies. One of the conditions for participation is that the registration requires minimal effort from the field workers. At the same time, the efforts are only worthwhile when sufficient information is registered to perform meaningful analyses. Another important condition for participation is anonymity; for some water companies it is unacceptable if their failure data are linked to location data in a database visible to third parties. This may be related to safety or legal issues.

In the start up phase of the project in 2007, many water companies were still in the process of digitizing their network data and therefore were unable to oversee the direction, possibilities and limitations of their future databases. For example, for a number of companies it was unknown whether they would use a system that links pipe information to valve sections and if so, how these sections are defined. The registration system therefore had to be designed for compatibility with any IT solution for pipe information systems to join. As a result, the registration is designed in such a way that each failure is an entity with certain characteristics that can be analysed irrespective of the corresponding XY coordinates or address.

Results

By June 2011 KWR had collected 3550 failures from five water companies (Table 1). Two of the seven participating companies had not been able to add their failures to the composite database; one company had been registering consistently but encounters difficulties with extracting the data in the requested format from their IT system (see the lessons learned section below). The other company is in the process of automating and integrating different systems and will start registering when the new system is up and running.

Of the 3550 registered failures 17% were caused by third parties. The remaining 2932 failures were 'spontaneous' failures related to degradation of some sort. Pipe length databases count 32,071km (diameter known), 95% of which (30,394km) consists of the materials PVC, PE, asbestos cement, ductile iron and cast iron.

As an example, the failures in asbestos cement (AC) of a subset of the database (from January 2009 until June 2010) have been analysed. The total length of AC pipes is 12,420km, for 91% of which the installation year is known. The number of registered 'spontaneous' failures (not caused by a third party) in AC is 1098, for 85% of which the installation year is known. Figure 6 shows the failure frequencies in AC per diameter group. From the figure it can be seen that large diameter AC pipes (>400mm) have low failure frequencies. Figure 7 shows the failure frequencies in AC per installation decade. Pipes from the period '50-'59 have increased frequencies (0.18 failures/km/year), while those from the period '60-'69 have failure frequencies of 0.08 failures/km/year, similar to the old pipes installed from

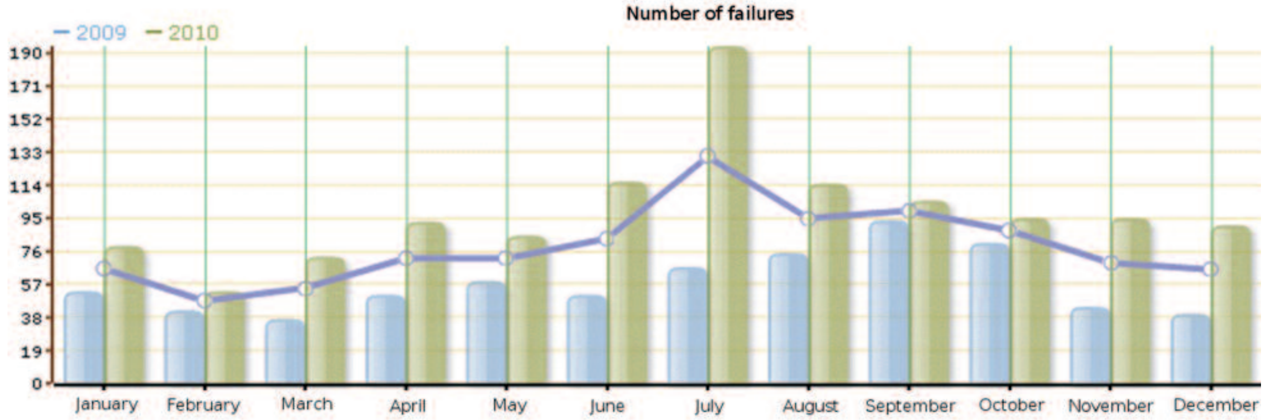


Figure 4
Time sequence of the number of failures of the composite database per month

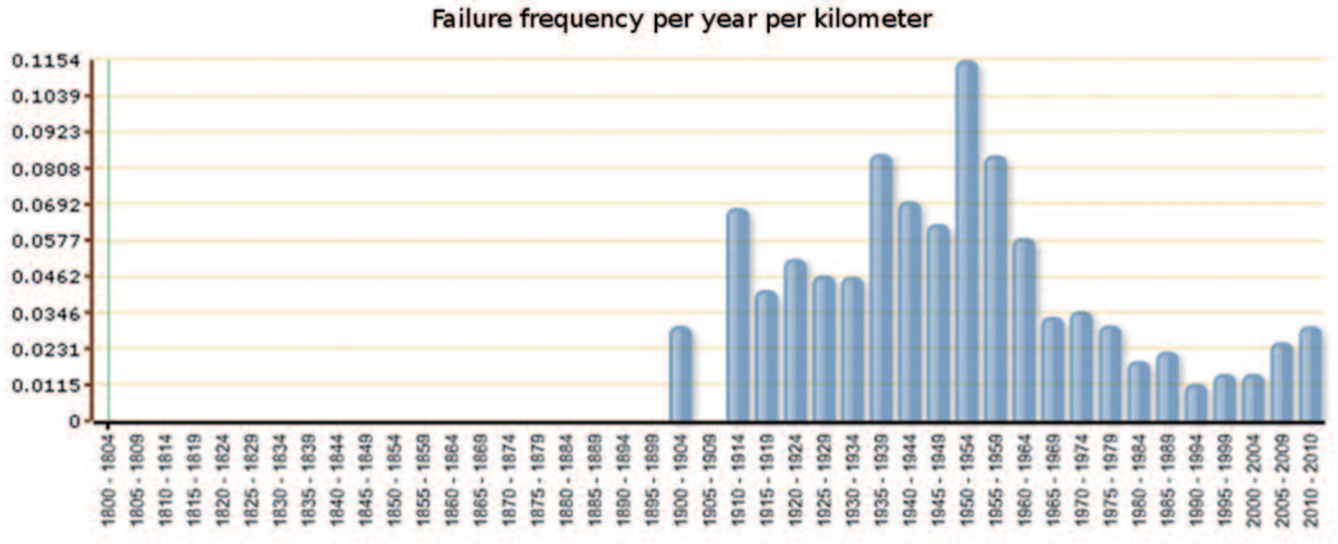


Figure 5
Failure frequency of the composite database per five-year period of the installation year

1930 until 1950. It is likely that the high failure frequencies of the two decades 1950-1969 are caused by problems with the rubber rings applied to the joints until approximately 1963 and low material quality. For the pre-1950 pipes, the higher failure frequency can be explained by the pipe age (>60 years).

Based on the failure frequency the following cohort division can be made (Table 2):

- Diameter: pipes <400 mm have an increased failure frequency
- Decade of installation: pipes in the period '50-'59 have an increased failure frequency.

More detailed divisions of the cohorts AC post 1960 and <400mm and AC 1950-1959 and <400mm seem appropriate because of their relatively large share of pipe lengths. The cohort division as exemplified here shows that failure data can provide useful information for long-term planning of pipe rehabilitation or replacement.

Lessons learned

In the process of designing the USTORE system, implementing it in the water companies and developing USTOREweb, valuable lessons have been learned which are worth sharing. The most prevalent lessons learned apply to the steps 1 to 6 depicted in Figure 2 and are discussed accordingly.

1. Failure registration using the failure form. When designing a registration system it is important to explicitly state and agree on the goals served by the exercise of setting up a failure registration system. The goal determines the requirements in terms of quality and quantity and the extent to which companies are willing to invest in the implementation. For example, if the participants do not see the need for analysis of failures in different diameter classes, it is not necessary to register this. It is important however to realize that what is excluded from the registration can never be investigated. Dependencies on certain parameters or values can only be investigated when registered. It is therefore better to be on the safe side with what is asked and agree on regular revision of the parameters and values (e.g. biannually). An additional advantage of this is that the initial administrative pressure put on the pipe fitters is such that it requires extra attention and serious training and education to ensure that they complete the forms accurately and consistently. Furthermore, the goal of the registration may have implications for anonymity. The needs and requirements of a failure registration system for benchmarking purposes differ from those of one for knowledge creation about the technical lifetime of pipe cohorts.

With regard to the actual registration the main lesson learned is that motivation of the pipe fitters to register consistently and accurately requires a substantial amount of energy and time. Quality Assurance is a possible solution to enforce correct handling of this process.

2. Failure storage in company database. It is important that one person within the company is responsible for the data and that person reports within the project group to the other participants. In this way the participants stimulate each other to continuously strive for high quality data. To achieve this, support of high level management is crucial.

3. Exchanging failure data between a utility and composite database. With the current use of automated information systems within organisations, a link has to be established to export the requested failure and network data and import them into the central registration system. Although this appears to be more of an organisational issue, for several companies it has been an obstacle that proved difficult to overcome. This aspect of implementation should not be overlooked.

4. Data check and insertion into a composite database. USTORE helps to clarify where improvements in the data quality are required, both from failure data and pipe length data. The importance of the quality of the pipe length data is equal to that of the failure data. The fact that this was not recognised fully at the start of the project may have been an advantage; if the requirements would have been considered too demanding at the start, this might have discouraged companies from participating. The companies are currently looking into the failure patterns over time, which causes them to realise that the pipe length data can and should be improved if they want to use it for directive outcomes for asset management.

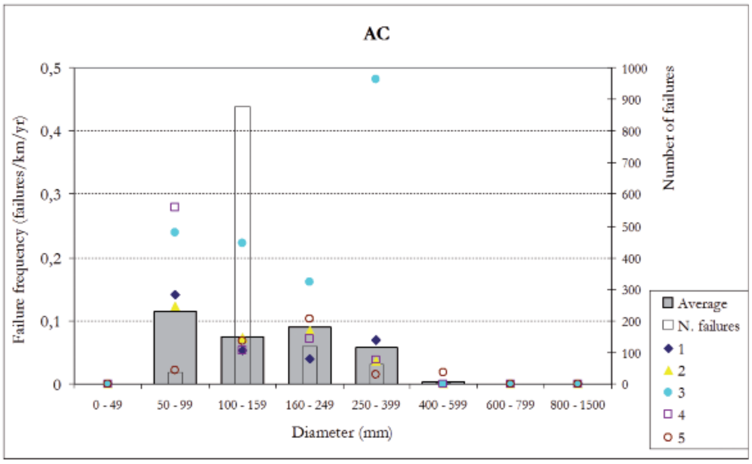
Table 1 - Overview of pipe length and failure data registration within USTORE

Number	Company	Uploaded pipe length	Registered failures
A	2010	Q1 2010 - Q4 2010	773
B	2010 + 2009	Q1 2009 - Q1 2011	603
C	2010 + 2009	Q1 2009 - Q1 2011	1101
E	2010	Q1 2010 - Q1 2011	188
F	2010 + 2009	Q1 2009 - Q1 2011	885
Total			3550

5. Analysing failure data. Using statistics to organise the data always shows where improvements are needed. The analyses performed with USTOREweb show for example that companies apply different regimes for unknown categories. In the example of Figure 5 it can be seen that 1800 has been filled in for the year of installation. Such 'pollution' of the data appears when analyses are made. It is therefore wise to create flexibility by agreeing on a (bi)annual revision of the data with the possibility to adjust them if necessary (step 6).

6. Input for asset management and improvements failure registration system. This last step closes the plan-do-check-act circle; the analysis does not only show whether data are lacking, but also what the data tell and what they do not tell. If the results of analyses do not fulfil the needs for information required for asset management decisions, adjustments should be planned and implemented.

Figure 6
Failure frequency of asbestos cement as a function of diameter range



In conclusion it can be said that data is important. Safe and reliable supply of drinking water is the water companies' core business. It becomes increasingly clear that high standards of supply can only be achieved if data of the assets is known. The experience described in this article underlines the importance of quantitatively and qualitatively sufficient data. Data gathering and processing are increasingly important to the water companies and may well become second to their core business.

The road ahead

Current position on the world map

An inventory of activities and initiatives regarding uniform failure registration in different places around the world performed by KWR shows that the UKWIR database (UK) seems to be the oldest database that is composed of multiple companies' failure data (since 1995). Recently a number of Australian and American utilities have aimed to use the same format as UKWIR, however, the obstacles encountered are similar to the ones discussed in the previous chapter. Implementation in the field as well as in IT systems appears to be more of a hindrance than initially expected.

In terms of contents, the UKWIR and USTORE databases have core parameters in common. USTORE, unlike the UKWIR database, does not offer the opportunity to choose a detail level for the registration of the failures. All participants must register the same. Although this may initially be a hindrance for some companies, it is also a motivational factor for participants. Germany also has a multi-utility failure database, which in 2004 contained failures of over 400 gas and water utilities (approximately 40% of all member utilities of the DVGW (German Technical and Scientific Association of Gas and Water). The DVGW database is merely a failure database, in which failures, the cause of the failure, pipe length, number of connections and volume of supplied water are registered. Currently the requirements for the design and implementation of a national failure database with additional information such as pipe material and soil properties are being investigated.

Other countries that were contacted include Portugal, Austria, Canada and Spain. For some no confirmation has been obtained that they have a joint failure registration system, despite recognition of the need for information. Not all Dutch water companies have joined the USTORE project yet, but important steps are made and a knowledge base that fits the needs of the companies is being built. Similar movements can be seen around the world. Initiatives that stimulate uniform failure registration like the German initiative discussed here, aware-p (www.aware-p.org) and the multi-sector asset management studies from EPA show a tendency towards more awareness and willingness to invest in registration.

Goals and developments

To serve all Dutch water companies, KWR aims to set up a national database. Out of the remaining three companies that until recently did not actively participate, one has recently joined, one is currently discussing participation internally and the third will be invited when the others have joined. Moreover, the two Flemish water companies within the joint research programme of KWR have also been invited to participate.

While discussions about participation are held with the remaining companies, the companies that have been registering according to the USTORE system for the past two years are discussing how quality assurance of the processes of registering and data management can be implemented. Developments in the advancement of automated systems bring more opportunities for data collection. The failure data will be linked with GIS. It will be investigated what the possibilities and limitations of GIS for USTORE are with regard to data input and analysis. Developments

Figure 7
Failure frequency of asbestos cement as a function of installation decade

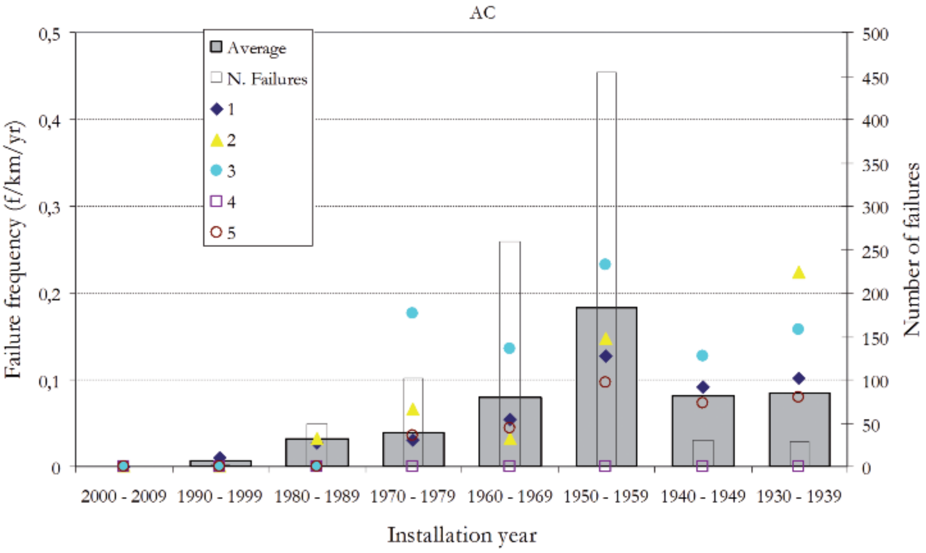


Table 2 - Cohort division for AC pipes based on the failure frequency

Cohort division	Share in pipe length AC
AC pre 1950 and <400 mm	5%
AC 1950-1959 and <400 mm	18%
AC post 1960 and <400 mm	71%
AC >400 mm and pre 1960	1%
AC >400 mm and post 1960	5%

bring forth opportunities as in the near future it may be possible to obtain certain parameters from GIS instead of having to ask them from the field worker in charge.

A logical sequence to the inventory of international initiatives is to seek possibilities for cooperation to increase the returns of the registration investments. The potentials of links with other countries and sectors will be investigated.

Route

To achieve the goals stated in the previous paragraph, a number of activities are and will be undertaken. The activities will be discussed in following order of the term within which they are executed.

- Opportunities of GIS for USTORE are being assessed in a research project that started in September 2011.
- Based on the results of the first two years of registration and exchange of failure and pipe length data, the parameters and values in the registration will be revised. Assessment criteria for in- or exclusion will be, for example, the extent to which the data can provide the companies with information for asset management useful to them. Besides the information for asset management decisions it is also the continuous improvement and actual use of data that participation in USTORE brings about that makes it attractive for companies to join.
- Quality assurance should pertain to the process of failure registration in order to guarantee correct data. For each step in the process it will be investigated how it can be controlled and checked. Pipe fitters for example may have the opportunity to become a Failure Registration Certified Fitter by taking an online training course. This may even become mandatory for pipe fitters if company policy requests so.

  The requirements posed on quality assurance will have to be determined by the participants first. It is expected that discussions about this will be held in 2012.

After the Dutch water companies have all been invited to join USTORE, possibilities and limitations of expansion of the database to other sectors will be discussed as well as international exchange of data or knowledge. ●

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Impact of climate change on asset management planning

UKWIR

Climate change has the potential to impact asset performance and hence the levels of service provided by the water industry. These impacts may significantly affect the capital maintenance or operational expenditure needed to maintain levels of service, mainly because of assets deteriorating at different rates as the long-term mean climate variables change. This project provides a methodology for assessing these impacts and where possible quantifying them. The methodology consists of a sequence of steps for specific mechanisms and asset types. The key concept is that a series of models is needed to establish serviceability or risk change and estimate the funds needed to restore the previous situation – some of these models exist whilst others have yet to be developed. The report includes a review of literature and consultation with the industry, description of the methodology, and training.

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Rehabilitation in Oeiras & Amadora: a practical approach

Urban water systems are essential to modern societies, but managing them strategically is a challenge as they require continuous and costly capital maintenance to ensure service sustainability. Wise rehabilitation and maintenance planning are therefore essential.

J Marques, AP Saramago, MH Silva, C Paiva, S Coelho, A Pina, SC Oliveira, JP Teixeira, PC Camacho, JP Leitão and ST Coelho present an application of an innovative urban water infrastructure asset management (IAM) methodology, developed by project AWARE-P, to the case of the Oeiras & Amadora water utility (SMAS O&A), where the application of the AWARE-P approach by SMAS O&A contributed to a shift of paradigm within the organisation with regard to rehabilitation and maintenance planning.

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During the 1970s and 1980s, investment priorities in urban water systems in Portugal were mainly directed towards the construction of new infrastructure, such as networks and treatment plants. This was a political response to the rapid, often underplanned growth of suburban areas around major cities, caused by internal migration away from rural areas and a significant influx of population returning from Portugal's former overseas territories, at the time of their independence. Such pressures led to the poor design of many urban and peri-urban systems, which grew piecemeal and often with inadequate construction standards.

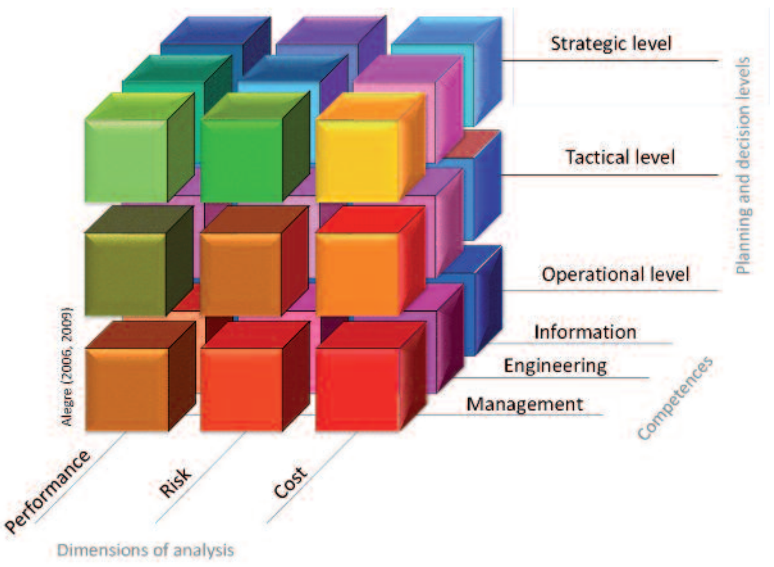
The main immediate problems faced by such systems today are related to early deterioration, as the initial defective construction is exacerbated by decades of insufficient capital maintenance, as well as by inadequate design. Hence, infrastructure asset management (IAM), and particularly rehabilitation, has become an important topic on the agenda of most urban water stakeholders. Many of the existing water mains have reached their expected lifetime, and high capital investments are required to renovate them. Well-devised IAM approaches are thus necessary to assist in defining priorities and solutions.

This is the case of SMAS O&A (Serviços Municipalizados de Água e Saneamento de Oeiras & Ama-dora), an administratively and financially independent public utility providing urban water services – drinking water, wastewater and stormwater – to the municipalities of Oeiras and Amadora, in the suburbs of Lisbon, covering approximately 70km^2 and a population of about 350,000.

SMAS O&A has a strong motivation in joining international R&D projects related to rehabilitation and asset management, as the organization strives to improve data collection and the management of its infrastructure. The main expected benefits are improved support in establishing reliable diagnoses and in using sounder decision-making methods. SMAS O&A aims to be known as an urban water utility of excellence as regards the quality of the services provided, and to develop its activities, taking into account the highest social responsibility, environmental and financial standards.

In order to address its IAM problem, SMAS O&A conducted a detailed asset management analysis of its water supply, wastewater and stormwater systems based on the AWARE-P IAM

Figure 1
The AWARE-P IAM methodology: the three levels of analysis



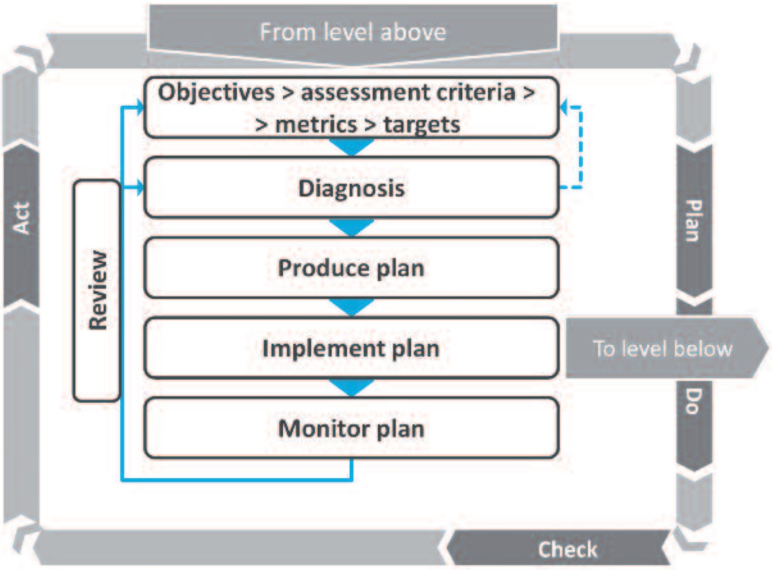


Figure 2
The AWARE-P IAM methodology: Plan-Do-Check-Act

approach (Alegre et al., 2011). This approach recommends three levels of analysis: strategic, tactical and operational, each corresponding to different levels of system detail and time horizons (Figure 1). The strategic level provides a long-term and global perspective of system evolution, whereas the tactical and operational levels have shorter time horizons and are progressively more detailed. Each level of analysis follows a Plan-Do-Check-Act-inspired cycle, as shown Figure 2.

This paper illustrates the application of the AWARE-P methodology to the production of an IAM plan. The entire utility was considered at the strategic level and at the first, geographically aggregated stage of the tactical level. One water supply DMA (district metering area), and one wastewater sub-catchment were used as pilots for testing the AWARE-P procedure at the more detailed level of tactical planning. The diagnosis and intervention alternatives explored in the pilot DMA are presented later in this paper, while details of the wastewater case may be found in Carriço et al. (2011). The alternative solutions were assessed and compared, using different cost, performance and risk criteria, leading to the selection of a solution. The operational level is not covered in this paper.

Strategic planning

The main objective of strategic planning is to establish long-term utility corporate policy, based on knowledge of internal strengths and weaknesses, and of key external opportunities and threats.

The strategic analysis conducted by the SMAS O&A highlighted a number of issues concerning the strategic objectives and policies that had been previously adopted by the organisation. The analysis showed that the strategic objectives, the strategies, the criteria, the metrics and the targets defined by the utility were not sufficiently consistent with one another. In addition, some of the objectives were not easy to monitor, some of the defined targets were not feasible, and alignment among the three different levels of planning was at least partially lacking. Due to these issues, it was necessary to involve the board of directors in a review of the strategic planning process. Strategic objectives were redefined and made clearer, in agreement with the utility's mission and vision statements and taking into account the service quality requirements set by ERSAR, the national water services regulator. Table 1 shows the revised strategic objectives and the corresponding assessment criteria. After the definition of strategic objectives and criteria (and their associated targets), a study regarding the external and internal context of the utility was conducted, leading up to a SWOT (strengths, weaknesses, opportunities and threats) analysis. The weaknesses of the utility were identified and a set of strategies, for both water supply and wastewater and stormwater systems, were devised. The strategies, which aim to respond to the strategic objectives, are summarised in Table 2.

Table 1 - Strategic objectives and assessment criteria

Strategic objectives	Criteria
1. Adequacy of the service provided	1.1 Service accessibility
	1.2 Quality of service provided to customers
2. Sustainability of the service provision	2.1 Economic sustainability;
	2.2 Infrastructural sustainability
	2.3 Physical productivity of human resources
3. Environmental sustainability	3.1 Efficiency of use of environmental resources
	3.2 Efficiency in pollution prevention

Tactical planning

The strategies identified at the strategic planning level are expanded in the tactical level of the analysis, which establishes the interventions to be implemented in the medium-term, and details them in actions at the systems level.

In the first stage, the water supply, wastewater and stormwater networks were subdivided into main trunk systems and subsystems: DMAs for the case of water supply, and sub-catchments for wastewater and stormwater. The selection of DMAs with a higher priority of intervention was based on the assessment, for every DMA, of the applicable strategic assessment metrics. Not only the current situation was taken into consideration, but also the response of the existing systems to the predicted evolution of external factors (e.g. demands, regulation, funding opportunities, economics). More information on this process is presented in Alegre et al. (2011) and in Cardoso et al. (2011).

DMA 542, in the Fábrica das Gabardines neighbourhood, was in this high priority group. It was chosen as a pilot for the next tactical stage since it failed to comply with four of the criteria in Table 1.

The wastewater pilot network selected for the detailed tactical planning is the Venteira catchment, where the main problems identified were poor structural condition, high frequency of pipe blockages and root intrusion in some areas, flooding events in localized areas, cross-connections and environmental problems such as direct discharges to receiving water bodies. As mentioned before, this case is not covered here; details can be found in Carriço et al. (2011) and Cardoso et al. (2011).

Producing a five-year tactical plan for DMA 542

DMA 542 is a stable and heterogeneous urban area, comprising new and old residential buildings, schools, shops and some larger commercial areas. It provides water to approximately 10,000 people (4388 contracts). The network has approximately 12.5km of pipes, 40% of which are asbestos cement and the remainder plastic (Figure 3). Water is supplied by gravity from the Amadora Média service reservoir at 185m elevation, to the north. The lowest ground elevation in the network is 107m.

The required tactical plan is for a five-year planning horizon. Any envisaged alternative solutions will have to be scheduled over a five-year period. However, they will be evaluated over a longer 20-year analysis horizon in order to ensure that the interventions planned are the best both in the medium-term and in a long-term perspective (Alegre et al., 2011). Reference times for assessment were considered at years 0, 1, 2, 3, 4, 5, 10, 15 and 20. Year 0 is 2011 and year 20 is 2031.

Based on the strategic objectives and criteria presented in Table 1 that are more relevant for DMA 542, SMAS O&A selected the following tactical objectives:

- Increase system reliability in normal and emergency conditions (see criterion 1.2)
- Ensure economic sustainability (see criterion 2.1)
- Ensure the infrastructural sustain ability of the system (see criterion 2.2)
- Decrease water losses (see criterion 3.1)

Compliance with these tactical objectives was assessed through the following performance, risk and cost metrics, for both the status quo situation (the current system and O&M practice) and for each of the IAM alternatives considered in this study:

C1: investment cost. This metric represents the economic effort in terms of investment in the network during the analysis period. In this case, only the investment corresponding to the five-year plan was included. Investment costs were converted into the net present value at year 0. Operational costs were similar for all alternatives and were not included. Only investment costs (pipe replacement) were thus considered. The effect of pipe failures was considered under the R1 risk assessment. Costs are expressed here in cost units (c.u.) rather than in a currency for reasons of confidentiality.

C2: comparative design efficiency. This cost indicator is assessed as the ratio between the replacement cost of a network designed as the alternative under analysis and the replacement cost of the existing network. It shows whether the new configuration is nearer to or further from a minimum cost configuration than the existing network. This metric was calculated only for year 5.

C3: infrastructure value index (IVI). This cost index represents the ratio between the current value and the replacement value of the infrastructure (Alegre and Covas, 2010); it should ideally be near 0.5.

P1: minimum pressure under normal operation. This performance index measures the demand locations that are supplied under the required pressure conditions; a minimum pressure (Pmin) requirement of 250 Pa was used. The index was assessed using hydraulic simulation results.

P2: minimum pressure under emergency conditions. This index is similar to P1 but is used to evaluate pressure at the demand nodes under emergency operation conditions, when the normal water source to this DMA fails and an alternative entry point is activated. The index was assessed using hydraulic simulation results.

P3: percentage of total pipe length in asbestos cement. Although it does not look like an ordinary performance indicator, this metric was selected as a proxy for system resilience, reliability and ease of maintenance. The utility assumed that all asbestos cement pipes had similar structural condition, based on the operators' experience and the approximately same age of the pipes.

P4: real losses per connection. This performance indicator measures the real water losses per service connection when the system is pressurised. DMA 542 has 559 service connections.

R1: risk of service interruption (water supply). This risk index was calculated using the method presented in Almeida et al., which uses a risk matrix also known as likelihood-consequence matrix (Figure 4). The likelihood of pipe failure was estimated using failure rates computed per pipe material; pipe failure consequence was estimated using a component importance model which computes the impact of each pipe's individual failure (% of total demand not supplied), based on hydraulic simulation. Pipe failure likelihood and consequence were converted into 1 to 5 scales as shown in Table 3. R1 is expressed as the percentage of pipes that are in the moderate (yellow) or high (red) risk levels (Figure 4).

Summarizing, the C1, C2 and C3 metrics assess cost; P1, P2, P3 and P4 measure performance; and R1 measures risk. In order to facilitate the multi-criteria decision-aid process, the values of the metrics were further assigned into three classes (Good, Fair and Poor) according to the thresholds presented below in Table 4, which were set by SMAS O&A based on the experience of key personnel.

Diagnosis

The diagnosis step carried out for each DMA at the first stage of tactical planning is relatively simplified, as it aims only at identifying priority areas of rehabilitation. It needs to be further

Table 2 - Strategies of SMAS O&A for water and wastewater and stormwater systems

Water supply system	Wastewater and stormwater systems
Perform planned rehabilitation	Perform planned rehabilitation
Reduce water leakage	Reduce illegal connections
Promote the efficient use of water	Evaluate the potential for wastewater reuse
	Update inventory and perform structural condition surveys

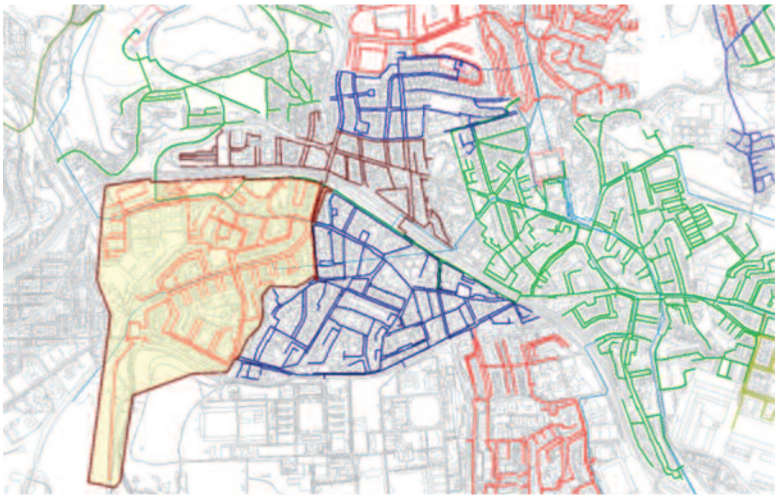


Figure 3
DMA 542 (in yellow), among neighbouring DMAs. Supply is from the north (shown in green).

Table 3- Scales of pipe failure likelihood and consequence

Classes	Pipe failure likelihood (failure 100km-1 year-1)	Pipe failure consequence (population not supplied)
1 (likelihood: rare/ consequence: insignificant)	0 – 30	0 – 100
2 (likelihood: unlikely/ consequence: low)	30 – 40	100 – 200
3 (likelihood: moderate/ consequence: moderate)	40 – 60	200 – 500
4 (likelihood: likely/ consequence: high)	60 – 100	500 – 2000
5 (likelihood: almost certain/ consequence: severe)	> 100	> 2000

developed as each priority DMA is analysed in detail. In this process, due consideration must be given to scenarios, defined in the AWARE-P methodology as those conditions not controlled by the utility which may influence the analysis, such as demographic trends or regulatory changes. DMA 542 is a fairly stable area in terms of water demand; however, some new residential and office development permits have been issued. These will increase demand in the DMA, but a thorough hydraulic model analysis showed that this would not significantly impact the network. Consequently, a single scenario was taken into account in the development of the tactical plan for DMA 542, already including future water demand associated with the proposed developments. An increase in pipe failure rates has also been reported; an increase of 6% per year was assumed.

Diagnosis of the current situation (year 0) at DMA 542 using the assessment metrics and associated reference values yielded the results shown in Table 5. As regards compliance with the set tactical objectives, the main problems identified were:

- Reliability of the system, in normal and emergency conditions: insufficient pressure under normal conditions, in a few confined locations; high pipe failure rates, the repair of which disrupts service; water quality problems localised in branched network areas associated with high water travelling times; and low resilience of the system to cope with emergency operation conditions.
- Infrastructural sustainability of the system: old and poor condition asbestos cement pipes, with high failure rates.
- Water losses: undesirable leakage levels.

It is thus clear that the current capital maintenance practice is not adequate and rehabilitation solutions need to be considered and implemented. Addressing the above problems is in accordance with the stated strategies 'Perform planned rehabilitation' and 'Reduce water leakage' (Table 2).

Design of alternatives

'Alternatives' are defined in the AWARE-P methodology as possible intervention solutions. These alternatives should be designed to solve or mitigate the problems identified in the diagnosis. The alternatives explored for the case of DMA 542 were as follows.

A0: the status quo alternative: This alternative (also known as the base case) corresponds to maintaining the existing network and a reactive capital maintenance policy (i.e. repairs after break only). It was used as the basis for diagnosis. Based on the diagnosis results, a few small and inexpensive possible improvements of the system were identified, including e.g.: installation of a pressure reduction valve to reduce pressure at a specific area of the DMA that has been reporting high pressure related problems, including high burst rates; and minor redesign of DMA boundaries to solve localised low pressure problems. These improvements were included in all new alternatives.

A1: alternative 1. This alternative gives a higher intervention priority to pipes with higher risk of failure, and replacing them with pipes with the same (or approximate) diameter, although of different material. In this case, likelihood of failure depends only on the type of material (plastic or asbestos cement). Consequence of failure is assessed as previously explained. Alternative 1 represents thus the conventional risk-based like-for-like rehabilitation practice. The replacement rate considered was 1km of pipe per year, to fit the available budget.

A2: alternative 2. This alternative corresponds to an optimal network design, in terms of energy dissipation and cost, for the current source location, network topology and demands. The optimisation was carried out using the design algorithm developed by Alegre (1994); this alternative was taken into consideration in order to assess how much the existing configuration differs from an optimal configuration from the cost and energy viewpoints, under normal operating conditions.

A3: alternative 3. This alternative is based on the A2 design, but with improved resilience. The AWARE-P software's component importance model was used to identify critical pipes. This allowed for design adjustments such that demands can be adequately supplied in the event of a critical main failure or of a supply interruption from the current DMA source point (the Amadora Média service reservoir). The activation of a temporary water source (the Atalaia service reservoir, to the south) was considered for emergency conditions. This configuration corresponds to a design that might have been adopted if the DMA would be built from scratch in the present.

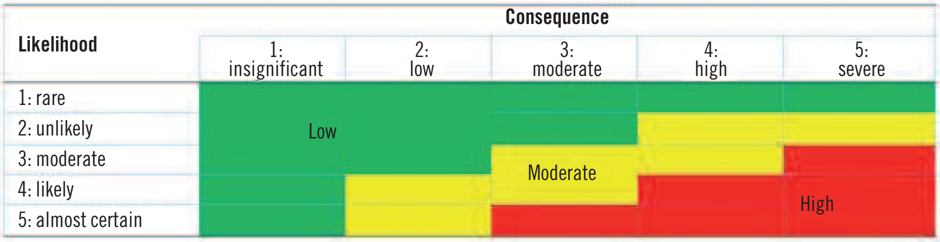
A4: alternative 4. This alternative resulted from comparing A0 and A3. In fact, in recent years this DMA has already been partially rehabilitated on a like-for-like basis, including pipe sizes that are now questionable. However, it would be unreasonable to start replacing newly laid pipes without good reason. Oversized plastic pipes have thus been accepted in this alternative. There were only a few plastic pipes with a diameter smaller than the corresponding A3 value. The need for replacing or reinforcing them was considered, but network analyses carried out showed that this is not the case. Some minor new pipes were included, as in A3, to allow using the emergency source. Replacement of the asbestos cement pipes was scheduled based on relative importance, at a rate of 1km per year.

Assessment of alternatives

In the assessment of alternatives in this second stage of the tactical planning, only one scenario was considered, for the reasons mentioned in the diagnosis. The assessment of the five alternatives was carried out for the five-year planning horizon and for a 20-year analysis horizon.

Figure 5 shows two of the metrics, P3 (% asbestos cement) and R1 (risk of service interruption), over time, for all alternatives. Up to year 5 (2016), there are significant variations in the assessment results, due to the differing

Figure 4
Risk matrix



Likelihood	Consequence 1: insignificant	2: low	3: moderate	4: high	5: severe
1: rare	🟩	🟩	🟩	🟩	🟩
2: unlikely	🟩 Low	🟩	🟩	🟨	🟨
3: moderate	🟩	🟩	🟨 Moderate	🟨	🟥
4: likely	🟩	🟨	🟨	🟥	🟥 High
5: almost certain	🟩	🟨	🟥	🟥	🟥

alternative implementation schedules. P3 decreases for all alternatives in the first five years, except for A0, for which it remains constant along the entire period of analysis. For R1, the effect of increasing pipe failure rates is clear (Figure 5b): the percentage of pipes rated as moderate or high risk is constant during the first five years for A0 but increases halfway through the analysis horizon; for the other alternatives, the percentage of pipes at moderate or high risk decreases to zero after year 5 due to the replacement of older pipes; and the overall risk increase due to escalating failure rates is delayed towards the end of the analysis horizon.

In this particular case, the values of the majority of the assessment metrics are constant after year 5, with the exception of C3 and R1. This is due to the constant demand scenario considered. Hence, in this case the comparison and selection of alternatives can be centred on the values for year 5.

Comparison and selection of alternatives

The comparison of alternatives was carried out considering the end of the tactical planning horizon, year 5. The results for the eight assessment metrics are shown in Table 6. Experience shows that it is often less costly not to invest (e.g. repairing pipes and paying for the water lost in leakage) than to invest (e.g. by proactively replacing) in a system. This was confirmed here by analysing A0 at year 5. However, after year 5, the problems identified in the diagnosis are even more evident than at year 0: poorer network reliability, and moderate water losses, which tend to intensify due to normal deterioration of pipe material. In addition, although the percentage of pipes classified at moderate or high risk of service interruption is the same between year 0 and year 5 (2%), it grows throughout the analysis horizon (Figure 5b) due to the increase in failure rates – 7.6% at year 20. Results for A1 show that it is generally better than A0 in terms of infrastructural sustainability, water losses and risk (C3, P3 and R1). Investment (C1) is higher than in A0 (243 c.u.), but within the acceptable range. However, A1 perpetuates the design deficiencies of the existing (A0) system.

Alternative 2 corresponds to the optimal network diameters in terms of costs and of energy dissipation. It is included only to help understand the differences it would create in terms of performance and risk. The associated cost for replacement of the entire network in five years would not be reasonable (664 c.u.), particularly when some of the existing pipes are less than a decade old. As expected, this is the alternative with significantly favourable C2 (comparative design efficiency). Besides, the network design obtained with this optimization method underperforms in terms of supply under emergency situations (P2 is 0.00).

Table 4 - Multi-criteria reference values

	Good	Fair	Poor
C1 (cost units)	0, 350	350, 450	450, ∞
C2 (-)	0, 1	1, 1.5	1.5, ∞
C3 (-)	0.45, 0.55	0.30, 0.45; 0.55, 0.70	0, 0.30; 0.70, 1
P1 (-)	3, 2	2, 1	1, 0
P2 (-)	3, 2	2, 1	1, 0
P3 (%)	0, 5	5, 10	10, 100
P4 (l connection^{-1} day^{-1})	0, 100	100, 150	150, ∞
R1 (%)	0, 1	1, 5	5, 100

Alternative A3 results from modifying A2 in order to increase the system's resilience. It still has a large investment cost associated, as total pipe network replacement by year 5 is assumed. However, this alternative network ensured a good performance in emergency cases caused by major pipe outages or interruption in the water source (P2 is now close to 3). The total network cost of this alternative is only slightly higher than in the case of A2.

Table 5 - Diagnosis of the existing DMA 542 system at year 0, using the assessment metrics

	Assessment metrics							
	C1 (c.u.)	C2 (-)	C3 (-)	P1 (-)	P2 (-)	P3 (%)	P4 (l conn.$^{-1}$ day^{-1})	R1 (%)
Diagnosis	0	1	0.5	3.00	0.00	37.2	116	2.0

C1 – investment cost; C2 – design efficiency; C3 – IVI; P1 – min. pressure (normal op.); P2 – min. pressure (emergency op.); P3 – % of asbestos cement pipes; P4 – real losses; R1 – risk of service interruption

Alternative 4 aims at realistically and progressively bringing the existing network closer to the A3 configuration. It is a combination of A1 and A3. Its resilience is improved over A0, A1 and A2, as it may be supplied from an alternative source, as in A3. However, investment costs are considerably lower (243 c.u.) than for A2 or A3. The percentage of asbestos cement pipes is also significantly reduced to 8.8% when compared with the results obtained for A0.

In order to choose the best alternative, the results from Table 6 were ranked in two different ways in Table 7. Ranking I focuses mainly on the performance and risk metrics (the only cost metric included was C2). The purpose was to understand the potential for improvement of the existing system regarding performance and risk. In Ranking I, A3 is the best solution, followed by A4; it responds well in normal conditions, and better than the other alternatives in emergency conditions (as highlighted by significantly better values of P2). The worst alternatives are A0 and A2, revealing the shortcomings of the current network design and, in the case of A0, higher levels of leakage and the poor result in terms of C3 in the case of A2.

Ranking II, the basis for the final selection, includes all assessment metrics and takes into consideration the limited available budget – if the investment cost of an alternative is higher than the available budget, then the alternative is outright rejected. Alternatives 2 and 3 are thus precluded. Of the three remaining, A4 is ranked first, then A1 and A0. A4 clearly corresponds to a good trade-off between performance, risk and cost; it sheds the network design deficiencies of A0 and A1 and, additionally, has better flexibility for emergency operation (as reflected by P2). It should be added that, after year 5, whenever a plastic pipe needs replacement, the corresponding A3 diameter will be adopted.

A note on urban water infrastructure information systems

The participation of SMAS O&A in the AWARE-P project has been an incentive and opportunity to review and improve data collection, data quality control and information management. For instance, the data included in the work orders registries have been adjusted in order to ensure that they are as simple as possible, but not simpler than needed for the decisions they inform (e.g. failure analyses and forecasting, condition assessment). The entire process

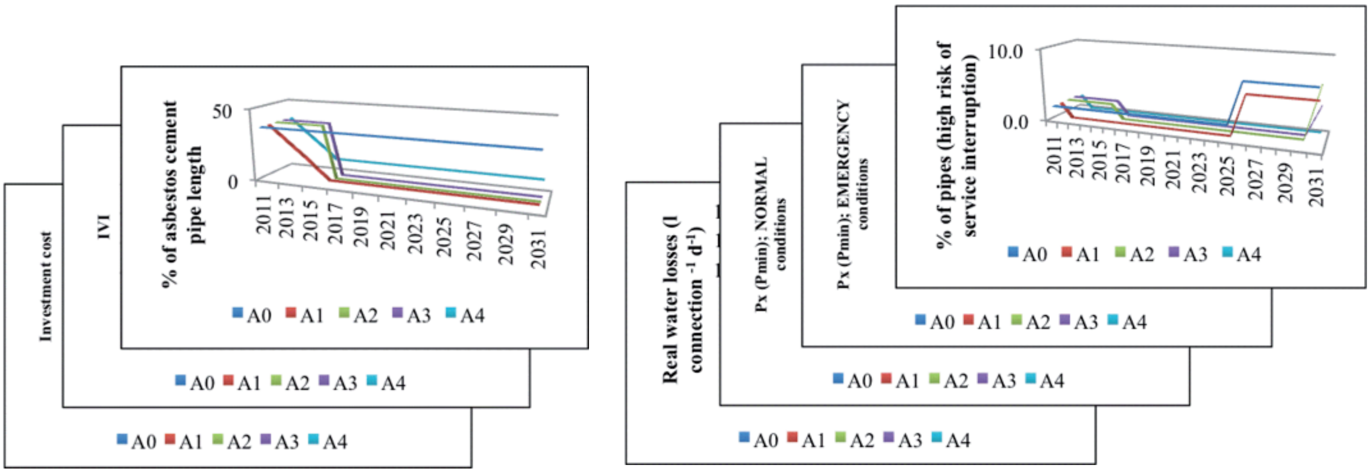


Figure 5
Assessment of planning alternatives over the analysis period: (a) P3: percentage of asbestos cement pipe length and (b) R1: risk of service (water supply) interruption

from field data collection forms to engineering review has been revised. Another example is the on-going process of creating a new asset accounting registry, more informative and fully coherent with the geographical information system (GIS). The latter's 1-to-1 relation consistency with the network model is a consequence of a solid feature of SMAS O&A systematic modelling procedure, whereby modelling files are always exported from their GIS counterparts. This is key in relating GIS, inventory and IAM analysis results.

A critical aspect that remains to be completely resolved in actual practise is GIS management of historical data (legacy pipes that are replaced, decommissioned or otherwise discarded) and their full and effective consistency with the work orders database. The realisation that dead or disposed pipes and components are just as interesting for meaningful failure analysis as existing live ones is slow to permeate current IT data solutions.

The IAM Tactical plan

SMAS O&A is using this case as a model to prepare a new style of corporate IAM tactical plan. This document is a synthetic document presenting the tactical objectives and targets, the issues arising from the diagnosis, the priority areas chosen and the alternative selected for each of them, presenting and briefly justifying the decisions made. This document also specifies the implementation plan, the financial plan and the procedure for monitoring and review. The intention is to generalize this type of contents for the entire utility, complementing it with the relevant operation and maintenance tactics and with the other relevant non-infrastructural tactics (e.g. related to information management, to organizational issues or to accounting and financing management). ●

Acknowledgements

SMAS O&A acknowledge all the AWARE-P partners (www.aware-p.org) for the shared experiences and for the new knowledge commonly created.

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Table 6 - Results obtained from the evaluation of the five alternatives (year 5)

	Assessment metrics							
	C1 (c.u.)	**C2 (-)**	**C3 (-)**	**P1 (-)**	**P2 (-)**	**P3 (%)**	**P4 (l conn.$^{-1}$ day^{-1})**	**R1 (%)**
A0	0	1	0.4	3.00	0.00	37.2	116	2.0
A1	243	1	0.7	3.00	0.00	1.5	51	0.0
A2	664	0.8	1.0	3.00	0.00	0.0	49	0.0
A3	729	0.9	1.0	3.00	2.97	0.0	49	0.0
A4	332	1.1	0.7	3.00	2.86	8.8	65	0.0

C1 – investment cost; C2 – design efficiency; C3 – IVI; P1 – min. pressure (normal op.); P2 – min. pressure (emergency op.); P3 – % of asbestos cement pipes; P4 – real losses; R1 – risk of service interruption

This paper was presented at LESAM 2011 – the Leading Edge conference on Strategic Asset Management, held 27-30 September 2011, Mülheim an der Ruhr, Germany.

Table 7 - Ranking of alternatives at year 5

Alternatives	**Ranking I – w/o investment costs**		**Ranking II – w/ investment costs**	
	Comparison results	**Ranking**	**Comparison results**	**Ranking**
A0	1.47	5	1.73	5
A1	2.12	3	2.16	2
A2	2.00	4	1.79	4
A3	2.50	1	2.13	3
A4	2.35	2	2.25	1