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ADB president calls for creative ways to tap savings for infrastructure

Asian Development Bank (ADB) president Haruhiko Kuroda told delegates at the Infrastructure Finance Forum last month that Asia must be creative in finding ways to tap its multi-trillion dollar savings and mobilise private sector support for new infrastructure needed to sustain growth moving forward.

Mr Kuroda told the event: 'The infrastructure challenge for developing Asia is one of the most daunting we face today. We must work diligently to be innovative, yet financially responsible, in mobilizing Asian savings to deliver successful, sustainable and robust infrastructure projects.'

The event, jointly sponsored by ADB, the APEC Business Advisory Council and the Japan Bank for International Cooperation, was held in Yokohama, Japan.

The bank noted that gross domestic savings in emerging Asia were close to $4 trillion in 2009 but that much of this large cash pile has been under-used, with regulatory obstacles, currency mismatches and underdeveloped capital markets hindering broader financing of essential infrastructure.

The needs are immense: ADB calculates that about $8 trillion in new infrastructure investments will be required in the region through to 2020 to support current levels of economic growth.

Of the infrastructure needs, water, sanitation and other public goods will account for around 25%.

With the public sector unable to meet the considerable costs on its own, public-private partnerships will be essential, the bank said. It urged governments to look to strengthen existing legal and regulatory frameworks to attract more private investors and finance from funds and institutional investors.

Mr Kuroda also issued a statement stressing that the key challenge for emerging East Asia to sustain growth is to expand domestic and regional demand by improving Asia's regional infrastructure networks and removing barriers to intra-regional trade. ●

Leaders warn of need to beat infrastructure deficit in MENA region

The Middle East and North Africa (MENA) region needs to overcome its infrastructure deficit if it is to boost its competitiveness and attract much-needed foreign investment, said government and business leaders in a panel at the World Economic Forum on the Middle East and North Africa, which took place in Marrakech, Morocco at the end of October.

Shamshad Akhtar, Regional Vice-President, Middle East and North Africa, World Bank, Washington DC, said that infrastructure deficits persist, despite many improvements in the last decade. 'The region's infrastructure needs are between $75 and 100 billion a year for the next five years, after experiencing an investment low of $6 billion in mid-2009.'

'To attract the massive foreign capital it needs, the MENA region needs to boost its competitiveness by enhancing regional infrastructure,' said Carlos Ghosn, Chairman and Chief Executive Officer, Renault-Nissan Alliance (France and Japan), France; Co-Chair of the World Economic Forum on the Middle East and North Africa. 'Good infrastructure is a necessary – though not sufficient – condition for investors to come in.'

José W Fernandez, US Assistant Secretary of State for Economic, Energy and Business Affairs, emphasized the need for the public and private sectors to work together. 'Government has a central, galvanizing role in developing infrastructure; while the amount of capital required means the private sector is essential.' The main thing that governments can do is to remove barriers to trade and free movement of goods and people, thus boosting intra-regional trade and integration, he noted.

'It should not be forgotten that there has been huge progress in improving infrastructure in the past decade,' said Khalid Abdulla-Janahi, Honorary Chairman of Vision 3, United Arab Emirates; Regional Agenda Council on the Middle East & North Africa. Nevertheless, there is much more that needs to be done – especially in terms of cross-border projects that enhance transnational integration, he pointed out. Andrea Canino, President of Conseil de Coopération Economique agreed: 'Rather than focus on the challenges and the failures, we need to showcase flagship projects which have been successful.' ●

water asset management INTERNATIONAL

EDITORIAL

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Survey finds major concerns over state of US water infrastructure

ITT Corporation recently released the results of its Value of Water Survey, a nationwide poll that included registered voters and industrial and agricultural businesses, and measures how the public values water and their level of awareness of the nation's aging water infrastructure.

The survey found that nearly one in four American voters is 'very concerned' about the state of the United States' water infrastructure. According to the US Geological Survey, pipe breaks and other leaks result in the loss of around 1.7 trillion gallons (6.5 trillion litres) of water every year.

'Water is a necessity, but our survey confirms that most people take access to clean tap water for granted,' said Gretchen McClain, president of ITT Corporation's Fluid and Motion Control business. 'Indeed, water is one critical issue missing from the national infrastructure debate.'

ITT's survey revealed that 63 percent of voters are willing to pay an average of 11 percent more on their water bill each month. In addition, a majority of industrial and agricultural businesses surveyed are willing to pay an average of 7 percent more per month for the water they consume. ●

Bentley launches infrastructure ranking

Bentley Systems has announced the release of its inaugural Bentley Infrastructure 500 Top Owners ranking. This global compendium of the top public- and private-sector owners of infrastructure is based on the value of their cumulative infrastructure investments (measured by reported net tangible fixed assets).

The rankings, which Bentley will update annually, make it possible to readily compare investment levels across types of infrastructure, regions of the world, and public and private organizations. The full list is available for download at www.bentley.com/500.

Bentley Systems has compiled the Bentley Infrastructure 500 Top Owners rankingto help global constituents appreciate and explore the magnitude of investment in infrastructure and the potential to continually increase the return on that investment. The infrastructure value represented is over $13 trillion.

'As the global economy improves and government investments in this area increase, the time to advance our infrastructure is now,' said Michael Valocchi, Energy & Utilities Industry Leader for IBM Global Business Services. ●

Putin announces drinking water access funding for Russia

Russian premier Vladimir Putin has announced a significant $292 million programme to expand access to drinking water over the next three years.

Putin told participants at the Clean Water 2010 forum in Moscow: 'We approved a national water strategy extending until 2020 a little more than a year ago. This strategy determines the main objectives for the development of the water industry in this country. We are planning to conduct a large-scale modernisation of the water industry, beginning with the adjustment of the relevant legal standards and the system of government control and ending with the reconstruction of the entire water supply infrastructure. We will thus channel substantial investments into ensuring the security of hydro-technical facilities and enhancing the safety of water resources.

'The Pure Water Federal Targeted Programme sets the task of supplying the population with quality drinking water,' he continued. 'It is designed to encourage the drafting of effective water management projects, particularly at the regional level. At present, the programme has been submitted to the government and will be carried out from 2011 to 2017.' ●

World Bank and IDB set up infrastructure funding initiative

The World Bank Group, in co-operation with the Islamic Development Bank, is setting up a regional initiative that could raise up to $1 billion to close the infrastructure gap in the Middle East and North Africa (MENA), which will undermine the region's growth if not urgently addressed.

The MENA region needs to invest between $75 billion and $100 billion a year to sustain the growth rates that have been achieved in recent years and to boost economic competitiveness. Private sector investment in infrastructure in MENA countries is limited, especially outside the Gulf countries despite huge unmet demand for infrastructure services.

The aim is to bring together the World Bank Group with the Islamic Development Bank as potential anchor investors in a regional investment vehicle to support both conventional and Shariah-compliant investment in infrastructure.

'This regional initiative will unlock new flows of private sector investment to help countries like Egypt, Morocco, Jordan or Tunisia eager to push ahead with critical infrastructure projects that will drive competitiveness and boost much needed job creation,' said Robert B Zoellick, World Bank Group President.

He added that the proposed regional initiative would include technical assistance to help governments tackle legal, policy and institutional constraints to public-private-partnerships and develop cross-border infrastructure projects vital to regional integration and competitiveness. ●

Development of a pragmatic rehabilitation strategy for a rural water supply network

The management of pipe networks is a continuous priority for water utilities, and strategies for renewal and rehabilitation vary according to the specific needs of the utility. Marcel Meggeneder and Ingo Kropp discuss the development of an asset management strategy for the relatively young network of German utility Trinkwasserverband Verden.

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In rural water supply areas with quite young networks a rehabilitation strategy could be developed based on sophisticated models and simulations, but this is not necessary in all cases. A sustainable rehabilitation strategy can also be developed by using a pragmatic approach.

The rehabilitation of pipes is a permanent task of water network operators nowadays and should rely on a good long-term rehabilitation strategy. The optimal strategy should combine two views: on one hand the (long-term) experience of engineers and technicians, and on the other hand results from failure statistics, material analysis, service life analysis, hydraulic conditions, economic evaluations, etc. A straight-forward approach that combines these two views has been chosen by Trinkwasserverband Verden (TVV), a German utility, for the rehabilitation of its 1341km water supply network.

TVV serves eight cities and municipalities in an area of 800km^2 around the city of Verden in Lower Saxony in Northern Germany. It operates three water works and manages a pipe network of 1341km and 38,400 service connections for 115,000 people.

It delivers also around 9.5 million m^3 of water to the city of Bremen every year. The overall annual water production is approximately 16.5 million m^3.

The history of TVV is quite young compared to an urban network operator, which often has a long history of central water supply. The average age is 30 years. The mean break rate with 0.025 breaks per km per year

Figure 1
Rehabilitation of a pipe under a motorway. Credit: Marcel Meggeneder.

is also very low. The German Association of Water and Gas Works (DVGW) provides in its guideline W400-3 a threshold of ≥0.1 breaks per km per year for low break rates.[1]

The rehabilitation of the water network in the past was mainly reactive, e.g. driven by clusters of main breaks in a certain area. TVV had set the focus on rehabilitation in older supply areas, which were taken over from other network operators at some point, and coordination with other works of network operators and municipalities.

The average annual rehabilitation rate during the last ten years was 0.5%, which is about 6.7km per year. If rehabilitation would continue at this rate, an average service life of 200 years would be required. The recent rehabilitation efforts are justifiable due to the low network age and break rates, but it needs to be increased step-by-step over the next decade. The current rehabilitation policy should change from re-active to more pro-active rehabilitation management that takes into account condition and severity factors in a kind of risk-based approach.

Nevertheless, this increase of the annual rehabilitation rate must be based on efficiency and technical objectives to select appropriate main sections for replacement. Since the available data for the young network was still not sufficient to carry out complex and sophisticated modelling supporting the decision process, TVV applied a pragmatic approach in collaboration with an engineering company.

The first step of the analyses was the determination of the strategic long-term replacement rate based on the technical service life of specific pipe groups. Table 1 shows the relationship between required service life and long-term replacement rates.

Today, pipe manufacturers specify a service life of 100 years for new pipes under ideal conditions. This means that the higher service life values in Table 1 are more of theoretical nature than realistic. However, if a network in bad condition (with high break rates and leakage volumes) requires higher replacement rates, investment budget constraints could influence significantly the feasible annual replacement rates. Service levels may need to be re-defined and thus higher service lives will be the consequence.

Service life (years)	Strategic replacement rate (% / year)
200	0.50
150	0.67
100	1
50	2

Table 1
Relationship between service life and strategic replacement rate

Descriptive statistics and condition of the water supply network

The first step for the development of a rehabilitation strategy was an analysis of the current network and its condition. For this purpose, available break data of the years 1998-2008 and rehabilitation activities within the same period were analyzed (Table 2).

The recorded break data includes information about the location (municipality, street, street number), the affected main (material, dimension) and the break itself (date, type, cause, leakage). Breaks were not geo-referenced in the past, but will be from now on to enable better analyses in the future.

First, all breaks caused by third-parties were removed from the analysis dataset. Third-party breaks comprise about 15%. The remaining breaks were assigned to the pipe groups.

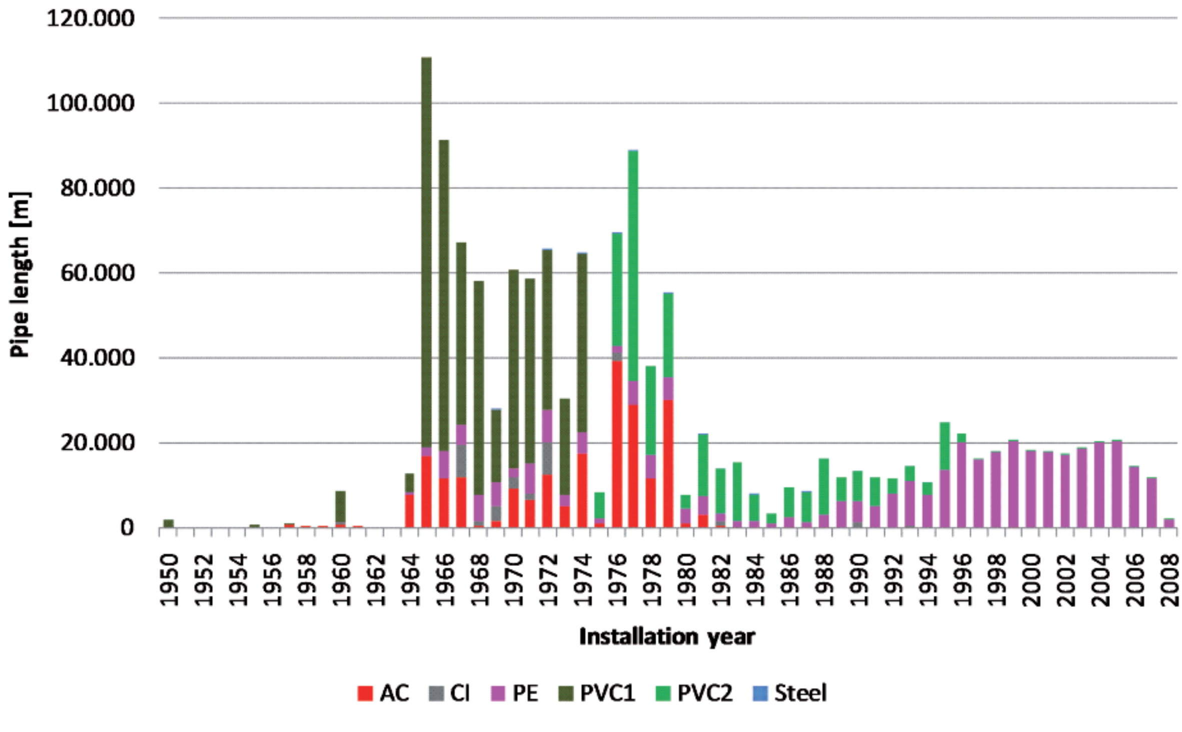
Furthermore it was attempted to assign breaks directly to single pipes by using the recorded information about the location and the pipe characteristics in the break database to calculate the age of the pipe at the time of the break.

Around 85% of all breaks occurred on PVC (polyvinyl chloride) pipes that account for only 54% of the network length. PVC pipes with glue joint connections show an above average break rate compared to all other pipe groups. The very high break rate on steel pipes is not representative due to its small length and only two breaks within the 11 years of break recording.

Figure 2 shows the current distribution of pipes that are in service, subdivided by pipe groups and installation years. The central water supply in the rural area of Verden was established in the 1960s and 1970s. In the middle of the 1970s, PVC pipes with plug joint connections were introduced. Previously PVC pipes with glue connection had been used. The network was continuously extended during the 1980s with annual installation lengths between 15 and 20km, and PVC as material for new installations was replaced increasingly by PE (polyethylene).

The analysis of break data by installation years (Figure 3) verifies

Figure 2
Distribution of installed pipes by installation year and pipe group



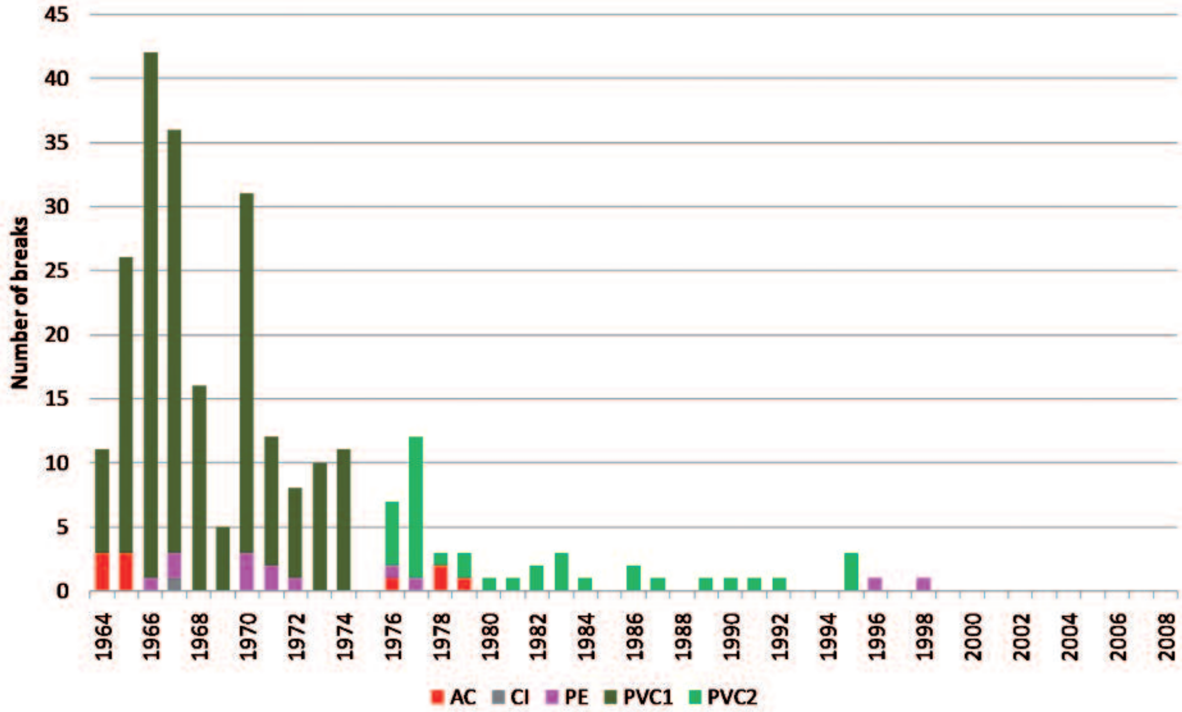


Figure 3
Condition analysis – Distribution of breaks by installation years

the statistics provided in Table 2. The first generation of PVC shows the highest number of breaks, especially in the 1960s. The years 1976 and 1977 show also higher break numbers. The other pipe groups do not show any break occurrence related to specific installation years.

Development of the rehabilitation strategy

Initially the future rehabilitation needs were determined based on the current network inventory and service life assumptions for the pipe groups. The ageing model – a cohort survival model - applied in this study was originally developed by Prof. Herz and implemented in the software KANEW.[2,3]

The model is recommended in the guidelines of DVGW as a method to determine rehabilitation needs and has been widely used in the last 20 years in Europe and North America. The KANEW software, developed for the Water Research Foundation, enables also the analysis and simulation of comprehensive rehabilitation strategy scenarios.

Due to the good network condition and the young age of the network it was not yet possible to determine and justify service lives from TVV's own data. Thus, service life assumptions based on the experience from more than 80 studies (150,000km of network and more than 100,000 breaks) and derived from literature references were used.[4,5]

The results of the forecast of future rehabilitation needs are shown in Figure 4.

The results show that the current amount of rehabilitation needs to be increased over the next years. If future rehabilitation would be carried out on the same level as in the past, model simulations showed that by 2020 required investments will increase significantly. Figure 3 shows also that the required amount of rehabilitation doubles every ten years approximately to fulfill the forecast needs.

On the part of TVV the results of the analyses and prognoses should be supplemented by current operational and financial implementation resources. Thus a strategy was selected that accomplishes the following constraints:

- Implementation of the strategy without affecting the current water price and concession fee
- Planning, preparation and supervision of rehabilitation projects feasible with current personal resources
- Implementation of strategy for the next ten years with a constant rehabilitation rate (set by available budget)

So, it was defined that between 2010 and 2020 the annual rehabilitation volume is 10km of pipes. This leads to an annual rehabilitation rate of 0.75%, which is an increase of 50% compared to the current average rehabilitation rate. Within this period the development of breaks will be closely observed and if required the rehabilitation strategy will be refined.

Selection of rehabilitation priorities

For the selection of rehabilitation priorities an approach was chosen that takes into account the results of the individual break data analysis as well as practical experiences and hydraulic supply conditions in the network.

The network is divided into 24,863 pipe segments according to GIS (geographic information system). Each segment was evaluated with respect to break statistics, minimum age, risk and importance. Risk and importance was defined by 'risk points' (another term could be 'impact points'):

- Break rate is above the average break rate in a specific area of the municipalities → selection of pipe segment if condition is fulfilled
- Minimum age (>25 years) of pipe segment to guarantee complete depreciation → elimination of pipe segment if not fully depreciated

Risk and importance (assignment of risk points)

- Hydraulics 1 (low remaining hydraulic capacity or low flow velocities) → one risk point

Table 2
Descriptive statistics of network and break data

Pipe group	Length (2008)		Age	Breaks (1998-2008)		Break rate	
	[m]	[%]	[Years]	[-]	[%]	[#/km]	[#/km.a]
AC – asbestos cement	218,327	16.29%	34.6	21	5.8%	0.096	0.009
CI – cast iron	29,868	2.23%	36.5	1	0.3%	0.033	0.003
PE	359,953	26.85%	14.7	31	8.6%	0.086	0.008
PVC1 – glue joint	482,621	36.00%	39.6	238	66.1%	0.493	0.047
PVC2 – plug joint	249,421	18.60%	26.0	67	18.6%	0.269	0.026
Steel	472	0.04%	30.9	2	0.6%	4.235	0.403
Total	1,340,662	100.00%	29.5	360	100.0%	0.269	0.025

- Hydraulics 2 (important segments to assure water supply and/or dimension ≥300mm) → one risk point
- Sensitive customers (hospitals, social facilities, large industries) → one risk point

Sub-categories were not weighted. All criteria were treated equally.

The evaluation of break statistics / minimum age and the resulting risk points (maximum of three risk points) lead to four rehabilitation priorities (P):

- P_{high}: pipe segments with high break rates and risk points assigned (high priority)
- P_{medium}: pipe segments with high break rates, but no risk points assigned (medium priority)
- P_{low}: pipe segments without high break rates, but risk points assigned (low priority)
- P_{zero}: pipe segments without high break rates and without risk points assigned (no priority)

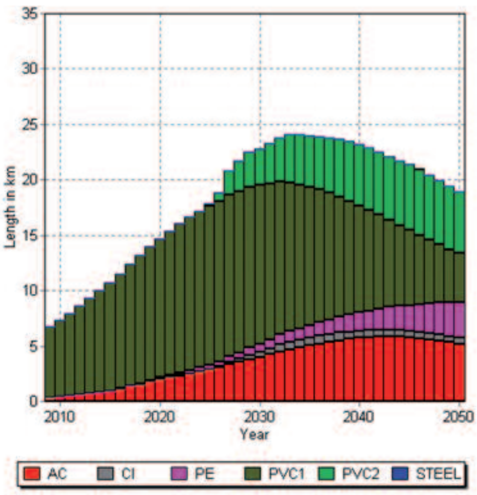


Figure 4
Development of annual rehabilitation needs based on current network inventory and respective service lives (calculated with KANEW)

Since the amount of pipes in P_{high} is relatively low, a further distinction of total risk points was not done, but could be performed if required. Table 3 shows the assignment of pipe segments to priorities.

Most of the pipes were assigned to priority P_{zero}. The percentage of pipes with high priority is around 5% (about 60km). Rehabilitation activities in the next years will focus on this group.

Following the selected rehabilitation strategy of 10km per year during the next ten years, all pipes with high priority can be rehabilitated as well as about 10% of pipes with medium priority. The rehabilitation rate of 0.75% per year does not fully meet the requirements of the needs forecast with KANEW, but this level of replacement is still justifiable due to the network age and current good condition. A higher rehabilitation rate is currently not economically feasible. The current rehabilitation strategy is chosen for the next ten years and should be revised after five years.

The workflow for the development of the described rehabilitation strategy can be summarized as follows.

A network inventry is created, and past rehibilitation work analysed and evaluated. A condition anaysis is undertaken based on pipe characteristics and break occurrences, and service life determined for pipe groups. A forecast of future rehabilitation needs and simulation of rehabilitation scenarios based on the ageing model of Prof. Herz with KANEW software is done and additional operational and economic constraints considered. A future rehabilitation strategy is determined and a selection of rehabilitation priorities (rehabilitation plan) made based on breaks and risk / impact. Lastly, the priority list is finalised by considering coordination possibilities with other network operators and / or municipality road works. ●

Priority	Description	No. of pipe segments	Length (km)	Pipe group*
P_{high}	High break rate, minimum age >25 years, 1-3 risk points	1113, out of which: 1 RP: 1058 2 RP: 55 3 RP: 0	57	62% PVC1, 31% AC, 7%PVC2
P_{medium}	High break rate, minimum age >25 years, no risk points	7416	379	84% PVC1, 4% AC, 12% PVC2
P_{low}	No high break rates, 1-3 risk points	1799, out of which: 1 RP: 1,676 2 RP: 113 3 RP: 10	124	6% PVC1, 22% AC, 26% PVC2, 24% CI, 21% PE
P_{zero}	No high break rates, No risk points	14,535	781	15% PVC1, 20% AC, 22% PVC2, 42% PE
Total		24,863	1341	

* missing proportions to 100% is assigned to other pipe groups

Table 3
Assignment of pipes to priorities

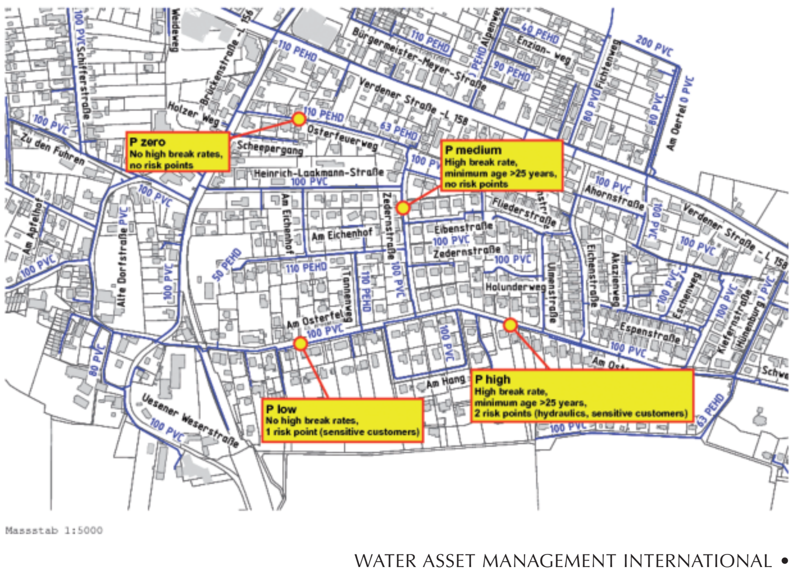


Figure 5
Mapping of priorities in the network

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Hydraulic criticality in a water network rehabilitation plan

Aging infrastructure is requiring US utilities to undertake asset management programmes to achieve efficient investment and minimize disruption to supplies. In this paper, Annie Vanrenterghem, Erik Bernard and Peter Galant describe a method for evaluating the impact of water main failure on service delivery when prioritizing pipes for rehabilitation in a water network. The method considers the direct impact of the broken main as well as impacts of a shutdown for the main repair on the rest of the network.

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Drinking water and wastewater treatment plants, sewer lines, drinking water distribution lines, and storage facilities ensure the protection of public health and the environment. In the US, much of this infrastructure was built after WWII and mostly after the enactment of the Clean Water Act in 1977. Like in all industrialized countries, the nation's infrastructure is aging and is in need of rehabilitation (repair, upgrade or replacement). Planning the necessary tasks in a cost efficient way that maximizes resources and minimizes disruption has become a necessity which many US utilities are attempting to tackle in pro-active and sophisticated ways through advanced asset management (AM) programmes. The US Environmental Protection Agency (EPA) has embraced the adoption of AM as one pillar of infrastructure sustainability (US EPA, 2008). In its 2004 report the US Government Accountability Office (GAO) also recommended that water utilities adopt AM approaches in view of better identifying their needs and planning for future investments (US GAO, 2004).

Aquarion owns and operates 23 public water supply systems, which includes a total of 36 communities in Connecticut. The company serves approximately 580,000 people and maintains approximately 2850 miles (4560km) of water main. Aquarion has always been interested in capital efficiency, now identified by the company as one of several critical success factors. In recent years, as competition for capital dollars has increased, it has become more important for Aquarion to properly identify and prioritize system risks to ensure that the right projects are being done at the right time for the least cost possible. Aquarion has used 'top-down' models such as KANEW to identify the appropriate level of investment in main rehabilitation but needed a 'bottom-up' tool to help identify and select specific mains for rehabilitation. Historically Aquarion has used a simplistic approach for identifying specific mains for rehabilitation that considers eight criteria (main breaks, pipe age / useful life, material integrity, critical system impact, water quality issues, hydraulic capacity, scheduled work coordination and other considerations). However, in order to support the increased investment indicated by KANEW, Aquarion needed to develop a more robust and objective tool for prioritizing specific mains for rehabilitation.

The rehabilitation (i.e., renewal or replacement) of a water network can be undertaken to mitigate various problems (e.g., structural degradation, water quality deterioration and loss of hydraulic capacity). When planning the rehabilitation of a water network, the utility manager must take into account the criteria that best express the problems the network is facing. Points of view and criteria included in the pipe prioritization tool developed for Aquarion are shown in Table 1. They are inspired from the Annual Replacement Planning (ARP) Tool developed by Le Gauffre (2008).

In prioritizing mains for rehabilitation, an index is calculated for each pipe in the network, based on the above criteria. An overall prioritization rank is then determined for each pipe using a Multi Criteria Decision Making Model (Le Gauffre, 2008). Mains can also be selected for replacement based on economic considerations, such as taking advantage of the savings achieved through coordination with other on-going street projects. In addition, Aquarion is working with InfraPlan, LLC to develop a repair-replace tool to identify mains for which replacement is cost justified based on projected main repair costs.

In the rest of this paper, we will focus on the consequences of a pipe break in terms of service interruption in the rest of the system. This is expressed through two of the above points of view: hydraulic criticality and water interruption.

Impact of failure

In the above framework, the water interruption point of view includes three criteria (predicted water interruption (PWI), predicted critical water interruption (PCWI) and predicted frequency water interruption (PFWI)) that measure the impact of a main

Table 1
Points of view and criteria for short term rehab planning

Point of view	Criterion
Water interruptions (in case a pipe breaks)	Predicted water interruptions (PWI) Predicted critical water interruptions (PCWI) Predicted frequency of water interruptions (PFWI)
Hydraulic criticality	Hydraulic criticality index (HCI)
Coordination of rehab tasks with other infrastructures (mostly gas, sewer and road paving)	Co-ordination score
Repair costs (after a pipe break)	Annual repair cost
Water loss	Water losses index Leakage vulnerability index
Damages and disruptions (in case a pipe breaks)	Damages due to flooding in housing areas Damages due to flooding in industrial or commercial areas Damages due to soil movement Traffic disruption Damages and / or disruption on other infrastructure
Water quality	Water quality deficiencies

failure on customer service. Mains that pose a higher risk (probability and consequence of failure) to customer service are given higher priority for rehabilitation. Impacted customers can be served directly by the pipe that broke or by any of the pipes that are affected by the break or the shut down to repair the break. Definitions of the criteria for the water interruption point of view are given below:

Predicted water interruption:

PWI(i) = PBR(i) x EDI(i) x NPS(i)
PWI expresses the consequences of service interruption in terms of the predicted break rate (PBR), the expected duration of the interruption (EDI), and the number of people served (NPS)

Predicted critical water interruption:

PCWI(i) = PBR(i) x EDI(i) x SC(i)
PCWI expresses the consequences of service interruption in terms of the PBR, EDI and sensitivity of the customers (SC) impacted.

Predicted frequency water interruption:

PFWI(i) = L (i)/100 x PBR(i) x EDI(i)
PWFI expresses the consequences of service interruption in terms of the length of main (L), the PBR and the EDI.

Each criterion is calculated for each pipe. Each utility must translate the meaning of a criterion based on preferences and the availability of data. Another paper presented at LESAM by Vanrenterghem et al (2009) concentrates on various ways criteria and variables can be defined, and the source of data that can be used.

A PBR was determined for each pipe in the system utilizing a customized and calibrated failure prediction tool. The EDI was determined as a function of water main diameter based on Aquarion's past experience. The pipe segments and length of main are defined in GIS. In order to calculate the water interruption criteria, it was necessary to determine the number of total customers (NPS) and the criticality of sensitive customers (SC) impacted by a potential break in each water main.

When considering the NPS and SC variables of a certain pipe, it is necessary to consider not only the impact of removing that pipe from service as the result of a break, but also the impact of removing all of the pipes within the area shut down to repair the pipe. This is illustrated in Figure 1. A break in the main shown in red will result in a loss

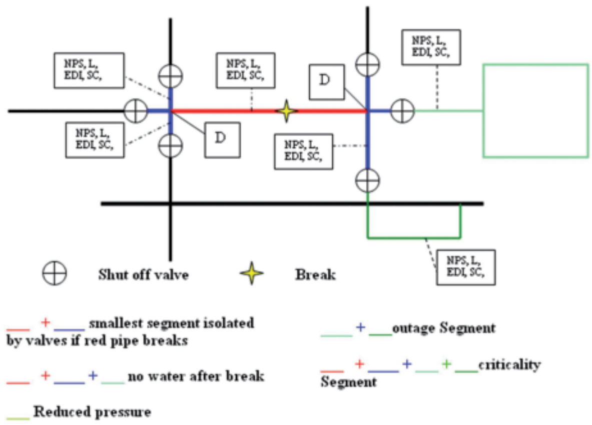

Figure 1
Pipe break effect on a hydraulic network

of service to all of the customers between the isolation valves (shown in red and blue on Figure 1). Repairing a main break can also lead to loss of service in pipes outside of the immediate shutdown area if they become isolated from the rest of the distribution system by the repair shutdown (shown in light green on Figure 1). In addition, some areas of the distribution system that are not completely isolated by the repair shutdown may experience unacceptably low pressure due to reduced hydraulic connectivity to the system (shown in dark green on Figure 1). The total consequence of a pipe break must therefore consider all customers connected to the red + blue + dark green + light green pipes on Figure 1.

The water interruption and hydraulic criticality criteria used to assess the impact of water main failure will be different for each utility depending on the format and quality of data and the tools available for analysis. Potential tools for assessing main break impact include GIS, hydraulic models, maintenance management systems, and hydraulic criticality models. In Aquarion's case, water main attributes, connectivity and customer location are stored in GIS. Customer information including consumption and historical main break data are stored in an enterprise business software package (SAP) and the hydraulic model utilized is WaterGems. The main prioritization criteria therefore needed to be customized to the capability of these systems.

The WaterGems hydraulic model has a criticality tool that can delineate the pipes included in each shutdown segment (red and blue in Figure 1) and associated outage segment (light green in Figure 1). A break on any pipe in the shutdown segment would affect all customers in the shutdown segment and the outage segment. Aquarion's GIS is linked to its customer information system and provides a link between individual customers and each pipe. The consumption and customer type information in GIS can therefore be used to identify the NPS and SC related to each pipe.

WaterGems will also quantify the demand lost when each shutdown segment is removed from service. For this project, demand lost was defined as the average day demand of customers that would receive less than 25 psi pressure. While this demand reduction is quantified in the model, the specific pipes that receive inadequate pressure are not identified. NPS and NSC indices therefore cannot be calculated to measure the impact of a main break on these customers. In the above framework, the Hydraulic Criticality Index (HCI) was developed as an alternate criterion to consider the impact of main breaks on customers who continue to receive service, but at inadequate pressure, during a shutdown. HCI is based on the demand lost for these customers, normalized to Aquarion's total average daily demand.

Using the above methods the failure forecasting tool, GIS and the hydraulic model can be used to calculate water interruption and hydraulic criticality values for each pipe in the network. Similar exercises were completed to develop indices for the other main rehabilitation criteria listed in Table 1. A multi-criteria decision making model was used to develop an overall rehabilitation priority score for each pipe. This method ensures that Aquarion is investing its available dollars in rehabilitating the highest risk water mains in their system. ●

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Advances in risk-based asset renewal forecasting

By developing a proactive, rather than a reactive, approach to asset management and investment, utilities can produce long-term plans for spending that saves money and allows the utility to provide a more efficient service. Simon Heart and Dilip Kumar discuss the development of a proactive approach to risk-based asset management, and its application in the US cities of Atlanta and Denver.

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Advances in risk-based asset investment planning are helping cities, utilities and other infrastructure-rich organizations develop a more proactive approach towards asset renewal that can save money, provide better customer service, develop sustainable renewal strategies and produce justifiable long-term budgets.

Typical challenges to a proactive approach include a lack of reliable local data on the life expectancy of assets and an inability to effectively coordinate plans across multiple departments. However, two recent projects in the cities of Denver and Atlanta, USA, demonstrate how organizations can overcome these obstacles.

Developing a proactive approach

The historical approach adopted by cities, utilities and other organizations to identify assets for inspection, repair or replacement has been reactive in nature, prioritizing renewals on a first-come, first-served basis as problems arise. This is particularly true for buried infrastructure and large asset networks such as pipelines and overhead and buried cables, which provide particular challenges in forecasting failure. This approach makes year-to-year budgets difficult to determine or justify and usually results in additional expense because reactive measures are typically more expensive than proactive ones.

Pipe Segments						
		Condition Score (Probability of Failure)				
		1 Very Good	2 Good	3 Fair	4 Poor	5 Very Poor
Consequence of Failure	C = 1 Low Impact	60	6	32	176	2
	B = 2 Medium Impact	99	12	34	371	2
	A = 3 High Impact	113	21	68	189	0

Figure 1
Area risk matrix

In contrast, structured risk-based planning determines budgets based on current versus target risk levels, allowing organizations to save money over the long-term while developing quantifiable capital planning that can be adjusted based on current budget constraint scenarios. Other benefits include improved customer service resulting from fewer interruptions and more coordinated long-term planning across different departments.

Figure 2
Risk-based planning. Different strategies are adopted based on the likelihood and consequence of infrastructure failure map

Getting started with risk-based planning

The following approach to developing initial asset risk scores and a risk-based financial forecast makes it easy to get started with risk-based planning:

Step 1: Data assessment and 'gap filling': compiling and reviewing existing asset data reveals gaps such as age, material, depth or asset condition. Various techniques, including GIS routines and collaborative staff workshops, help fill gaps for initial risk scoring effort.
Step 2: Initial risk score development: estimated scores for probability of failure and consequence of failure are used to develop initial risk scores. These scores can be refined over time as additional data are collected in the future.
Step 3: Risk-based inspection and renewal forecasting: asset inspection and renewal priorities (determined based on risk scores and organizational preferences), combined with unit inspection, repair or replacement costs, enable risk-based forecasts of future costs to be developed over a 50- or 100-year period.
Step 4: Scenario analysis and refinement: using modelling tools to analyze the cost and risk impacts of various investment scenarios. Common scenarios evaluated include a no-action scenario, a budget-constrained scenario and a risk-constrained scenario. Inspection programmes and asset renewal budgets can be refined through these scenario analyses in an effort to balance system risks.

Three key benefits to this approach include:

- A bottom-up approach based on local data, providing more accurate predictions of the likelihood and consequence of critical infrastructure failure
- A transparent process that provides clear justification for identifying, prioritizing and / or deferring asset renewals
- Easy modification and re-prioritization of forecasts, using tools that implement various risk and budget scenarios

Organizations develop risk scores for individual assets based on the probability and consequence of failure and plan accordingly over the long-term based on target risk levels. This facilitates planning of routine maintenance activities and scheduled upgrades and minimizes reactive repairs on critical infrastructure. A blended approach often provides maximum cost effectiveness – using a proactive approach for critical infrastructure while continuing a 'run of failure' approach for lower-risk assets. When multiple departments collaborate in the renewal planning process, more efficiencies and benefits are realized.

Organizations sometimes hesitate to embrace risk-based planning because of concerns over data gaps. As a pilot programme in Atlanta shows, cities can achieve good results by using the data available at hand and expanding on it as time progresses.

The Atlanta project

The city of Atlanta partnered with management, engineering and construction company MWH to develop a risk-based asset renewal forecast for more than 1000 wastewater pipe segments spanning 54 miles (86km) in the southwest region of the city. The region was selected because of the variable conditions in soil, pipe type and depth, and other factors that allow for extrapolation to other areas of the city, and because closed-circuit television condition data was available for 100 percent of the pipe segments.

An area risk matrix (see Figures 1

	Estimate	Std.Error	t value	Pr(>ItI)	
(Intercept)	0.089	0.099	0.905	0.36574	
log(Age)	0.328	0.011	29.186	<2e-16	***
MaterialCO	0.224	0.055	4.046	5.49E-05	***
MaterialDI	0.141	0.079	1.792	0.07334	
MaterialPE	-0.019	0.104	-0.184	0.85423	
MaterialPVC	0.164	0.073	2.237	0.02543	*
MaterialRCP	0.218	0.085	2.561	0.01053	*
MaterialRPM	0.010	0.109	0.093	0.92608	
MaterialVC	0.237	0.057	4.151	3.51E-05	***
log(Dia)	-0.262	0.017	-15.248	<2e-16	***
Depth	0.007	0.002	2.810	0.00502	**
log(Length)	0.034	0.012	2.697	0.00709	**

and 2) was generated, grading each pipe segment based on its probability of failure (current condition) and consequence resulting from a failure (level of impact).

A statistical regression analysis produced a local pipeline deterioration curve predicting pipeline condition for a 100-year period (see Figure 3). The analysis incorporated physical data describing the system infrastructure, such as age, depth, material and size of pipes, as well as analysis data describing conditions around the infrastructure, including inspections of pipes, soil type and traffic and weather patterns. The deterioration curve and asset risk scores were then incorporated into a decision support tool to forecast long-term pipeline renewal costs necessary for risk management.

This project represents an advancement in risk-based asset renewal forecasting because it was based on a statistical analysis of local data, rather than industry standard expected life curves, to better predict what this utility can expect in the future. This forecast could be used as a basis for planning for the rest of the city, and expanded to include other infrastructure, including storm sewer, water, telecommunications and pavements.

While no project can achieve 'perfect data', reliable results can be achieved by developing initial risk scores based on available data, including input from field and operations staff, and refining scores over time as additional information is gathered. This approach saves time and money by prioritizing future data collection efforts to where they will provide the most value – typically for the most critical assets with high consequences associated with failure.

Another common hurdle to risk-based asset renewal involves the challenge of coordinating among various departments. While risk planning proves effective for single infrastructure types, the highest amount of efficiency is gained by considering multiple asset types – particularly for underground projects that typically require resident disruptions during upgrades.

The Denver pilot study

In Denver, a recent pilot study examined the challenges and benefits of integrating long-term pipeline renewal forecasts with the long-term renewal programme for the overlying streets. The study utilized a GIS-linked decision support tool to integrate renewal needs and laid the groundwork for development of an optimized capital improvement programme for the street and pipeline departments.

Programme managers first collected data on sewer pipeline condition, generating risk scores for each section of pipe over an area of 150 miles (240km) in a northwest region of the city (see Figure 4).

An optimized plan for pipeline renewal was then generated, based on target risk scores, with the goal of reducing high-risk pipes to an average 2 percent of the total infrastructure by 2018 and maintaining that risk level through 2055. A similar project for road improvements resulted in an optimal timeline for upgrades. Plans were overlapped to identify maximum efficiencies – some projects were moved ahead of schedule to overlap with other planned upgrades, and some were delayed based on risk tolerance and budget constraints (see Figure 5). The result was a more strategic and quantifiable plan that saves money over time and reduces interruption to customers. Wider application of this 'cross-asset optimization' approach could yield substantial cost savings for the industry.

Conclusion

Advancements in risk-based asset forecasting are enabling cities, utilities and other infrastructure-rich organizations to overcome traditional hurdles to a proactive approach to asset renewal planning. As fewer obstacles are perceived, this approach will become the common currency of planners, creating more efficiencies, cost savings and improved customer service across many agencies, as well as better cross-department cooperation. As these approaches evolve, planners will have access to same level of data about buried infrastructure that they have for growth and capacity planning. Two keys for success include organizations' ability to produce reliable, local data and to integrate plans across departments. ●

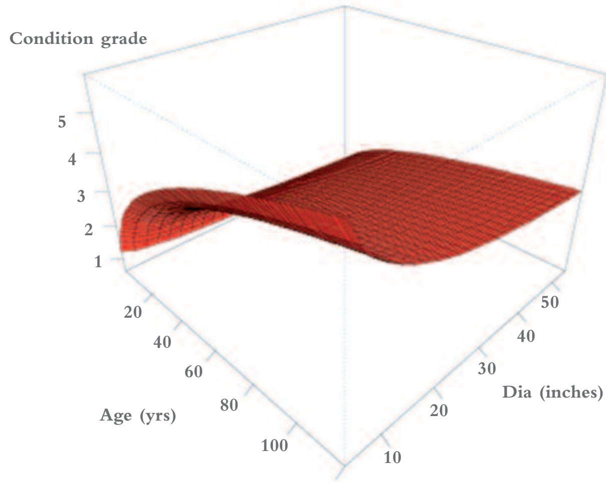
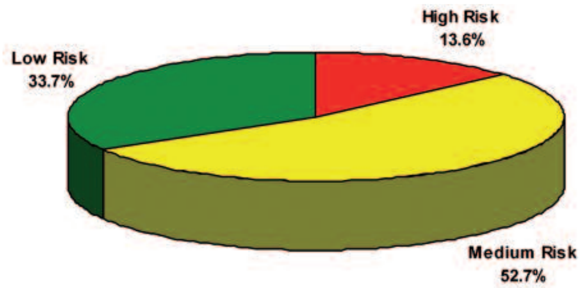


Figure 3 Statistical regression analysis – pipe deterioration



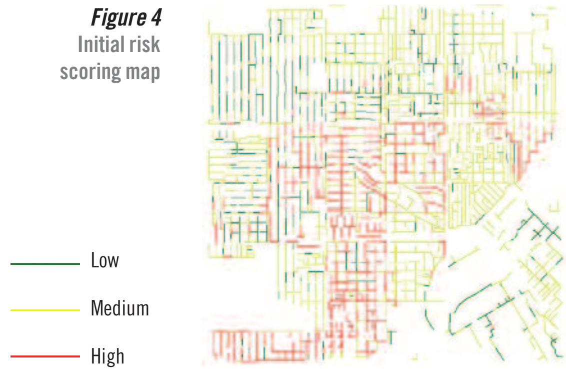
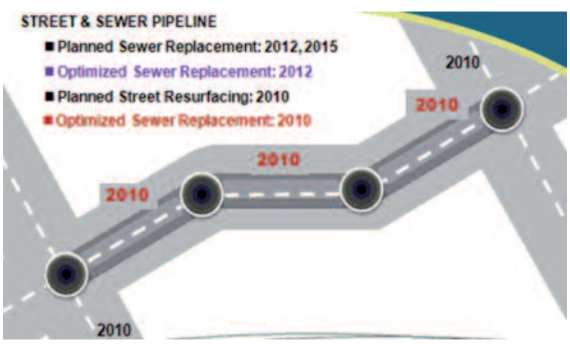


Figure 4 Initial risk scoring map

Figure 5 Integrated planning – streets and pipelines



Leading asset management practices help utilities optimize their asset life cycle cost

The Water Environment Research Foundation (WERF), Water Research Foundation (WaterRF), and Global Water Research Coalition have collaborated in an ongoing research programme to define strategic asset management (SAM) practices and develop tools and techniques that help utilities implement asset management programmes. In this paper, Linda Blankenship, Terry Brueck, Frank Godin and Walter Graf look at the progress of this research.

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The Water Environment Research Foundation (WERF) has been planning and conducting research related to asset management since late the 1990s. This research has been designed to provide guidance and tools for utility managers to address decisions on operating, maintaining and investing in their infrastructure, based on service and risk levels.

In early 2002, WERF convened a workshop with an international group of experienced utility managers to develop its research priorities for strategic asset management (Wagner et al, 2002). Several key efforts recommended in that workshop have since been completed, including a comprehensive set of strategies and protocols on condition assessment for water and wastewater utility assets (Marlow et al, 2007) and the development of WERF's Sustainable Infrastructure Management Program Learning Environment (SIMPLE), a web-based knowledge base for asset management, which is now also supported by the Water Research Foundation (WaterRF).

In 2006, WERF decided to focus on a more comprehensive research approach to address the needs of utilities for providing comprehensive guidance and tools to implement strategic asset management. WERF and research partners WaterRF, UK Water Industry Research and the Global Water Research Coalition, further defined the goals of the research to define strategic asset management (SAM) practices and develop associated tools and techniques for implementation. Specifically, in its request for pre-proposals, WERF indicated that it wanted the research programme to:

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

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

Overview of the research programme

The research programme began in July 2007 with completion of Task Orders 1 and 2 in June 2009. Task Order 3 work took place from July 2009 to July 2010. Additional research is being undertaken from 2010 to 2011. The first three task orders of the research programme comprise more than $2 million in research funds between WERF and its global funding partners.

As previously noted, there are four concurrent tracks of research. Track 1 addresses public communication tools that utilities can use to engage decision-makers and ratepayers in supporting the need for SAM and investment in infrastructure. Track 2 addresses best appropriate or leading practices for asset management among utilities, as well as development of case studies so that utilities can learn how to implement SAM. Track 3 addresses the development of tools for decision analysis and implementation of asset management practices. Track 4 addresses the state-of-the-science on techniques and models for predicting remaining asset life for both above- and below-ground wastewater assets.

Some key deliverables published include:

- A report (Blankenship et al, 2009) on the perception of elected and appointed decision-makers on issues related to public support for SAM and infrastructure sustainability. It

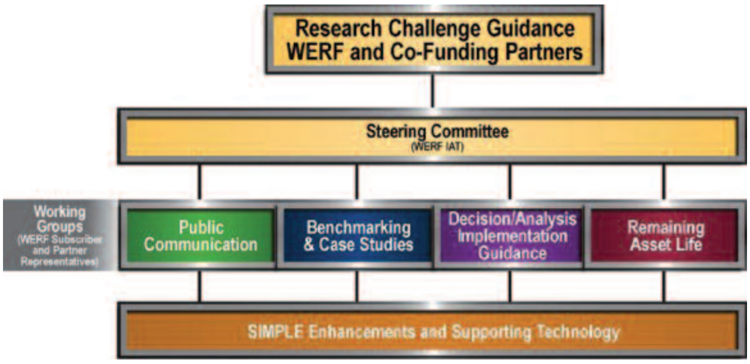

Figure 1
Overview of WERF SAM Research Programme

includes key communication messages, a compendium of available public outreach materials, a strategic communication checklist and case studies of utilities with successful outreach programmes. This report was followed by a report on the experience using Citizen Advisory Committees (Blankenship et al, 2010) to gain support for infrastructure sustainability, and provides insight in how to establish and work with such committees.

- A report (Rose, 2010) that provides guidance to asset managers on critical success factors for developing an asset management programme and alternative pathways to implementation, data and information requirements for decision-making, and readily-available decision support tools. Recommendations are provided for development of other tools for future phases of the research.
- A report (Marlow et al, 2009) identifying the state-of-the-science for predicting remaining asset life for both above- and below-ground wastewater assets. This report documents the worldwide experience using key approaches to estimating remaining asset life.
- Case studies of utility implementation of elements of SAM. To look at options for current asset state, the approach being used by the city of Atlanta, Georgia, USA, to assess and prioritize combined and sanitary sewer system improvements was described. To identify the best operations and maintenance (O&M) strategies, the Massachusetts Water Resources Authority's use of reliability-centred maintenance to lower maintenance costs at the Deer Island Treatment Plant was examined. To understand which assets are critical to sustain performance, Seattle Public Utilities', Washington, business risk processes developed for identifying critical sewer infrastructure were documented. To better understand stakeholder expectations of required level of service, Columbus Water Works', Georgia, independent customer survey programme was described. Lastly, in looking at the best funding strategy, the approach that the city of Hamilton, Ontario, uses to gain support from its elected city representatives was documented.
- A tool called SAM GAP for utilities to self-assess their asset management practices as compared to leading practices based on a set of approximately 160 practice statements.
- A tool for utilities to assess benefits and costs of investments as a means of optimizing asset life cycle by comparing operations and maintenance investments with capital investment alternatives. The tool provides a practical application of fundamental benefit-cost concepts.

These last three items are available only online at SIMPLE, WERF and WaterRF's web-based knowledge platform. This knowledge platform contains all of WERF's research products that address strategic asset management. It can be accessed at www.werf.org.

Benchmarking leading practices

In North America, SAM began to be applied in the late 1990s in response to issues of aging infrastructure and associated financial viability. SAM differs from operational and tactical asset management in that it addresses a longer time horizon, encompassing the entire life cycle of the assets, while operational and tactical asset management focus on timeframes of typically one year or less. A key part of the research process has been to benchmark best appropriate or leading practices for SAM.

As an initial step to prepare for the benchmarking process, the research team developed an initial survey to identify the greatest areas of opportunity for improvement for the implementation of strategic asset management. This survey was based on the ten-step process that guides utilities to develop their SAM plan as illustrated in Figure 2.

These ten steps are described briefly as follows:

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

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

54 utility organizations responded to the survey issued by the research team, resulting in initial identification of gaps for improvement as shown in Figure 3.

Clearly, many utilities believe that understanding condition (and associated performance) of their assets is an important focus. Determining business risk and appropriate maintenance levels are also high priorities. Determining residual life, replacement costs and date and appropriate capital improvement are also ranked highly. The research team used these results, in combination with the benchmarking process, to determine the areas of focus for best appropriate or leading practice. The subsequent benchmarking process used in Track 2 is shown in Figure 4.

The utilities that completed the previously-noted initial survey were invited to use a self-assessment tool to compare their asset management practices with leading practices. The self-assessment tool was developed in collaboration with WaterRF. The tool is called SAM GAP and it is available through WERF and WaterRF's web-based knowledge platform SIMPLE. Through approximately 160 practice statement questions, SAM GAP assesses practice levels for seven core organizational 'quality elements' of SAM: processes and practices; information systems; data and knowledge; service delivery; organizational issues; people issues; and asset management plans. These 160 practice statements address the practices required to complete the ten-step process as shown previously in Figure 2, which leads to an asset management plan and programme.

36 utility organizations completed a SAM GAP-based self-assessment of their asset management practices. In order to maximize the learning opportunities in the benchmarking process, the research team looked to identify asset management practice areas where some utilities had practices in which they scored significantly better than the majority of other utilities.

Utilities with leading practices were found by identifying practice areas where some utilities had relatively high scores (generally above 0.85 to 0.90 depending on the area) in combination with many utilities that had lower scores (generally 0.70 and below) to be able to identify practice areas where the opportunity for significant numbers of utilities to learn and significantly advance their practices existed. These results were verified with the utilities by phone interview. Further refinements were made based on applicability to the majority of North American-based utilities, as well as having a manageable number of practice areas to document.

With the self-assessments completed and the results analyzed, six key areas of opportunity were identified, together with the corresponding leading utilities, as follows:

- Accounting and costing – this practice area includes asset valuation, tracking and reporting, residual life, and future renewal liabilities.
  Corresponding leading utilities: Orange County Sanitation District (California, USA)
- Strategic (asset) planning and asset management plans – this practice area includes predicting likely failure modes, life cycle cost, and optimized decision making (repair, rehab, replace), and state-of-the-asset portfolio reporting.
  Corresponding leading utilities: Orange County Sanitation District, EPCOR (Edmonton, Canada), United Utilities (UK) and Sydney Water (Australia)
- Business risk management – this practice area includes business risk exposure, probability and consequence of failure and risk analysis and reduction.
  Corresponding leading utilities: DuPage Water Commission (Illinois, USA), Orange County Sanitation District, EPCOR, Seattle Public Utilities (Washington, USA), United Utilities and Sydney Water
- Maintenance – this practice area includes maintenance policies, use of reliability centred maintenance and maintenance planning, scheduling and control.
  Corresponding leading utilities: Orange County Sanitation District and Sydney Water
- Secondary data and knowledge – this practice area includes asset condition and performance data
  Corresponding leading utilities: EPCOR
- Organization and people – this practice area includes organizational issues (roles and responsibility for asset management) and people issues (culture, managing change, etc.)
  Corresponding leading utilities: Orange County Sanitation District, Seattle Public Utilities and United Utilities
  (Note that strategic asset planning and asset management plans, as well as organization and people, are separate practice areas in SAM GAP. However, given that the areas are interrelated, it was decided to combine these practices areas).

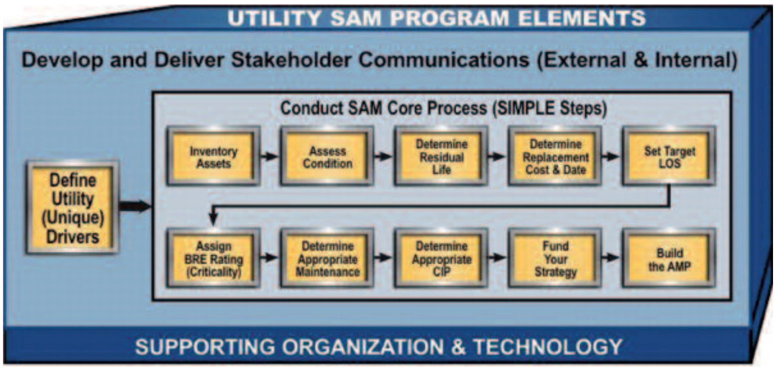

Figure 2
Ten-step process for SAM plan development

The areas identified above include most of the highest ranked priorities confirmed in the initial survey (including asset condition, maintenance, and business risk exposure). All of the leading practice utilities noted above have had business-focused, results-driven asset management programmes in place for five years or more.

Leading practice identification

The research team conducted detailed site visits to analyze and document the leading utility practices. Results from this analysis are presented as follows:

Accounting and costing

This practice area includes asset valuation, tracking and reporting, residual life, and future renewal liabilities. Leading utilities use multiple valuation methods depending on the purpose and intended audience for the information.

For example, they will use replacement cost instead of historical cost-to-value assets for planning. In addition, they will use alternate methods to depreciate assets based on actual evaluation of performance to identify renewal needs. For example, one utility conducts condition-based assessment of all asset classes on a five-year rolling basis, with the use of a modern engineering equivalent replacement approach (basically using current engineering approaches to the design of replacement assets) to determine future renewal.

Leading practice utilities use business case analysis to make decisions on capital improvements, as well as O&M budget improvements. This analysis incorporates all relevant cost categories, including capital, labour for O&M, materials, contract and rental services. It may include consideration of non-financial benefits and costs such as environmental and social benefits, for so-called triple bottom line analysis. It may also include risk-weighted costs, in which cost of the consequence of occurrence are weighted by the probability. These types of analyses are generally undertaken for larger investment decisions due to the resources required to conduct the analysis. These approaches help utilities to optimize the asset life cycle cost.

Business risk management

This practice area includes business risk exposure, and risk analysis and reduction, with risk defined as 'the product of the probability and consequence of failure'. Leading practice utilities assess risk on a periodic and regular (e.g. annual / biannual) basis and look broadly at all types of risks. Multiple levels of risk are defined and reviewed including strategic (longer-term) and operational (shorter-term) risks.

For example, one leading practice utility uses nine risk categories as follows: environmental (defined as non-anthropogenic water quality

Figure 3
Results from survey of 54 utilities to the question: 'What steps will most improve asset management for your utility?'

impacts), regulatory impacts including air quality and noise issues, financial (affecting their bond rating or rate impact), legal (lawsuits and claims), public health (human-caused water quality impacts), public trust, safety, security (including thefts and vandalism) and workforce (grievances, equality complaints, workplace violence prevention and succession planning).

Leading practice utilities identify areas of unacceptable risk for further evaluation and mitigation. Analysis followed by corrective action for critical infrastructure is undertaken to mitigate risk – for example, development of contingency plans for all high risk issues.

Periodically, they will conduct incidence reviews with their governance. A corporate risk policy is in place, which is used to implement risk management on an organization-wide basis. They use a standard risk assessment methodology with a business risk exposure score for assets. For assets that score above a threshold risk level, they will take appropriate action such as a capital project for the asset. This approach allows risk to be reduced while optimizing asset life cycle cost and meeting target service levels.

In analyzing business cases, leading practice utilities will conduct an analysis of all relevant risk factors in a business case analysis. They will define risk profiles based on probability (likelihood) and consequence of occurrence. The probability factor may be adjusted based on timing of projects to mitigate risk or result in projects that are given more consideration in the near term. In addition, leading practice utilities analyze the probability of failure considering multiple factors and modes of failure. For example, the use of deterioration curves based on multiple factors improves confidence in probability of failure predictions.

Leading practice utilities assess performance using post-implementation audits to understand the results that were achieved, identify lessons learned, and ensure actions are taken to adjust levels of risk to the desired level.

Organization and people

This practice area includes vision, roles, and responsibility for SAM in the organization, development of a supporting culture, continuous improvement to improve business processes, and training and knowledge for the workforce. Leading practice utilities will have a mission as well as a vision and policies that specifically refer to SAM, which demonstrate their commitment to their principles of level of service, risk management, addressing the entire asset life cycle, and so on, as a means to achieve business goals.

A leading practice in this area includes creating a corporate asset manager and steering team, with well defined roles and responsibilities. The steering team, comprised of senior management, sets policy and provides guidance to achieve and maintain cross-organization commitment to asset management. The corporate asset manager serves as the day-to-day support to ensure certain key functions are carried out. Identification of asset management functions and responsibilities is made in all organizational units where appropriate.

Leading practice utilities have asset management goals and concepts that are clearly defined and widely communicated in a way that is meaningful to all staff. There is an organization-wide understanding and commitment to asset management. Demonstrated willingness to change processes is evident because continuous analysis and improvement take place. A workforce development programme is in place to support asset management. Specific training has been identified to improve knowledge of asset management principles, concepts and their application specific to the roles of staff. For example, one leading practice utility has provided business case development, reliability centred maintenance and customer service training to ensure understanding and application consistent with its SAM programme.

New staff are educated in the role of asset management in the organization. Knowledge sharing and exchange of personnel to foster asset management principles and practices takes place. In leading practice utilities, there is a mindset of infrastructure sustainability that supports the asset management culture. Asset management is viewed as a positive force that helps the business succeed and improve services for customers and stakeholders. Quality processes exist for asset management, such as management systems, quality processes, audits, routine self-assessment, and formalized benchmarking processes.

Maintenance

This practice area includes maintenance policies, maintenance planning, scheduling and control. Leading practice utilities have a maintenance strategy in place for their key asset classes. They have developed this strategy using a variety of analyses of failure such as fault tree analysis, use of Weibull curves (which is a type of probability distribution that defines time-to-failure based on specified factors for the asset) and reliability centred maintenance to focus maintenance resources and to select the appropriate maintenance tactics. Failures are analyzed to improve the inspection process. Information on the condition of assets is collected during routine preventive maintenance work.

Leading practices utilities have very targeted procedures when responding to a work request. For example, when responding to field system issues, one utility uses a three-tiered review process. First, highly trained customer service representatives identify / screen calls for priority. Then, dispatch performs a validation process by calling back the customer to determine which crew to dispatch. A First Call Responder (FCR), a highly experienced technician is dispatched. These individuals typically resolve 60% of calls on the first visit. If the FCR cannot resolve the call, they provide scopes for the field crew. In addition, the field staff has appropriate mobile solution tools to capture information directly in the field.

Workflow management is supported by maintenance management software interfaced with other systems as required. For example, the maintenance management system is embedded in GIS (geographic information system) to support work management in the field, and integrated with FIS / purchasing to track material cost against work orders. Technology is used to create work bundles to optimize on-site work and minimize travel time.

Planner-schedulers or maintenance specialists focus on improving the planning of maintenance including the coordination between operations and maintenance functions. A certain amount of planned backlog is maintained by trade in order to have projects available for maintenance staff at all times. Planned work is compared to unplanned work to determine how effective the programmes are and make adjustments. Flexibility of the workforce is assured by staffing for a base load of planned maintenance, and contracting out items, such as corrective work as well as high-volume, low-risk items, such as closed-circuit television inspection of pipes, silt removal, leak detection, and extension of lines. Planned maintenance frequencies are analyzed to optimize the work. All these approaches help to ensure that the asset life cycle cost is optimized.

Secondary data and knowledge

This practice area includes asset condition and performance data. Leading utilities focus on defining the data that is truly necessary to make informed decisions. They recognize that data requires resources to collect and maintain and therefore strive to reduce the costs of data collection and management. They assure quality data by periodic reviews for completeness. For example, one leading practice utility assigns data stewards, whose roles are to assure the data quality as part of their job, which typically includes many other related functions.

Leading practice utilities have good data hierarchy of assets reflecting parent-child relationships so that asset data can be rolled up. The data

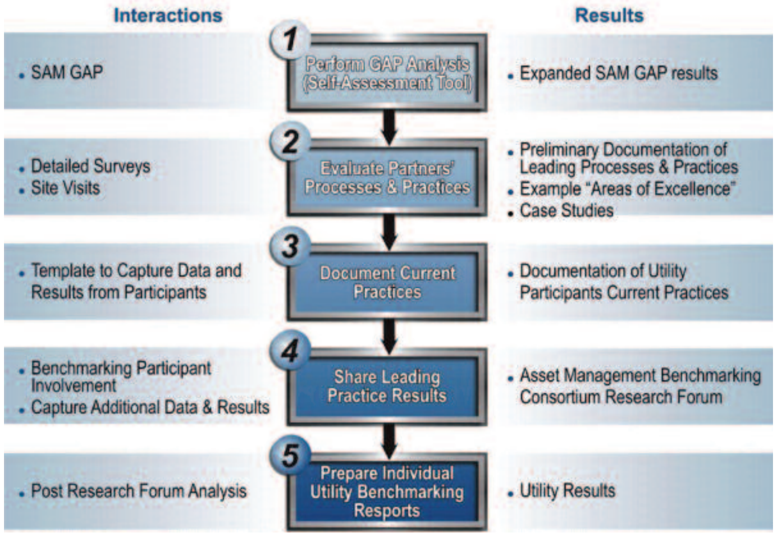

Figure 4 **Benchmarking steps, interactions and results**

collected includes capital, operating and maintenance costs including labour, and contract expenses. SCADA system data is used to determine performance and condition issues. Condition-based assessments are performed based on an analysis of asset risk (likelihood / probability and consequence of failure) as well as cost.

Strategic (asset) planning and asset management plans

This practice area includes predicting likely failure modes, life cycle cost, and optimised decision-making (repair, rehab, replace), and state-of-the-asset portfolio reporting.

Leading practice utilities have identified the resources required to maintain the viability and sustainability of the utility in the long term. They do this by analyzing how to balance service levels, environmental regulations and financial limitations, and the impacts of changes in each area. They have engaged their customers and stakeholders in a variety of ways, such as through willingness to pay and other types of surveys. These evaluations are typically done to look at short, medium and long-term implications, in lesser levels of details for longer time horizons.

They have linked asset management to their business improvement. They have taken a continuous improvement approach to their asset management plans, starting with the most critical need or area, and expanding and refining over time to keep their plans up-to-date.

Leading practice utilities have clearly defined business goals that drive budget planning for both O&M and capital budgets. They track and measure performance against goals on a regular and frequent basis, such as monthly, quarterly and annually. State-of-the-asset reporting and key performance indicators are used.

They use risk-based approaches for overall asset strategy and separate assets into distinct groups. For example, one leading practice utility uses the categories of 'avoid to fail' and 'plan to replace' strategies to distinguish its most critical assets. Leading practice utilities prepare different types of plans for different purposes and audiences. These strategies and plans are clearly linked to and drive operation plans and tactical response for their maintenance strategy. They identify the confidence in decisions that are being made and act to either improve confidence when needed through additional evaluation. Quality processes are in place such as auditing of capital improvement projects decisions to analyze results and identify lessons learned.

Next steps

An Asset Management Benchmarking Consortium Research Forum (ABC Research Forum) was held in the United States during the summer 2010. At the ABC Research Forum, the research team and leading practice utilities presented the leading practice results. In addition, working sessions were held with participating utilities in order to compare, contrast and adapt practices, and identify critical success factors and implementation needs for their selected two practice areas. ●

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Systematic use of operational experience to improve drinking water safety

Organisations can learn from each other's operational experience, including both experiences with success and failures. However, much of the knowledge used to design, build and operate infrastructure has been gained by learning from failures. The problem is that failures often tend to be left hidden and unexplained. Therefore, systems to report and analyse failure experiences have been applied in different industries, from aviation to healthcare. In this paper, Aditya Lukas, Ernest Mayr and Reinhard Perfler describe a method for the systematic collection and use of operational experience to improve drinking water safety.

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Water supply systems are regarded as critical infrastructure, 'which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments' (Commission for the European Communities, 2005). Failure to continuously provide water of an adequate quantity and quality can severely compromise the supplied population, farming and industrial processes. Therefore, risk management approaches are increasingly being applied to drinking water supply. The Water Safety Plan (WSP), for example, is highlighted by the World Health Organization (WHO) as an effective concept to ensure safe drinking water (WHO, 2006). The concept is based largely upon the principles of the Hazard Analysis and Critical Control Point (HACCP) approach, which has been used in the food manufacturing industry to manage and reduce risks to an acceptable level. The WSP incorporates risk assessment and preventive risk management from source to the point of consumption.

The identification and assessment of risks requires an analysis of failure causes and their consequences in water supply systems. This task can be supported by exchange of experiences since failures in different water supply systems often have similar root causes and show similar failure propagation. Currently, the experience drawn from failure events occurring in water supply systems is not shared in a systematic way. Knowledge exchange between water utilities is therefore limited and the potential to prevent future failures by failure analysis and by sharing failure experiences with others yet remains largely unused. The Failure Experience Improvement System (FEIS), which was funded by the Austrian programme for security research, aims to make use of this potential.

Development of the FEIS

Similarly to the adaptation of the HACCP concept, which has been used in other industries for decades before it was applied to water supply, the FEIS combines and tailors two existing concepts to the context of water supply: failure reporting systems and Social Network Analysis (SNA). Voluntary failure reporting systems, which have for the first time been used in the aviation industry to improve air safety, aim at collecting information on failures and thus at providing a basis for failure analysis. Failure reporting systems are therefore an important first step in the process of improving safety. For the development of the FEIS, failure reporting questionnaires have been used at six Austrian water utilities to systematically collect information on failures which have occurred in practice. In addition, a literature review and a survey of guidelines were carried out to collect information on potential failure events.

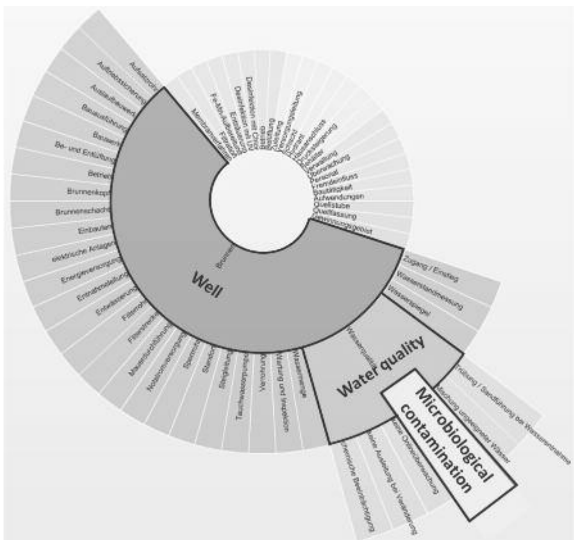
The collected information was used to build the database of the FEIS, which basically consists of failure events and their interconnections in the water supply system. By linking failure causes with their effects, a failure network is created, which describes failure propagation in water supply systems. The relations between failure events are given the properties time lag ('how long does it take until the consequence comes into effect') and impact ('how large is the impact on the following event'). In order to visualise the interconnected cause-effect chains and to analyse failure propagation, the concept of SNA was applied. SNA, which has been developed to investigate relations in social structures, is used by the FEIS to identify causal interrelationships and to localise vulnerable points in the water supply system.

Application and features of the FEIS

The FEIS database is located on a server and its Flash-based user interface is accessed by the water utilities through an internet browser. After login, the user can select a specific failure event to visualise its cause-effect chains. Selection of events is possible through a keyword search or a three-level categorisation (category – system element – failure event). To select the event 'microbiological contamination at the well', for example, one navigates to the category 'well', the system element 'water quality' and the failure event 'microbiological contamination' (see Figure 1).

Figure 2 shows the cause-effect chains upstream of the failure event 'microbiological contamination at the well'. Within the three-step neighbourhood, the FEIS database contains 47 causes of this failure event. In Figure 2, the paths originating from two causing events are labelled. One of the causes is unregulated land use in the

Figure 1 Selection of the failure event 'well – water quality – microbiological contamination' through a three-level categorisation in the FEIS user interface.



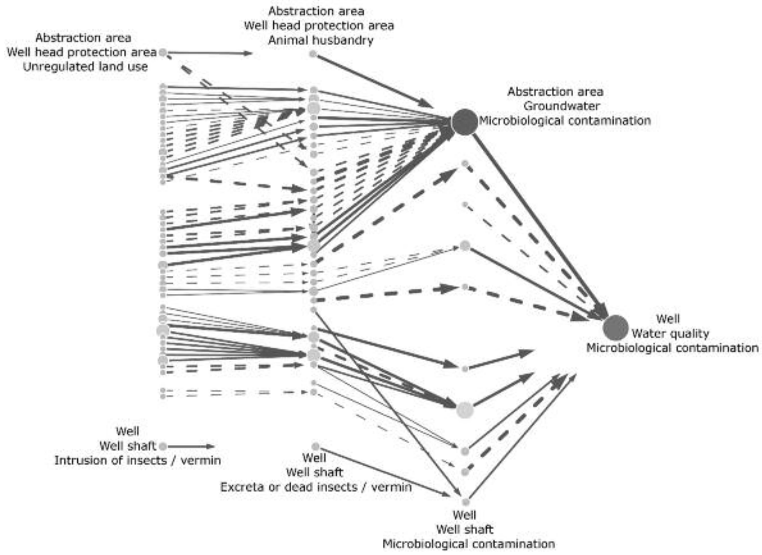


Figure 2
Visualisation of the cause-effect chains upstream of the failure event 'well – water quality – microbiological contamination'.

well head protection area, leading to microbiological contamination by animal husbandry. Another causing event is the intrusion of insects / vermin into the well. In order to identify the root causes of these failure events, the user can further navigate through the failure network. The intrusion of insects / vermin into the well, for example, can in turn be traced back to three root causes as shown in Figure 3. In addition to the visualisation of cause-effect chains of single failure events, the FEIS provides visualisations of whole categories. Figure 4 shows the category 'well'. The event 'microbiological contamination at the well' in the centre of the graph occurs in the end of the failure network of this category. In contrast, failure events in the periphery of the network represent events that occur in the beginning of the water supply process.

As shown by these simple examples, the FEIS visualisations provide a

Figure 3
Visualisation of the cause-effect chains upstream of the failure event 'well – well shaft – intrusion of insects / vermin'.

concise overview of the failure systems in water supply infrastructures and help to understand the causes of failures and to identify possible corrective actions. Moreover, the graphs show information on analytical indicators. The size of the circles in Figure 2 to Figure 4 relates to the indicator system dependence. This indicator is a measure for the dependency of a failure event from upstream events. Thus, failure events with a high system dependence are triggered by a great number of possible upstream failure events. On the other hand, the indicator system influence shows how strongly a failure event influences downstream events. Failure events with a high system influence provoke many consequences (see Figure 5). These indicators, which represent relative values and evaluate events in comparison to each other, can be used in the FEIS to rank failure events in order of importance and to identify high-consequence or high-dependence events. This approach is a qualitative method, which aims at assisting water utilities in analysing risks.

In contrast to quantitative risk assessment methods, which aim at delivering objective numerical values to evaluate risks, the FEIS can therefore be used as a qualitative risk assessment tool. The advantage of this approach over quantitative methods is that it does not require numerical input values such as probabilities of occurrence of failure events and magnitudes of potential loss. Probabilities of occurrence from historical data are often not available and consistent quantification of potential loss, such as loss caused by water supply outage or contamination of water quality, remains difficult. The FEIS supports water utilities to gain better knowledge of potential risks without the need for extensive investigations. The system can easily be customised and is therefore particularly suitable for small water utilities where financial and personnel resources are usually of limited availability.

In order to customise the FEIS visualisation to match individual water supply systems, users can hide single failure events. In addition to the indicators derived from SNA, the frequency of occurrence of failure events from historical data can be entered into the FEIS. A more detailed verbal description of failure events and follow-up actions can be entered into both confidential and public text fields. The contents of confidential text fields are only visible to a single water utility, whereas information in the public text fields is available to all FEIS users. In this way, FEIS supports documentation and knowledge sharing within and between utilities. For the systematic exchange of past failures, the FEIS is intended as an expandable database. By reporting failure events to the developers of the FEIS, these events can be added to the database in order to increase the current number of about 1200 event relationships and to assist other utilities to avoid similar failures in their operation.

Conclusions

Failures in different water supply systems often have similar root causes and show similar failure propagation. The main causes of failure events in water supply systems are human factors, extreme conditions and materials failures. However, most of these causes can be traced back to flaws in management, planning and design.

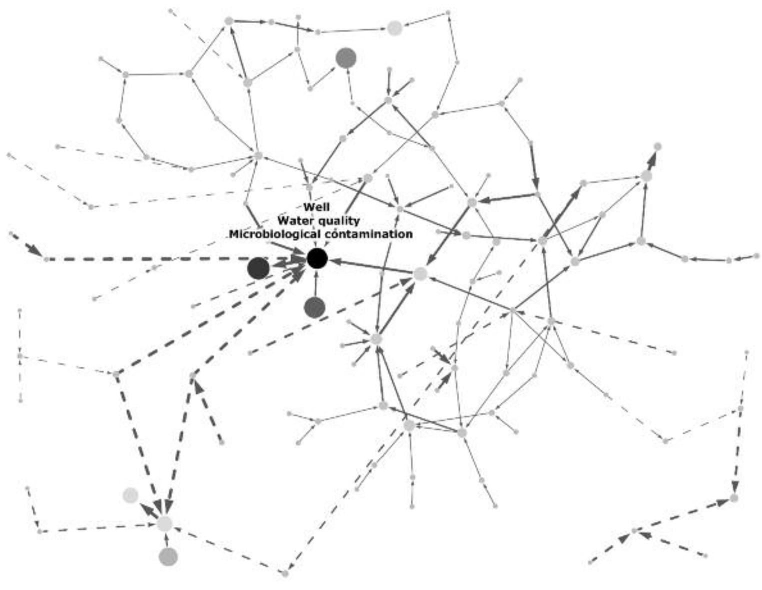


Figure 4
Visualisation of the category 'well'.

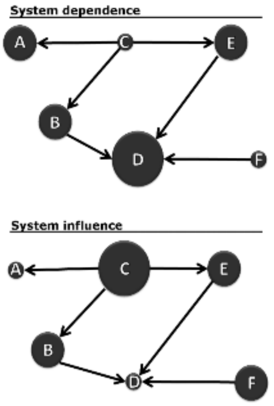


Figure 5
Schematic diagram of the indicators system dependence and system influence: Event D has a high system dependence as it is triggered by a great number of possible upstream failure events. Event C provokes many consequences and thus has a high system influence.

There is a high potential to avoid these failures by exchanging experiences within and between water utilities. The FEIS aims to make use of this potential by systematic documentation of past failure events and analysis of the interrelationships between their causes and consequences using SNA. The user interface is accessed by the user through a browser and provides visualisations of the failure systems in water supply infrastructures, which help to quickly identify causes and effects of failure events and possible corrective actions. Analytical indicators allow a prioritisation of failure events and support the identification of critical events.

This information can be used for planning of corrective actions in the short term, of maintenance and rehabilitation, and of design improvements in the long term. The FEIS can also be used to train staff and develop awareness of the importance of failure management. Using a qualitative approach, the FEIS does not require extensive investigations and numerical inputs for adaptation to an individual water supply system and is therefore well suited for use by small water utilities with limited financial and personnel resources. Currently, the authors are investigating possible links of FEIS with other (quantitative) risk assessment systems in order to achieve additional benefits for the user through synergistic effects. ●

Acknowledgements

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Using an asset management programme to support financial analysis and long-term planning

As part of developing a long-term asset management programme, financial forecasting is needed to balance renewal and replacement of assets with utility growth and regulation compliance. David Sklar and Ivan Velez discuss the example of Lee County Utilities in Florida, USA, and the process it undertook to incorporate financial planning into its asset management strategy.

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Many utilities struggle with accurate long-term financial forecasting of capital needs, including the significant funds required for renewal and replacement (R&R), as critical infrastructure components and systems age. Balancing the financial requirements for R&R projects with requirements for new growth and regulatory compliance is an ongoing challenge for many in our industry. Financial issues are moving to the forefront at a time when utilities are facing funding constraints and increasing pressure from the public and stakeholders to reduce costs and hold rates steady. The ability to borrow money is also becoming more difficult, with credit rating agencies taking a closer look at long-term system reinvestment policies and financial sustainability.

To address these challenges as part of an overall asset management philosophy, Lee County Utilities (LCU), Florida, USA, realized the need to integrate capital and financial analysis into their asset management programme to ensure that:

- A comprehensive asset valuation and effective useful life (EUL) methodology is established to support long-term financial planning.
- Financial planning is addressed in parallel with an inventory, condition and criticality assessment strategy and incorporates risk and service levels.
- Comprehensive financial information and data is available to staff to support utility-wide capital and financial planning efforts.
- The approach is rational and defensible and supports communication and discussions with stakeholders and public officials.
- A long-term plan can be established to support stakeholders' desire for a forward-looking and stable rate structure.

LCU provides water, wastewater, and reclaimed water to over 300,000 residents in southwest Florida. The system contains six water treatment plants, eight wastewater treatment plants, 1300 miles (208km) of water mains, 775 combined miles (1240km) of gravity sewers and force mains, and 590 pump stations. Through LCU's comprehensive asset management programme, they wanted to ensure that financial planning issues remained in the forefront, as reflected in their asset management vision and mission statement:

'Lee County Utilities is committed to an asset management programme that provides reliable service, protects the environment, and ensures regulatory compliance. We continue to build upon our long-term asset strategy focusing on financial sustainability, employing business practices to measure and manage risk, optimize life-cycle costs, and prioritize capital and O&M (operation and maintenance) decisions.'

This article discusses how LCU tackled some of their key financial sustainability issues and developed a comprehensive framework and methodology for asset valuation, useful life, and financial forecasting as part of their asset management programme planning. The project started with an initial pilot project covering 5% of their system, and LCU is currently in the process of an ongoing utility-wide implementation.

Information and data supports analysis

LCU realized that comprehensive asset attribute information was needed in order to support the level of financial planning and analysis that they desired. To start this effort, LCU staff were trained in the common principles of accounting and asset management, including: alternative depreciation and valuation methods; cost allocation; and industry standards for effective useful life (EUL). This training highlighted some of the fundamental differences between data requirements for finance / accounting along with asset management so that different parts of the organization could 'speak the same language' and ensure that their efforts were aligned. Some of these common differences are highlighted in Table 1.

By working together to understand their differences, the finance, asset management, O&M and other departments at LCU were able to ensure a uniform approach that met common needs across the organization. This included ensuring financial compliance and accounting standards as well as meeting business needs, educating employees and stakeholders so they understand the differences, and establishing a strategy to meet the long-term goal of reconciling financial asset registries with computerized maintenance management system (CMMS) data.

To understand data needs, LCU had to evaluate existing attribute data, including installation date, historic costs, replacement cost and EUL. Existing information was reviewed for completeness and quality, and detailed standards and methodologies were developed to ensure a consistent approach across departments and assets. All three levels of attribute data were reviewed including physical (manufacturer, model, serial number, etc.), financial (installation year, historic cost, etc.), and asset management (condition, criticality, etc.). Some of these efforts were complicated by the fact that many of LCU's assets were inherited through recent mergers with smaller surrounding utilities, all with different design and construction standards, and had limited historical records or institutional knowledge.

The EUL attributes were one component in developing improved financial forecasts and were handled in a consistent way as shown in Figure 1.

Figure 1
Sample EUL standards

Wastewater Treatment Plant / Lift Station Assets	Average Expected Useful Life (Years)
Mechanical Assets (Influent / Screening)	
Grit Mixer, Grit Collector, Classifier, Removal Equipment, Grinder	15
Screen	25
Mechanical Assets (Treatment)	
Process Equipment (General)	20
Process Piping	40
Anoxic/Anaerobic Mixer, Aerator/Jet Aeration Equipment, Blower, Tertiary Filter, Air Vessel, Skimmer	20
Flocculator	15
Polymer and Chemical Feed Equipment	10
Odor Control Equipment	15
Trickling and Disk Filters	20
Mechanical Assets (Disinfection)	
Chlorination Equipment (General)	10
UV System Components	20
Mechanical Assets (Solids Handling)	
Belt Press, Conveyor, Sludge Hopper	20
Centrifuge	15
Incinerator	25
Sludge Drying Bed	30

This demonstrates a sample of the EUL standards that were developed using a combination of industry research and data from other utilities, which was validated with actual field condition assessment data, customized to LCU's environment and operating conditions. Once standards were developed, they could be applied uniformly by asset class across LCU's system. In a similar fashion, standards were also developed for replacement costs and other important financial attributes.

Financial planning links to asset management

A common goal of asset management is to support improved financial planning and forecasting, which was especially important for LCU. Validation of historic levels of spending on R&R was critical in providing support for determining what realistic annual expenditure levels should be. This would allow LCUs leadership to develop more accurate long-term planning forecasts looking forward over the next five to ten years, and ensure that investments were adequate to meet service level, reliability, and regulatory objectives. There were several key considerations in aligning financial planning with asset management principles, including:

- Ensuring that financial forecasts were enhanced based on observed useful lives rather than financial depreciation schedules to better support R&R planning.
- Determining a reasonable and sustainable level of annual R&R funding to be included in the capital programme.
- Predicting and demonstrating 'spikes' in capital and O&M needs and understanding impacts on service levels and rate requirements.
- Supporting five to ten-year business planning and capital project prioritization.

The enhanced attribute data described earlier was used to drive a comprehensive R&R modelling tool that was applied to a complete pilot area of the system, including water mains, sewers, pumping stations, and treatment plants (see Figure 2). The model has greatly improved LCU's forecasting of current and future R&R needs for both above and below ground assets. The model encompasses financial and asset management principles using customized guidelines built from industry standards for expected useful lives, historic and replacement costs, financial escalation factors, and standard unit costs for linear asset renewal. The model includes a summary dashboard with critical information needed to communicate with internal and external stakeholders including customers and public officials. The underlying asset data that drives the model can be

Table 1
Summary of common asset management and financial needs

Finance / accounting needs

- Straight line or modified depreciation based on reasonable accounting lives 'lump-sum' costs for new or rehabilitated assets are adequate for financial registers / records
- Focus on 'average' annual depreciation and cash flows for financial reporting purposes

Asset management needs

- Emphasis on actual observed useful lives to support R&R planning
- Require additional detail at the asset level for planning purposes and to support CMMS implementation
- Need to predict 'spikes' in capital and O&M needs and understand impacts on service levels and rate requirements

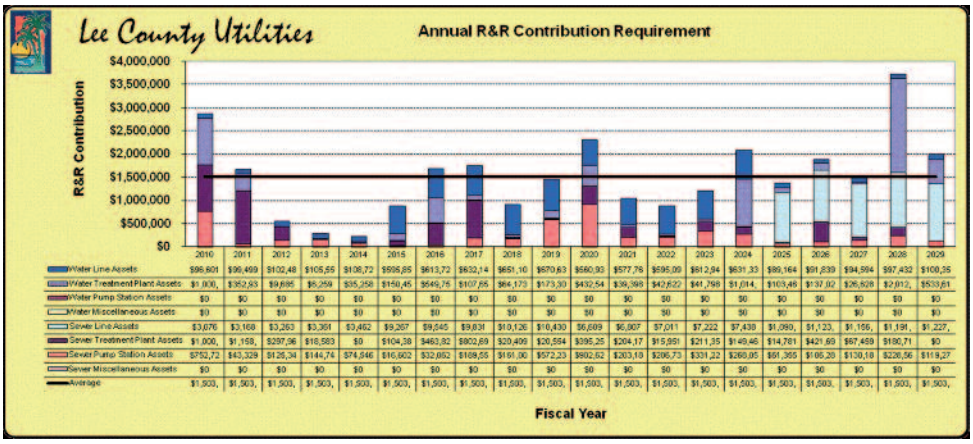

Figure 2
Sample R&R model output

updated periodically, and the results will become even more accurate as the asset management programme moves forward in future phases and data sources and systems continue to improve over time. The information is in the process of being populated into an enhanced CMMS and GIS (Geographic Information System).

Strengthening financial forecasting

One of the final tasks completed was a detailed analysis of the rate and financial impacts for the pilot study area and an extrapolation to the entire utility to ensure that proposed infrastructure investments were in alignment with financial goals and objectives, including customer rates. This included a scenario analysis (see Figure 3), during which LCU's management team evaluated various investment scenarios (i.e. minimum, moderate, and aggressive) and were able to look at the rate impacts in real time. The financial modelling allowed LCU to analyze alternative capital programmes based on risk and priority, determine optimal funding strategies, including revenue, reserves and debt, and assess long-term rate revenue impacts.

Communicating with stakeholders

The R&R modelling described above predicted a reasonable reinvestment rate of 2.3% per year, based on current replacement value of assets. However, this was more than had been funded historically, and would require slightly higher rate increases than had been proposed in the past. The data analyzed from the pilot area was the type of information critically important for LCU to communicate to stakeholders to get approval for additional rate increases, needed to ensure a sustainable long-term financial strategy.

All of this information was critical for LCU's leadership in communicating the benefits and outcomes of asset management before the Board of County Commissioners (BOCC), and build support for the programme. In addition to the pilot financial results, stakeholders needed to understand the process involved in completing ongoing asset inventory, condition, and criticality assessment of water treatment, wastewater treatment, distribution, collection, and pumping stations assets over time. The pilot approach allowed LCU to communicate benefits within the first nine months of the programme and allowed quick wins, staff engagement, and clear demonstration of the effectiveness of the programme in a short time frame.

Future implementation plans

LCU is currently building on the success of the pilot programme, with an incremental approach to implementing asset management over the next three to four years, focusing on several high-priority initiatives. The team has already developed a summary implementation plan to guide this effort, several important elements of which are as follows.

Technology implementation and integration

LCU is in the process of implementing a new enterprise asset management (EAM) / CMMS system, which will provide enhanced data and analysis tools for LCU staff. This system replaces two existing stand alone systems and includes built-in interfaces to improve communications between department staff and provide efficiencies in handling customer service and maintenance requests.

Ongoing asset inventory condition, criticality, and risk assessment

Building on the pilot project, LCU is systematically capturing and analyzing detailed asset attribute data across the entire system and service area to better support capital planning, including the identification of likely rehabilitation, renewal, enhancement, regulatory, and growth projects.

Enhanced capital and financial planning process

Building from enhanced condition data, LCU is developing more accurate long-term financial forecasts that can be updated on annual basis and integrated with annual budgeting, rate, and financial analysis. R&R forecast reports are being configured in the EAM / CMMS system for ease of use. Capital projects will also be prioritized using a triple bottom line (social, financial, and environmental) framework that was developed during the pilot for the FYE 2011 budget.

Development of service levels and performance measures LCU will develop a focused set of service level measures that are aligned with the existing strategic plan. These will be formally tracked through the EAM / CMMS system, and reported to internal and external stakeholders, and will help justify and prioritize capital investments. ●

Figure 3
Rate and financial analysis showing increased R&R based on pilot