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Assessment report warns of reduced aid for water and sanitation projects

The latest Global Annual Assessment of Sanitation and Drinking-Water (GLAAS) report, launched by UN-Water and the World Health Organization (WHO), warns that between 1997 and 2008 aid commitments for sanitation and water fell from 8% of total development aid to 5%, lower than commitments for health, education, transport, energy and agriculture.

The fall occurred despite 'compelling' evidence that achieving the water and sanitation Millennium Development Goal (MDG) would reduce health care costs, improve school attendance and increase productivity.

Dr Maria Neira, WHO director of public health and environment, said: 'Neglecting sanitation and drinking water is a strike against progress. Without it, communities and countries will lose the battle against poverty and ill-health.'

The findings from the report were presented at the first annual High Level Meeting of Sanitation and Water for All, hosted by UNICEF on 23 April in Washington, DC.

At the event, governments, donors, multilateral agencies, and civil society organisations discussed challenges, shared best practices and committed to bringing safe drinking water and adequate sanitation to the unserved.

The participants focused on the GLAAS recommendations for greater political prioritisation of sanitation and drinking water, better resource targeting, strengthening of systems and development of stronger partnerships at all levels.

Clarissa Brocklehurst, UNICEF Chief of Water, Sanitation and Hygiene (WASH), said: 'This high level meeting represents a watershed in our sector. As a global partnership, Sanitation and Water for All will involve the people who make decisions about investments, and who can change the outlook for the sector. We firmly believe giving priority to sanitation and water and tracking our progress together will aid development and give new hope to countries who struggle to reach their poorest citizens, including vulnerable children, with these essential services.' ●

$100 million credit for Kenya service improvements

The World Bank has approved a credit of $100 million to improve service delivery in Kenya's municipalities.

The International Development Association (IDA) credit for the Kenya Municipal Program will focus on strengthening local governance, institutions, and physical infrastructure, with the ultimate objective of improving services delivered to Kenyans in the 15 largest municipalities. It will also improve the viability of the five largest cities and all provincial capitals.

'Kenya's municipalities are critical to economic growth and regional equity but are operating far below their potential, due to infrastructure bottlenecks, weak finances, and poor management,' said Johannes Zutt, the Country Director for Kenya. 'Rapid urbanization has left Kenyan cities with a huge unmet demand for critical infrastructure and basic services, and this has constrained the productivity of businesses and negatively impacted the quality of life of residents.'

The Municipal Program will support Kenya's Vision 2030, the country's development blueprint which identifies urbanization as one of the key development challenges, and will deepen the reforms that the government has undertaken since 1996 to strengthen accountability by local authorities. It will also strengthen the capacity of municipalities to cope with the rising demand for quality services arising from the rapid increase in urban population.

In 1999, Kenya's urban population was about ten million people, representing 35 percent of the country's total population. The five largest cities, including Nairobi and Mombasa, accounted for a third of the urban population. It is estimated that this population will rise to 16.5 million people (45 percent of the population) by 2015 and increase further to 23.6 million people or 54 percent of the population by 2030.

'The urban transition in Kenya will play a critical role in determining the country's growth prospects and social stability,' said Sumila Gulyani, Task Team Leader for the Program. 'The government recognizes that the quality of life in cities cannot improve without strong performance of the level of government that is closest to citizens,' she said.

The Bank funding is part of the $165 million that is being invested in the programme by the government and development agencies. The other partners in the programme are the Swedish International Development Agency (SIDA) and Agence Française de Développement (AFD) – the French international development agency. ●

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EDITORIAL

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Peru to boost coverage, improve water and sanitation services in rural localities

Peru will increase the coverage of drinking water and basic sanitation services for some 380 rural communities and small towns in the regions of Apurímac, Ayacucho, Cusco, Huancavelica, and Puno to improve services to 206,000 people.

The project, which requires a $90 million investment, will receive an unprecedented $72 million grant from the Spanish Cooperation Fund for Water and Sanitation in Latin America and the Caribbean (Spanish Fund). The Inter-American Development Bank (IDB), which provided technical assistance for the project's preparation, will develop it together with the Peruvian government and the Spanish cooperation over a five-year period. The government of Peru will provide an additional $18 million to the project.

The programme will finance mostly infrastructure and other works needed to expand and improve drinking water and sanitation networks in small towns of between 2000 and 15,000 people and rural localities of fewer than 2000 inhabitants.

The project will promote a model that integrates water and sanitation solutions with community development activities and strengthening of service providers in order to ensure that drinking water supply and wastewater disposal treatment services are delivered in an efficient, sustainable fashion. The programme will promote gender equity, a key feature that should help boost the efficiency and sustainability of investments.

The funds will also help strengthen the sector's management capacity in the areas of technical assistance, development of technical standards, sector planning and research.

'This historic Spanish Fund grant is a sign of solidarity from the people of Spain,' IDB's President Luis Alberto Moreno said. 'This is the Fund's fifth grant in less than one year. Once again, the project being financed aims to improve the health and quality of life of hundreds of thousands of people living in some of the hemisphere's poorest communities.' ●

Mott MacDonald wins role establishing Botswana regulatory agency

Mott MacDonald and Merz and McLellan Botswana, which is now part of the Mott MacDonald Group, have been appointed by the Ministry of Minerals, Energy and Water Resources in Botswana as lead consultant on a consortium (which also comprises Cameron McKenna and Collins Newman & Co) that will help establish a new energy and water regulatory agency in Gaborone, Botswana, southern Africa.

The government is reforming and restructuring its energy, water and sanitation sectors and hopes to attract private capital in infrastructure investments, which requires an independent regulatory authority to leverage private sector support.

Mott MacDonald and Merz and McLellan's team will work closely with colleagues on the consortium to develop a regulatory framework and legislation to cover all operational, organisational and governance procedures for the newly established authority. The team will also help the client to recruit new core staff and provide training to help build their knowledge and enhance capacity of the new authority. An important role of the new independent regulatory authority will be to establish cost reflective tariffs in the electricity and water sectors.

The project is due for completion towards late 2010. Mott MacDonald's project director, Dr Guy Doyle said: 'This is an exciting project for Mott MacDonald and our new colleagues from Merz and McLellan Botswana as it will be our first joint project in Botswana since the acquisition in early 2010 and will bring together both companies' engineering expertise and Mott MacDonald's world leading power economists and strategists.' ●

Kansas agrees multi-billion sewer system improvements

Kansas City has agreed to make extensive improvements to its sewer systems, at a cost estimated at over $2.5 billion over 25 years, in order to eliminate unauthorised overflows of untreated raw sewage and to reduce pollution levels in urban stormwater, the Justice Department and US EPA announced recently.

A consent decree requires the city to implement an Overflow Control Plan, which is the result of more than four years of public input. When completed, the sanitary sewer system will have adequate infrastructure to capture and convey combined stormwater and sewage to the city's treatment plants. Under the agreement, Kansas City will pay a civil penalty of $600,000 to the US, in addition to the estimated $2.5 billion it will spend to repair, modify and rebuild its sewer system. ●

CDM wins water and wastewater master plan, design and delivery contract

CDM has been chosen by the US Agency for International Development (USAID) to develop a comprehensive water and wastewater infrastructure master plan and design, and deliver water and wastewater infrastructure improvements in Jordan.

The five-year, multi-site, multi-project investment programme will provide urgently-needed system enhancements and improve water resources management over the next 25 years in Amman, Zarqa, Ma'an, Tafilah, and Jerash.

Working with the Water Authority of Jordan (WAJ) and other key stakeholders, CDM will focus programme efforts on developing water and wastewater master plans and feasibility studies, and identifying cost recovery opportunities to guide design of new and upgraded facilities that meet effluent reuse standards.

The company will also train WAJ staff to maintain system improvements. This project will be the sole contract for funding all USAID-funded water and sanitation design and construction work in Jordan over the next five years. ●

The use of GIS and hydraulic modelling to establish criticality for water main replacement and rehabilitation prioritization

As there are a wide range of factors affecting the lifespan of a pipe, not just age, asset management requires the analysis of these variables to form a repair or replace strategy. Annie Vanrenterghem, James Carolan and Seth Garrison discuss the use of Geographic Information System and hydraulic modelling in renewal prioritization analysis.

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For decades, water systems have invested heavily to replace and rehabilitate ('renew') their distribution systems. At the same time, they have added new pipes in response to growth, increasing service demand and new regulatory mandates. Many distribution systems are now a complex conglomeration of pipe materials from different time periods, installed under a range of conditions. Experienced water system managers know that some types of older pipe appear to last much longer than some newer pipe. This challenges the conventional wisdom that has long dictated that older pipes should be replaced first, and generates the question, 'If age is not the best criterion for selecting pipe for renewal, what is the appropriate selection protocol?'. To answer this question, specialized asset management practices, and advanced modelling tools are required to weigh the many factors influencing renewal prioritization. These tools can help utilities make decisions about which pipes should be renewed and how to maintain existing levels of service. The guesswork and estimation associated with renewal prioritization can thus be better controlled.

A renewal prioritization analysis can be conducted at many levels. For example, it can be done spatially at the system, pressure zone or pipe level, or time-wise looking at short-term (one to five years) or long-term (20-50 years or longer) trends. In this paper the authors concentrate on the use of Geographic Information System (GIS) and hydraulic modelling (HM) to assist in the development of short-term distribution prioritization plans at the pipe level, and more specifically to define criticality in view of water main renewal. The approach outlined in this paper provides answers about which specific mains should be chosen for renewal and in what priority over the short-term.

Prioritization methodology, criteria and variables

Several multi-criteria decision making models (MCDMMs) are available for prioritizing the criteria associated with renewal planning. One option that is gaining popularity is the Annual Rehabilitation Planning (ARP) model that was developed for the European research programme CARE-W (Saegrov, 2004). ARP is based on the Electre tri. It provides a rigorous definition of selection criteria and a robust analytical approach that uses reference profiles (as opposed to just adding scores) (Le Gauffre, 2008). ARP methodology is illustrated in Figure 1.

A series of criteria and their weights is defined by the utility as factors influencing prioritization (see section 'criteria') and their relative importance. Each pipe is represented by a vector of criteria values. The value a given pipe takes for a specific criterion is plotted on a vertical axis (g_1, g_2, g_i; one criterion per axis). The dots on each g_i axis are connected, which results in line a_j that represents a pipe. The model compares a pipe profile a_j with two reference profiles b_1 and b_2 that define three zones: below b_1 (no action needed), between b_1 and b_2 (maybe), and above b_2 (action required).

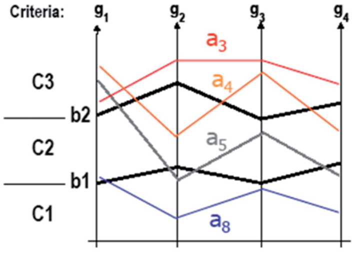

Figure 1
ARP reference profiles

While pipes like a_3 and a_8 are easy to classify, i.e. needs renewal (a_3); does not (a_8), the model advanced algorithm is particularly useful to assign priority order to pipes which oscillate between one zone and another one, e.g. a_4 and a_5. The model takes into account uncertainty, itself translated by the proximity of a value on an a_j line to its threshold values on the references profiles b_1 and b_2. The model stays away from more classic methodologies that assign a score to each criterion of a given pipe and then aggregate all the scores to create an overall score that pertains to that pipe. One major weakness of such an approach resides in the fact that a pipe with a score of, for example, 100 for one criterion, and zero for the others, would score the same as a pipe with ten criteria with a score of ten each, regardless of where the threshold values (action/no action) stand for each criterion.

ARP may be intimidating for new users because it requires access to a broad range of data (but so does a methodology that relies on scoring) –

Table 1
Strategy for data selection

Level of data importance	Data: Not readily available and difficult to obtain	Data: Readily available and easy to obtain
Low importance	Ignore data	Use data on a trial basis
High importance	Formulate a strategy to obtain data	Use data immediately

many utilities may not be in a position to provide values for each criterion. This can be addressed by first defining only the basic criteria for which data are readily available, improving the quantity and quality of data over the years. Using a systematic approach like ARP puts the utility on the path to a more advanced methodology as additional data becomes available.

It is important for utilities to keep an eye on the balance between the cost and the benefit to obtain additional data. Some criteria may not be applicable to a certain water system, and/or the expense of data collection may outweigh the benefits. Performing a basic cost-benefit analysis may help determine the value of obtaining certain data. This is illustrated in Table 1.

In this paper the authors do not focus on the MCDMM portion of the prioritization analysis, but on the definition of the criteria themselves based on data availability.

ARP criteria

ARP provides a number of imbedded criteria that can be used for renewal prioritization. Utility-specific criteria can also be created. An abbreviated list of criteria that tend to affect renewal decisions and their description appear in Table 2. Table 3 shows that criteria can be expressed mathematically as functions of variables or as simple indices. The variables that appear in the 'Definition' column are described in Table 4.

The criteria, their function and variables that appear in Tables 2, 3 and 4 are inspired from the original criteria created in the CARE-W ARP tool (Le Gauffre, 2008). They could be used in any other MCDMM tool. The final choice of criteria depends on what data will ultimately be available, but may also be site specific. For example, the system may have areas prone to flooding or landslides, which increase the consequences of damage that should be evaluated in the analysis. ARP provides for a way to appropriately include specific risks, allowing them to be considered in the renewal prioritization process.

Note that criteria defined with predicted break rate (PBR) are risk-based (traffic disruption due to flooding (DFT); damages and/or disruption on housing, commerce or infrastructure due to flooding (DF); predicted water interruptions (PWI); predicted critical water interruptions (PCWI); and annual repair cost (ARC)). A few criteria do not carry any sensitivity or criticality factors (ARC; co-ordination score (COS); water quality deficiencies (WQD); water losses index (WLI); and hydraulic criticality index (HCI)), and some criteria are indices (COS, WQD, WLI, and HCI).

Most of the variables described in Table 4 are self explanatory. A few necessary comments follow:

- PBR: A failure forecasting model is needed to generate PBR. Note that a PBR depends on the risk factors of failure and the past history of failure. A minimum of five years of failures assigned to their pipe is necessary.
- SC: A sensitivity index that measures how much a customer is sensitive to service interruption due to no water or low pressure after a break.
- SF: A sensitivity index that measures how much a customer – or any local entity that may not be a customer, e.g. a tunnel or a rail track – is sensitive to flooding in a housing, commercial or industrial area. Same for the sensitivity of the road to flooding (SFR), for traffic disruption, as a result of a break.

The value of each variable has to be developed for each pipe asset. In the rest of this paper we illustrate how certain variables have been defined for projects the authors have completed.

The intent is to offer an overview of possibilities given data availability.

Values for the variables that come into the computation of the ARP criteria (Table 4) can be derived using a wide array of sources, most of which are readily available at US utilities. These data sources include the following:

- GIS data sets and asset inventory data. GIS data sets provide an accounting of system assets as well as an electronic platform by which to store, analyze and track the renewal plan results.
- Information found at other utility departments. For example, field operations, planning, customer service, etc.
- Spatial analysis of utility assets in GIS relative to sensitive receptors or asset degrading factors (soils, transportation infrastructure, etc.)
- Hydraulic model. The HM helps define the hydraulic criticality of a system, i.e. how a pipe failure would affect water service, allows analysis of water age and helps determine which valves would be needed to isolate a given pipe.
- Information emanating from, or in collaboration with, other public works departments.

Some of the variables have one specific value for each pipe (e.g. length (L), PBR, pressure (P)), or are defined based on a range of values (e.g. diameter (D)), or based on a function of their factors or on a narrative combination. To illustrate the various steps that lead to the definition

Table 2
ARP criteria definition

Criterion	Description
COS – coordination score	Index that accounts for how much other infrastructure projects impact the renewal decisions for the pipe. For example, everything else equal, the renewal priority of a pipe that is under a road that has been repaved within the last five years should be less than the priority of a pipe in a road that will be repaved next year.
ARC – repair cost	Measures the cost of a repair associated with a failure. Users can introduce direct and indirect costs depending on availability. Everything equal, the renewal of a pipe with a higher repair cost should make it a higher replacement priority.
WLI – Water Loss Index	Everything else equal, the renewal of a pipe that is leaking or is in a zone more prone to leaking should be a higher priority than if it is not leaking.
WI (PWI, PCWI, PFWI) – water interruptions	Water interruption family of criteria that evaluate the consequences generated as a result of a failure in terms of service interruption. Everything being equal, the renewal of a pipe that generates more impacts when it is shut down over one with fewer impacts should be a higher priority. Type of customer affected, duration of a repair, and frequency of a break are taken into account.
DFT, DF - damage and disruption family of criteria	Evaluates how much damage and disruption is generated as a result of a break because of flooding. Everything being equal, renewal of a pipe that is more likely to create damages and disruptions after it breaks and as a result of flooding should be a higher priority.
WQD – water quality	Measures the contribution of the pipe to water quality deficiency. Everything being equal, renewal of a pipe that has shown to be responsible for more water quality problems should be a higher priority.
HCI – Hydraulic Criticality Index	Defines the relative impact a pipe has on the rest of the network from a hydraulic standpoint (no water or low pressure) if that pipe was shut down or failed. Everything being equal, renewal of a pipe with a higher HCI should be a higher priority. A hydraulic model is needed to compute HCI.

of a variable, we will use the example of the unit of cost of repair (UCR).

ARP variables

Definition of variables – example UCR
Step 1 – Data used for this variable will come from any available information regarding the repair cost of past breaks. Such information is typically available at most utilities. Trends will be identified based on the evaluation of the raw data. For example, records may show that cost depends on diameter and that diameter can be regrouped in three intervals: 0-12"; >12-36"; and >36". In our example (Table 5) the ratios of the cost of repair of the two latter diameter groups compared to the reference one (less than 12") are 2 and 3, respectively.

Step 2 – Then, a general knowledge of other factors that do not clearly appear in the quantitative data provided by the utility, but are known to affect repair cost (in general, or more specifically at that utility), will also be considered. For example, the context of the break may affect cost (this could be due to access issues resulting in economical and social costs because of road usage, shutdown of traffic, proximity to tunnels, high cost zoning, etc.)

Step 3 – Steps 1 and 2 will be translated as a multiplying factor as shown in Table 5.

Table 5 reads as follows: if C_0 is the cost of repair of a pipe whose diameter is smaller than 12", that is neither in a high traffic zone, nor in a high cost area, nor near the entrance of a tunnel, the cost of repair of, for example, a large diameter pipe (>32" diameter) running over or alongside a tunnel, on a major roadway, and in a high cost economic zone (e.g. the financial district or shopping district of a city) will be C_0 multiplied by 6 (3 + 1 + 1 + 1). The UCR value of each pipe asset can be similarly calculated based on the additive 'score' of the two factors that make up UCR; cost of material/work (diameter based) and access cost (summed up here as 'context').

The value of the UCR variable can also be defined qualitatively by regrouping the factors in various pertinent combinations (see Table 6).

Definition of variables – general comments
It is important for utility managers to not only determine which criteria they would like to use when analyzing their system, but also to determine where the data will be derived from to support each criterion (and at what cost as mentioned in Table 1). It is possible that a criterion cannot be defined because its variables cannot be defined. In this case, if that criterion has been found to be important, the utility may decide to undertake the kind of work necessary to obtain such information, or that the added value is not worth the effort. In most cases the utility will start with the data available for analysis and fine tune or add to the data over the years and refine their analysis as more data become available. As always, the better the data the more accurate and complete the final model will be, and the more effective the renewal plan.

Users must keep in mind the relative importance of each factor (whether a criterion or one of its variables, or a risk factor of failure) being analyzed as they relate to the specific system. If, for a certain analysis, a factor is the same for all the assets, it is of no use to differentiate the assets for the renewal plan, and therefore it should be abandoned. For example, if the renewal plan pertains to one zone and the diameter or the pressure is the same for all the pipes in that zone, diameter or pressure should not be considered as a risk factor (of failure in the failure forecasting model) or as a criterion variable in the prioritization model.

Through using combinations of factor types as well as adjusting the values of each factor, users can tailor the importance of each factor to their specific systems. However, one has to understand whether a certain parameter expresses a consequence or a likelihood of failure. For example, if a utility functions in an area with large volumes of mass transit, heavy rail or underground tunnels, the proximity of the system assets to these features will affect not only UCR (cost of repair) but also the risk of failure (this is taken into account in the failure forecasting model), as well as the disruption of traffic and potential heavy property damage and/or litigation. Therefore a utility with such services/items/characteristics in its service area should carefully define them and identify the capacity in which they intervene. One is trying to avoid redundancy at each step of an analysis. There is often confusion between risk factor (of failure) and prioritization variable.

Defining the risk factors, variables and criteria is the first step; however, applying their values to each and every asset in a system with hundreds of miles of assets can be daunting. The use of HMs and GIS datasets and software can provide valuable assistance.

Examples illustrating how variables can be defined range from the simple to complex, including:

- A GIS asset attribute assigned to each pipe, e.g. L, D, etc.
- Proximity or connection of a pipe to a specific object found in the GIS, e.g. water supply to sensitive customers such as a hospital or a school.
- An asset's proximity to a specific item or within a certain zone that can be isolated as a polygon in the GIS, e.g. rail road track, tunnel, zoning.
- Outputs from other tools, e.g., PBR (from the failure forecasting model); P (from the HM); and HCI (from the HM).
- A surrogate value can be used. For example, as will be seen in the number of people served (NPS) section, surrogate values for NPS could be demand or consumption.

We will now review the various variables described in Table 4 and define their possible sources of data

Criterion name	Abbreviation	Definition
Co-ordination score	COS	Score [-1,1]
Annual repair cost	ARC	ARC(i) = PBR(i) x UCRp(i)
Water Losses Index	WLI	Index [0,1]
Leakage Vulnerability Index	LVI	Index [0,1]
Predicted water interruptions	PWI	PWI(i) = PBR(i) x EDI(i) x NPS(i)
Predicted critical water interruptions	PCWI	PCWI(i) = PBR(i) x EDI(i) x SC(i)
Predicted frequency of water interruptions	PFWI	PFWI(i) = L(i)/100 x PBR(i) x EDI(i)
Traffic disruption due to flooding	DFT	DFT (i) = PBR(i) x SFR(i)
Damages and/or disruption on housing, commerce or infrastructure due to flooding	DF	DI(i) = PBR(i) x D(i)^2(i) x P(i) x SF(i)
Water quality deficiencies	WQD	Index [0,1]
Hydraulic Criticality Index	HCI	Index [0,1]

Table 3
Description of ARP standard criteria

D	Diameter
NPS	Number of persons supplied
EDI	Expected duration of interruption
L	Length
P	Pressure
PBR	Predicted break rate
SC	Sensitivity of customer to service interruption
SF	Sensitivity of housing, commercial, institutional properties, or infrastructure, to flooding
SFR	Sensitivity of the road to flooding
UCRp	Unit cost of repair

Table 4
Variables

Table 5
UCR – example of factor subgroups, factor type and factor value

Factors	Factor Subgroup	Factor Type	Value
Context	High traffic	Yes/No	1/0
	Tunnel	Yes/No	1/0
	High cost zoning	Yes/No	1/0
Diameter (inches)	0-12	Range	1
	>12-32	Range	2
	>32	Range	3

values, and general factors to consider when developing them.

Definition of variables

Coordination score
Generating such information requires communication with other infrastructure departments (sewers, gas, roads). COS can be considered within or outside the suite of criteria and can often be developed separately from the other factors as a post-process.

Expected duration of interruption (EDI)
It is important to first check with a utility what their practices are. Do they bypass and temporary feed in case of a break? If yes, what are the criteria to do so and how long does this take?

Raw data regarding the duration of a repair will be examined if available, and rules will be identified. Field people may also be good sources of information. EDI tends to depend on diameter, and sometimes on material as some materials (e.g. asbestos cement) require standard operating procedures, which are more stringent.

Number of people served
It is necessary to reflect first on what one wants to communicate when using the NPS variable. NPS appears in PWI and therefore pertains to water service interruption. The number of individuals served (or not served) seems to be more relevant for residential accounts. On the other hand, the importance (sensitivity to service interruption) of the other types of accounts (non-residential) will be better captured by a sensitive customers (SC) factor that indicates how sensitive to water service interruption that specific client is. To define NPS, ideally, one would want to have access to the following information: service points on each GIS pipe; and billing or any information that allows identifying the user.

If service points or water customer data are not available, at the minimum, zoning information could be used in a GIS layer. Each zoning map has various levels of differentiation. Residential zones may be characterized by single-family homes, multi-units, etc. that can be further related to a certain NPS, e.g. single-family home equals four people. All pipes that belong to a certain residential area would be given that NPS (or a multiple of it depending on an estimate of the number of homes per unit length).

Consumption reports may allow us to fine tune the above evaluation if the user's address (as it appears on the bill) can be plotted in the GIS, even if service points are not identified. In this case, any account (that is located in a residential zone or is identified in the bill or in the CMMS as being residential, often rates differ) will be assigned geographically to the closest pipe. Consumption will be a substitute for the NPS (again, for pipes in the residential zones). The total consumption delivered by a pipe could be computed.

Demand could be another substitute for NPS (in residential accounts). Demand is typically identified and assigned to each node for the development of the HM. Demand could have been obtained from consumption data (in which case NPS should also directly use consumption data as described above), or assigned to each node through various allocation techniques used by hydraulic modellers. Demand at one pipe would be the average of the demand between the two nodes that define a pipe. This approach requires that there be a perfect matching between hydraulic and GIS segments, and that the link between two nodes and their pipe be known, which is normally the case in HMs.

Sensitive customer
The SC index pertains to water interruption. That criticality index differs from the ones that are to be used in case of flooding after a pipe breaks. In effect, a tunnel may be affected by a break because it can be flooded, but there is no disruption to traffic through a tunnel because water service in the area has been interrupted.

The SC factor appears in PCWI. Customers may be sensitive to water interruption for various reasons:

- Physical damage: health centres, hospitals, dialysis centres.
- Business interruption: commercial (could be broken down in type of commerce; hair salon has been identified as a sensitive type of commerce in Italy); industrial; financial districts; biotech centres.
- Image: schools (a primary school closing in the middle of the day because of a main break is very likely to make the news headlines regardless of how damaging that break has been because a large number of families have had to leave work to pick up their child); high profile area, e.g. Strip in Las Vegas; Wall Street, 5th Avenue in New York City.

The above information is drawn from the personal knowledge of local residents, papers or GIS maps. Similar to what is mentioned for NPS, if service points are known and the type of above information is assigned to a customer in the billing records, SC could be defined precisely. If service points are not known and the above information has been plotted in the GIS it can be assigned geographically to the closest pipe. One pipe most likely serves many customers. The global SC to be attributed to a pipe could be the largest one or an addition of all the SC values.

Valve isolation within HM packages can be used to identify the effect of the loss of each pipe asset by leveraging valve isolation to determine all of the additional pipes, and therefore

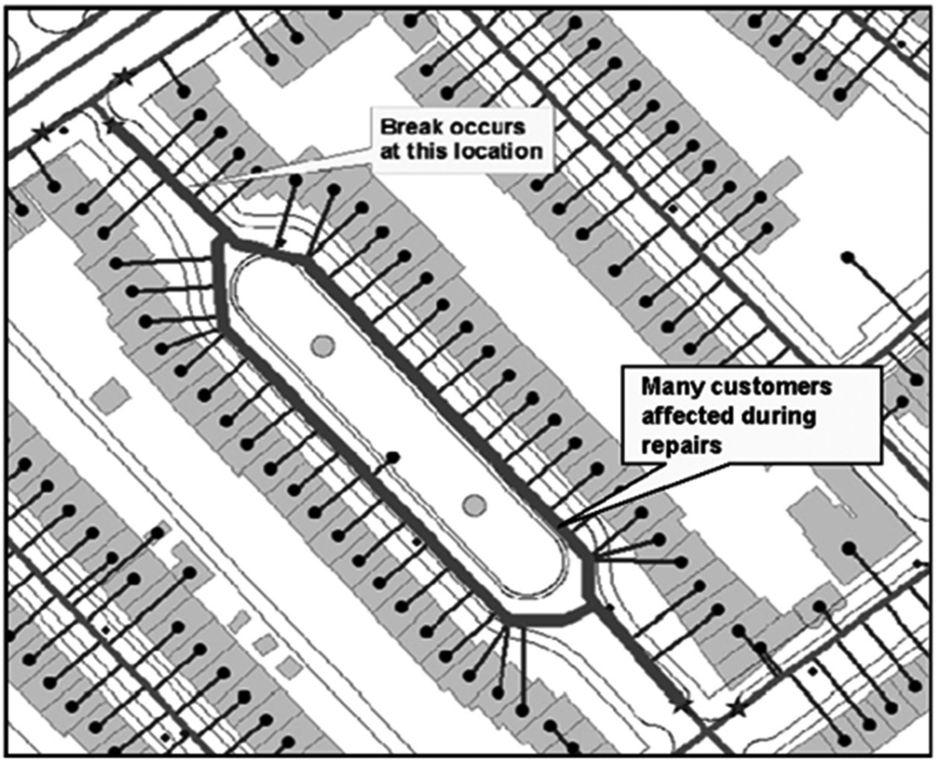

Figure 2
Single pipe failure affecting additional pipes due to valve isolation during repair

customers, affected by a failure. Figure 2 illustrates the 'cascading loss' of a single pipe failure.

Since SC appears as a multiplying variable in the PCWI formula, it must be given a value that reflects its relative impact on service interruption. PCWI could be further differentiated by multiplying SC by the demand (or consumption) attributed to each user if available as a continuous variable, or creating finite categories based on ranges of consumptions (e.g. large health care centres vs. small health centres).

PWI and PCWI could be combined in one criterion with residential customers being given a certain value for SC.

Sensitivity to flooding

SF reflects the sensitivity of local properties to flooding. SF can represent a residential, commercial, institutional, infrastructures or industrial customer. Infrastructures include rail tunnels, tunnel ventilation shafts, power stations, etc. These can be identified (in a GIS) per a zone or per a GIS object. If a zone defines the sensitive customers (e.g. a commercial area) a buffer area can be drawn around that zone using a GIS polygon, and all pipes within the buffered zone will be considered as potentially presenting a flooding hazard to the commercial centre. The same approach can be used with a GIS object (e.g. a hospital that becomes the centre of a circle within which pipes would be considered as a flooding source that could potentially affect the hospital). Many different data sources can be used and the analysis can take the form of a simple proximity analysis to a more complex analysis using available land topography data to determine the direction water will flow during a pipe failure to determine a more accurate flooding risk. This is illustrated in Figure 3.

Sensitivity to flooding for traffic

The same principles used for SF can be applied to SFR (GIS polygon vs. object, topography, buffer zones). SFR requires information on road and traffic similar to the data used in UCR. However, with respect to UCR we were concerned with how higher traffic would make a repair more difficult (and more costly), while with SFR we are interested with how much a road could be impacted by flooding and with the traffic disruption this would create.

Water quality deficiency

Complaints regarding appearance or taste of water or public health incidents (not linked to the water source or point contamination) may indicate that

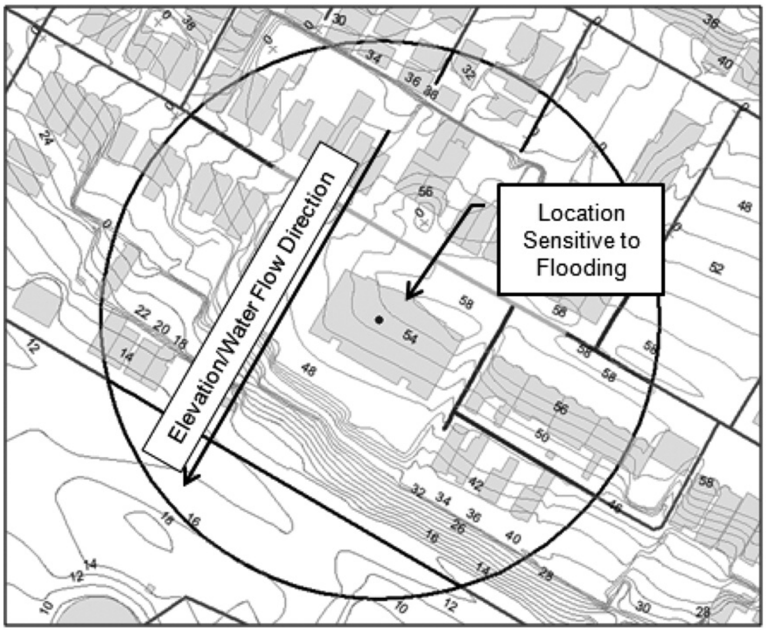

Figure 3
Flooding risk using GIS analysis and topographic data

a water quality problem exists at the distribution pipe level. Complaints may also reflect punctual incidents (after service interruption for repair). While it is still very difficult to identify which pipe contributes to the problem, one may look at complaints that show a recurring pattern of water quality complaints or at the main flushing programme. It can be assumed that a utility has set up a systematic flushing programme for certain pipes because this has proved to have a positive effect on water quality complaints and therefore these pipes can be considered responsible for the declining quality of water. Because flushing is expensive, everything being equal, renewal should be undertaken at a pipe that is part of the flushing programme or that can be linked to water quality complaints.

Water loss index

If detecting a leak generates an immediate response, then leakage cannot be considered as a criterion for rehabilitation planning. However, if detecting a leak puts the pipe in the pool of candidates for renewal, then this information should be accounted for within the prioritization programme. Even if a leak detection programme exists, some background leaks are not likely to be detected or leak detection may be cyclic so that leaks may exist before they are detected. A leakage vulnerability index (LVI) may capture these latter types of leaks and be a valid criterion.

Non-revenue water (NRW) values can be used in calculating a LVI but these may not be sufficient. If the systems to be studied have more than one district metering area and NRW value, and these values differ significantly, then this might indicate that leakage is higher in one area than the other. However, NRW is comprised of several components as seen in the IWA water balance table (Table 7). If these components cannot be further quantified in some way, then a higher overall NRW value is not necessarily indicative of higher leakage. So the recommendation is only to use NRW values if it is believed that they are representative of the leakage in that (sub)system. Otherwise, the leakage factors can be considered to be:

- Number of service connections – this is a key factor as leakage often occurs at joints. The type of connection between pipes could also be considered (if data is available).
- Material type – some materials are more prone to leaking than others. This factor does not necessarily need to be included in the leakage vulnerability formula, rather materials associated with low leakage can be automatically assigned a low value. Leaking materials could be due to corrosion, but then again due to the type of connection.
- Pressure – the pipe's static pressure (average between its two nodes) should be included.
- Pipe length.
- Diameter – while a large diameter pipe can potentially generate a larger volume of leaked water, it will also have thicker walls so should be less prone to leaking.
- Age.

Some of the above factors (D, L) are already included as risk factors of failure.

LVI offers the capacity to distinguish between two pipes which have similar characteristics and predicted break rate, but where one is more prone to leakage than another. For leakage

Table 6
UCR – example of values and definitions, narrative approach

Code	Value ($)	Definition
1	3000	Unknown
2	1600	Diameter <200mm and easy context
3	2800	Diameter <200mm and normal context or diameter >=200mm and difficult context
4	3400	Diameter 200-600mm and easy context or diameter <200mm and difficult context
5	5900	Diameter 200-600mm and difficult context
6	5100	Diameter >=600mm and easy context or diameter <200-600mm and difficult context
7	6500	Diameter >=600mm and difficult context

calculations across the whole network, there is a formula for background leakage unavoidable annual real losses (UARL):

$$UARL = P(18L + 0.80Nc + 25Lp)$$

Where, P = pressure, L = mains length, Nc = number of service connections and Lp = length of service pipes from main until customer. One option is to use this formula at an individual pipe level. A weighing could also be added for material/joint type if preferred (and if data is available).

Hydraulic Criticality Index
HCI measures the demand not met in the rest of the system if a pipe breaks. In other words, it captures the extent of service interruption in the rest of the system as a result of a break. Therefore HCI and the water interruption (WI) family of criteria are both concerned with the same consequence of a break (i.e. service interruption). While HCI provides an overall measure of the consequence (in the form of demand not met), the WI criteria express the interruption in a much more precise way (as described in the WI section and captured in SC or NPS). Therefore, if the pipes (or segments of pipes) impacted by a break can be identified, applying the family of WI criteria to those pipes is a stronger measure of the consequence of a break than the HCI. The HM or a hydraulic criticality assessment tool would thus best serve the prioritization programme if it can identify all the pipes impacted by a break.

With this respect, every HM or hydraulic criticality module has different output. They must be well understood and the other criteria must be adjusted accordingly. In addition, hydraulic criticality (whether expressed through HCI or WI) will be more accurate if the valves that need to be shut off to isolate the broken pipe can be identified, and the whole 'isolated zone' that is out of service during the repair is taken into account.

If the pipes impacted (besides the pipe that broke) cannot be identified, then the HCI can be calculated, which will give an overall evaluation of the extent of the demand lost as a result of the break. In this case, dead ends must be identified as they tend to have a misleading HCI (in effect if a dead end pipe breaks, 100% of the demand it serves is lost; HCI=1). Also, pipes may need to be merged to create a single dead end segment.

Table 7
IWA water balance

<table>
<tr><td rowspan="9">System Input Volume (corrected for known errors)</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="2">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td></td><td>Leakage on Service Connections up to point of Customer Metering</td></tr>
</table>

Conclusion

In this paper the authors show how the suite of criteria (either found in, or inspired from the ARP suite of criteria, or new ones developed to meet the specific needs of a utility) that are pertinent to renewal decisions can be quantified. The task may first look intimidating because a wide array of data is needed, but the authors demonstrate how values for the variables that come into the computation can be derived using multiple sources now available to utilities, including GIS and HM or other external readily accessible sources of data. The techniques described are drawn from real life examples and work currently done at with US utilities. While a utility may first start with the basic criterion, going through the exercise of working with a rigorously defined suite of criteria will put them on a track to a more systematic decision making methodology for the prioritization of renewal tasks. At every step of this work it is important for the utility to keep an eye on the cost and benefit of obtaining additional data, define and build their plan slowly, factor by factor, and refine that plan as more data becomes available. ●

References

Le Gauffre, P (2008) 'Assessing the benefits of rehabilitation programmes defined with the CARE-W decision support system', Water Asset Management International 4.1, IWA Publishing, London, UK.

Saegrov, S et al. (2004) 'CARE-W final report', Research and Technical Development Project of European Community; 5th framework program; EVK1-CT-2000-00053.

Vanrenterghem, A et al. (2009) 'Hydraulic Criticality in a Water Network Rehabilitation Plan', Proceedings from the IWA-AWWA LESAM 2009 conference.

Sharing failure data to gain insight into network deterioration

Maintenance and failure records can be used to obtain information about the condition of underground infrastructures. Failures, although in themselves unwanted events, offer a great opportunity to obtain network information, provided that they are registered, collected and analyzed. Dutch water companies generally have low failure frequencies. By sharing failure data between water companies, information about a larger network can be obtained, thereby sooner enabling statistical analysis with reliable outcomes. In order to perform statistical analysis on different data sets, the data have to be uniform. In the Netherlands, a system has been developed to enable uniform failure registration and an exchange of information between water companies. In this paper, Irene Vloerbergh and Mirjam Blokker describe the experience of the development of this system, which aims at application at a national scale, and delineates the hindrances met at the implementation at company level and how these are overcome.

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Mirjam Blokker, KWR Watercycle Research Institute NV, Nieuwegein, The Netherlands

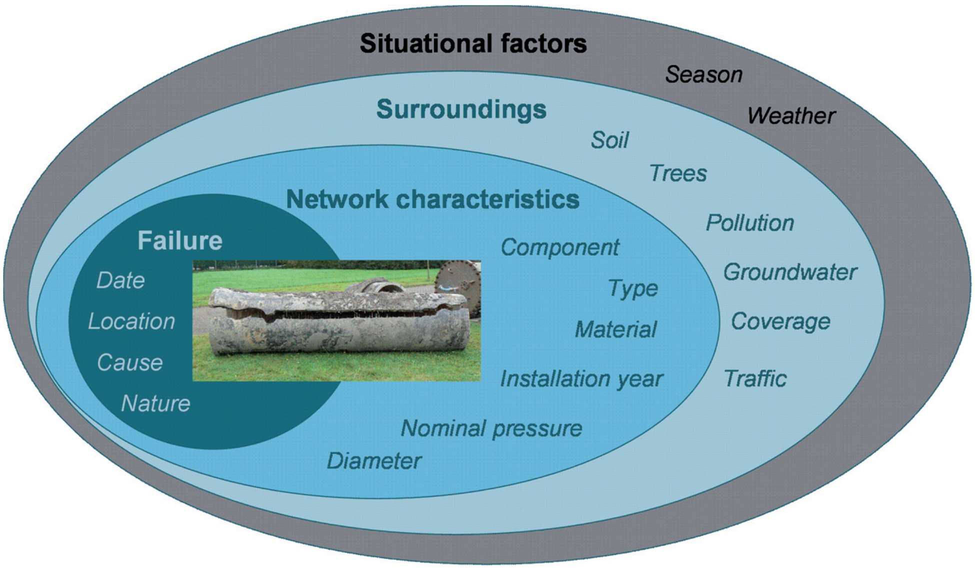


Figure 1
Aspects of failures can be categorized on four levels: 1) failure, 2) network characteristics, 3) surroundings and 4) situational factors

Worldwide, ageing drinking water distribution networks are subject to increasing failure rates and leaks. The underground capital – consisting of a diversity of materials under an even greater variance of circumstances – is invisible for inspection and therefore little is known about its condition. Deterioration of the water mains causes supply interruptions, pressure loss and decreasing water quality, which in turn leads to increasing costs over time. Insight into the deterioration process of individual water mains and pipe groups can help to predict when replacement is due. Since monitoring of the mains' conditions is relatively expensive, these techniques are not appropriate for widespread application. Alternatively, maintenance and failure data can be useful sources of information to estimate remaining lifetime or expected failure frequencies. Statistical analysis of registered failure data can reveal patterns in the occurrence of failures. In 2007 the registered failure data of a number of Dutch water companies were analyzed[1], showing that despite the incomplete registration and varying data quality, some trends could already be made visible, indicating for example relations between age and the occurrence of failures in asbestos cement pipes.

As low failure frequencies (annual number of failures/km) prevail within the Dutch water companies, limited knowledge can be derived from the failure occurrences of individual water companies and it takes a long time before statistically reliable outcomes can be expected. One way to overcome this problem is by gathering failure information from a larger network, i.e. sharing failure information between water utilities. This way more diverse data of pipes and surroundings can be gathered. Previous research findings, for example on the failure behaviour of asbestos cement mains in clay soil[2], can thus be broadened to other types of pipes and other circumstances, thereby providing information about a wider variety of network populations.

Prerequisite to analysis of combined failure data sets is that the registration is done in a uniform manner; with standard parameters describing the failure, failing object characteristics and circumstances[3].

A uniform failure registration system that multiple water companies can use has been developed. The system, called U-STORE, is currently being implemented and helps to improve the quality and quantity of the registered failure data for statistical analysis. This paper describes the development of the U-STORE system, explains what it comprises of and how its implementation is realized. Special attention will be given to organizational aspects because these have appeared to be crucial for successful implementation. With this paper the authors hope to inspire water utilities worldwide to register their failures in order to build a knowledge database about their buried infrastructure for decision support on the repair or replacement dilemma.

Development of a tool for joint failure registration and exchange of data

Background

The KWR Watercycle Research Institute serves the Dutch drinking water sector by generating and broking knowledge. In the Netherlands, a joint research programme of the drinking water companies exists in which nine out of the ten drinking water companies take part (for more detailed information, see Sulmann, 2009[4]). The companies cooperate to enable the research, for example by carrying out pilots and providing data for input. The research findings of the joint programme are for the benefit of the sector as a whole, however, it is the choice of the individual water companies whether they use the findings or not.

In 2007, within the joint research programme, the failure databases of seven of the water companies were scrutinized to gain insight into the possibilities and limitations of failure and maintenance databases for statistical analysis. Statistical methods were considered that could help to determine which factors influence the occurrence of failures. Results were presented at the 2nd IWA Leading Edge Conference on Strategic Asset Management[5] and to the Dutch water companies. The exercise proved that with the qualitatively and quantitatively limited failure data that were available within the water utilities, it was already possible to perceive some relations between the occurrence of failures and other factors. With the help of this insight the water companies could be convinced that the effort of consistently and accurately registering aspects of failures is not only worth the trouble, but moreover that it is a waste if nothing is registered when a failure occurs.

As of 2006, Dutch water companies are registering their supply interruptions for the purpose of asset management and the water companies' benchmark. The performance indicator 'substandard supply minutes'[6] was introduced for this. It requires registration of the duration of supply interruptions caused by planned maintenance and unplanned works (due to failures). Registering some extra information per failure for statistical analysis is a relatively mild adaptation. This, combined with the insight that not registering failures and keeping records of this means unnecessary loss of information every day, seven of the water companies joined forces to set up a uniform failure registration system. KWR facilitated the project and enabled anonymous exchange of failure and network data.

Common goals and individual implications

The goal of the joint efforts is to set up a system to register failure data in a uniform manner so that the information can be collected and merged in a large database that can be used for analysis. The system consists of uniform registration guidelines, agreements for data collection and exchange, analysis and feedback on the findings.

For the water companies, some points require special attention and effort. Although these are not difficult to overcome they need to be addressed honestly and openly, so that no party has unrealistic expectations.

Committing to participation means that the efforts are primarily aimed at the common benefits. As a tool to investigate predetermined relations, a uniform failure form is set up designed to demand as little as possible from the companies. For individual water companies this may mean that what is asked in the uniform system does not cover the information or data needed for the company's management. Additional questions or adaptation of the form to the companies' needs is possible. However, one must be aware that this requests adaptation of IT solutions and filtering the data again for exchange in U-STORE.

Participation means that all employees who are influenced by the implementation of a (new) failure registration system will have to be informed, trained and cooperate to give and receive feedback. This includes, among others, field workers, auditors and IT personnel.

Communication strategies must take into consideration the diversity in backgrounds of all involved. All comments and questions from all levels need to be taken seriously as they indicate difficulty and therefore predict problems when not addressed. Employees need to be given time and space to regularly participate in project meetings, within the company as well as outside with the multi-company working group.

What to register (U-STORE form content)

A working group with representatives of the participating companies was brought together. Their first task was to agree on what to register (which parameters) when a failure occurs. For statistical analysis the best way to store data is by using standardized categories. It was therefore decided to make a multiple-choice form to be filled in by the field worker who has to repair the failure or replace the failing part. Because filling in forms is not the core business for field workers and accurate filling in is key to a useful failure database upon which asset management decisions can be based, it is of great importance that the form is as limited as possible. At the same time, the opportunity of gaining information about the buried assets should be used optimally because once buried again, the possibility is gone. Agreement was sought on a minimum set of parameters that were in common interest.

Previous research (Vloerbergh and Blokker, 2007[1]; Hu and Hubble, 2007[2]; and Urbanus et al, 2004[6], among others) and the practical experience from the companies lead to the assumption that each of the factors in Figure 1 have a relationship with the occurrence of failures, or may help otherwise to give insight in the state of the network. The factors included in Figure 1 were drawn up after discussing with the participants which relationships they wanted to know more about. It is important to realize there is a strong link between the content of the registration and the analysis results for insight in failure behaviour and prediction.

Figure 1 shows the factors that are assumed to be related to the occurrence of failures or help to define populations by distinguishing

Table 1
The nature of the failing object is requested using multiple choice. In U-STORE a distinction is made between failing pipes and joints.

Pipe	Pin leak, corrosion hole
	Circumferential break
	Rupture / blow-out
	Longitudinal break
	Other, namely…
Joint / connection	Bell split
	Pulled out joint
	Damaged gasket
	Other, namely….

characteristics of the failing object or surroundings. The factors are categorized on four levels:

- Failure level (described by date, location, cause and nature, i.e. the failure mechanism such as circumferential break)
- Network characteristics (described by failing component, type of component, material, installation year, nominal pressure and diameter)
- Surroundings (described by soil, soil pollution, vicinity of trees, ground water, ground coverage and traffic load)
- Situational factors (described by season and weather)

By registering the date on which the failure occurred, the weather, seasonal dependency or calamities that occurred on this date or in a certain period can be investigated. In this way, not all aspects have to be registered on site; some can be obtained from other sources like weather institutes. A study on the relationship between asbestos cement pipes and a number of aspects of weather for example, shows that the weather has an effect on the occurrence of failures in asbestos cement pipes older than 40 years of age[7]. The registration of the location of the failure (by means of postal code, address or GPS-coordinates) may help to designate areas where above average failures occur. Through registration of the nature (the observed failure mechanism) and the cause of the failure, the possible relationship between both can be investigated. At a later stage this may help to identify, for example, the causes of failures by means of observable aspects. The nature of the failure is divided in failure in pipe or connection (connection being defined as any type of joint) (see Table 1).

The cause of the failure is often factually unknown or can be a combination of several causes. Asking people to fill in a cause will often indicate the feelings or ideas that people have about failures in specific materials or under specific circumstances. For example, failures in steel pipes are often attributed to corrosion, while the actual failing mechanism could have been a combination of a weakened pipe and high traffic load. By registering cause and nature, the relationship between these aspects can be investigated and perhaps when more data are available some of the presumptions can be (dis)proven.

Registering distinct network characteristics may help to find explaining variables for the occurrence of failures in certain pipe populations. The distinguished element characteristics are: component (pipe or connection), type, material, year of installation, nominal pressure and diameter (to determine quality or class).

In case the failing object is a joint or connection, the type of joint also needs to be specified eg. leadjoint, restrained push fit, flanged joint etc. The specification of the type of joint is derived from Mesman, 2001.

Several materials and means of protection are included in the multiple-choice options (see Table 2). Inclusion in the list is based on the occurrence or appliance of the type of material or protection. Materials or protection means that do not occur often can be written down in the 'other, namely…' category. If after some time it appears that certain materials that are currently excluded from the multiple choice options often do fail, than it can be considered to include those as well. Or, if a certain material or the means of protection are often unknown or not filled in, it may be wise to remove them from the multiple choice options.

The occurrence of failures under certain circumstances can be investigated when particular aspects of the surroundings are known. The type of soil in which the pipes are laid, whether the soil is polluted, and the proximity of trees (roots can cause failures) are collectively assumed to be relevant aspects. Moreover, the companies are curious about possible relations between groundwater and the occurrence of failures, ground coverage and traffic load.

As a basis for the analysis, background information about the network is required as well. Information about the length per material is indispensable to calculate failure frequencies. Installed pipe-lengths per material and diameter are available in The Netherlands. To a large extent installation years are known. Relating the number of failures to the amount or percentage of material laid, diameter classes or installation year tells more about the actual state of the network. Ideally, the length per each of the variables in the previous paragraph is known, also for example how many kilometres of pipe are in proximity of trees, or how many kilometres are situated below groundwater level. However, available data are usually not this detailed.

Table 2
Materials and their means of protection listen on the U-STORE form

Cast Iron	External protection	
		Bituminous
		PE
		Epoxy / polyester / polyurethane
		Cathodic protection
		Galvanized
		None
		Unknown
	Internal protection	
		Cement lining
		Epoxy / polyester / polyurethane
		None
		Unknown
Ductile Iron	External protection	
		PE
		Epoxy / polyester / polyurethane
		Cathodic protection
		Galvanized
		None
		Unknown
	Internal protection	
		Cement lining
		Epoxy / polyester / polyurethane
		None
		Unknown
Asbestos cement	External protection	
		Tar- or bituminous
		None
		Unknown
Steel	External protection	
		Bituminous
		PE
		Epoxy / polyester / polyurethane
		Cathodic protection
		None
		Unknown
	Internal protection	
		Cement lining
		Epoxy / polyester / polyurethane
		None
		Unknown
PVC	Distinguish regular or biaxial oriented PVC	
		'Regular' PVC
		Biaxial oriented PVC
PE		
Concrete		
Other, namely…		

Implementation of U-STORE

The U-STORE system consists of more than a failure registration form to get data, it is also about working with these data and fitting it into the company's processes. The U-STORE form is essential for what is being registered, which factors and aspects are distinguished, and therefore which relationships can be investigated. The U-STORE system furthermore comprises of the following steps (see Figure 2):

- Gathering data: field workers register on the previously described U-STORE form.
- Recording data: the forms are collected and put in a database according to an agreed protocol.
- Exchanging data: each participating company has to electronically send in the data in an agreed format.
- Merging data: KWR collects the failure data that have been submitted in one database and filters out incorrect or incomplete data.
- Analyzing data: KWR analyzes the data.
- Reporting data/use: KWR reports back to the companies that can use

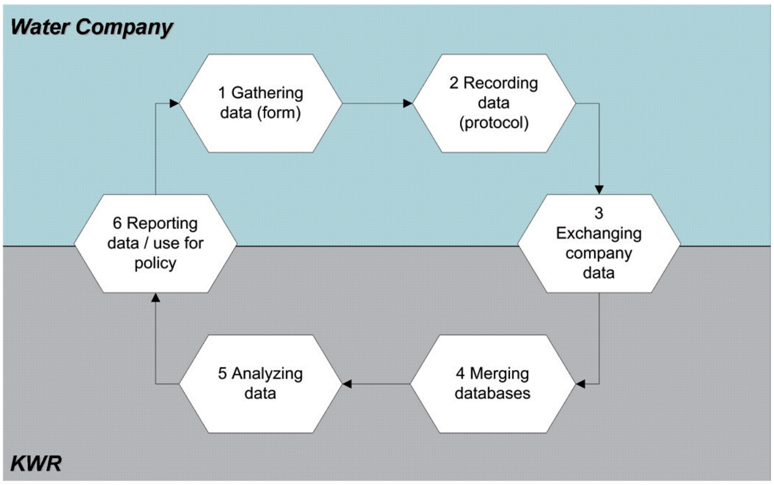


Figure 2
Aspects of the U-STORE process

the info for adjustments in policy or operations management. The info should also be used to evaluate the U-STORE form and processes for improvement.

In the following each aspect of the process will be described in more detail. Points of attention that arose from our experience are elucidated.

Gathering data

Gathering data is done by means of the U-STORE form. The multiple choice questions should offer a clear set of questions with all-encompassing and mutually exclusive answer categories. The meaning and intention of the questions must be clear to the field workers who have to fill in and hand in the forms. For correct use of the form and registration results, training and explication of each factor/question on the form is required. Filling in the forms and handing them over to the responsible department should become a part of the routine of repairing failures and processing work orders. Nowadays, many of the field workers are equipped with personal digital assistants (PDAs). If they are trained to use these in their work processes, the failure registration form should also be digitally available. Guidance should be provided to the IT-personnel responsible for the conversion of the form to fit the (digital) company processes, because if the meaning and intentions of the used terminology and questions are not entirely clear, this can lead to mistakes or even unworkable forms. The extra time taken in advance for explanation and guidance is well spent because corrections cost more time and effort and are likely to cause delays.

Recording data

Recording data refers to translating the form into strictly defined database records. This requires the multiple choice answers to the questions on the form to be standardized. Recording the data can be done by means of a protocol in which all columns and possible values in each column (the requirements per cell) are defined. The reason for strict rules is that each cell content that does not comply with the agreed format, may either provide extra work to correct it (and it is not always possible to correct afterwards) or is excluded from the database and that means that the effort taken to register it is wasted. An example of a question that is transformed into the agreed protocol is given in Figure 3.

Standardization is crucial for the analysis. Each character that deviates from the permitted cell values in the protocol – and this may be as little as a single space or a capital – can cause troubles at the next stage of merging databases.

The protocol has to be explained to those filling the database and those responsible for translation of the standardized format to company processes. For example, if a company has failure and maintenance records, than the information for the standardized database has to be subtracted from or added to this. All people involved have to be informed. If implementation of the standardized format is automated, extra attention should be paid to the conversion of the data from the forms (written text) into the strictly defined cell-values (codes) in the database.

Because the Dutch companies prefer anonymity, one party collects and constructs a merged database for the purpose of analyzing the data.

Exchanging data

For the exchange of data, in the start-up phase of the project it was decided to distribute an Excel format in which the companies could record and collect their failure data. Alternatively, directions were given for exchange as CSV-file for those companies that would find that easier to fit in or extract from their existing systems. In practice however, all companies are using the Excel template. In the first month a test was run to monitor the process of exchanging the data. Then for the first year it was agreed upon that the companies send in their database files quarterly. This gives more opportunities to uncover mistakes and impediments and thereby to make incremental improvements in close cooperation with the companies. It helps to prevent large databases being filled with incorrect data. The representatives who participate in the project group are responsible for the exchange of the data. If data are exchanged incorrectly, or the data are not accurate enough for the database, it will be reported back to them and they will be asked to improve the data or prevent the same mistakes from being made again in the future.

Merging data

Constructing a merged database requires all data to be consistent with the agreed format and protocol. Therefore, if the previous activities are done with the greatest care, then this step will meet few difficulties. However, in practice there will always be obstacles to be overcome. As mentioned before, even the smallest faults like one space too much or a capital letter where a lower case should have been entered can cause data to be seen as errors (depending on the design of the database). The quicker the companies are given feedback on the quality of their data, the sooner they can make efforts to fulfil the requirements. This step demands perseverance from all people involved and continuous communication back and forth.

Analysing data

Once the merged database is being filled, the analysis of the data can start. The companies are asked to provide the lengths of their network per characteristic (if available), for example how many kilometres of pipe are in service per material. The results of the analysis depend on which parameters are registered, which in turn is based on the relationships that were predefined as being of common interest.

Figure 3
Example of a protocol for the translation from multiple-choice answers to strictly defined cell values for the database

Question: What is the material of the failing object?

Ductile Iron	The Protocol	*MAT_DI*
Asbestos Cement	may define how	*MAT_AC*
Steel	each answer	*MAT_ST*
PVC	must be	*MAT_PVC*
PE	displayed in the	*MAT_PE*
Concrete	database, for	*MAT_CON*
Other	example:	*MAT_OTH*

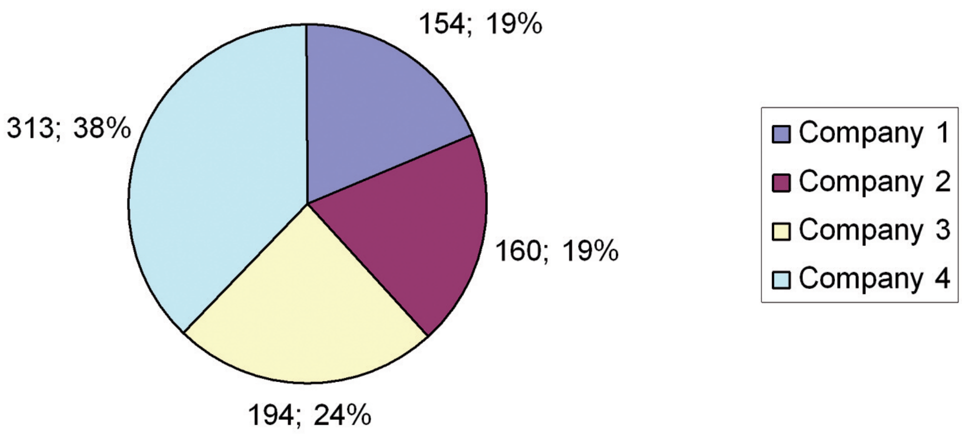


Figure 4
Distribution of the registered numbers of failures per company (Jan - Jun 2009)

Reporting data / use
The results of the analysis are reported back to the participants who can use the results as input for their replacement strategies. The results of the analysis can be a rich source of information for the repair or replacement dilemma if the right parameters are registered. The info will also be used to evaluate and improve the U-STORE system itself.

Preliminary results
To give an impression of the opportunities that uniform failure registration offers, in the following some preliminary results will be discussed by means of example.

KWR has, since the start of the uniform registration in January 2009, received failure data from five of the seven participating companies. Some have been registering according to U-STORE agreements since January, others started later. In all cases the implementation within the company (the moment of getting it up and running) turned out to comprise more than was foreseen. Some companies are in a period of transition with regard to their asset management systems, with the roles and responsibilities of all those involved in asset management undergoing a shift. This can cause uncertainty about roles and responsibilities, which in turn may hamper the implementation. Clear steps and goals are helpful in finding people prepared to do the job.

So far, four companies have exchanged data over six months. In total 821 failures have been registered and exchanged. See Figure 4 for the partitions of the total number of failures that each company has contributed so far.

Companies 1, 2 and 3 registered approximately similar numbers of failures, Company 4 a much higher number. The failures per company distributed per type of material are depicted per company in Figure 5.

Most of the failures have occurred in asbestos cement, PVC and steel (the latter only in company 4).

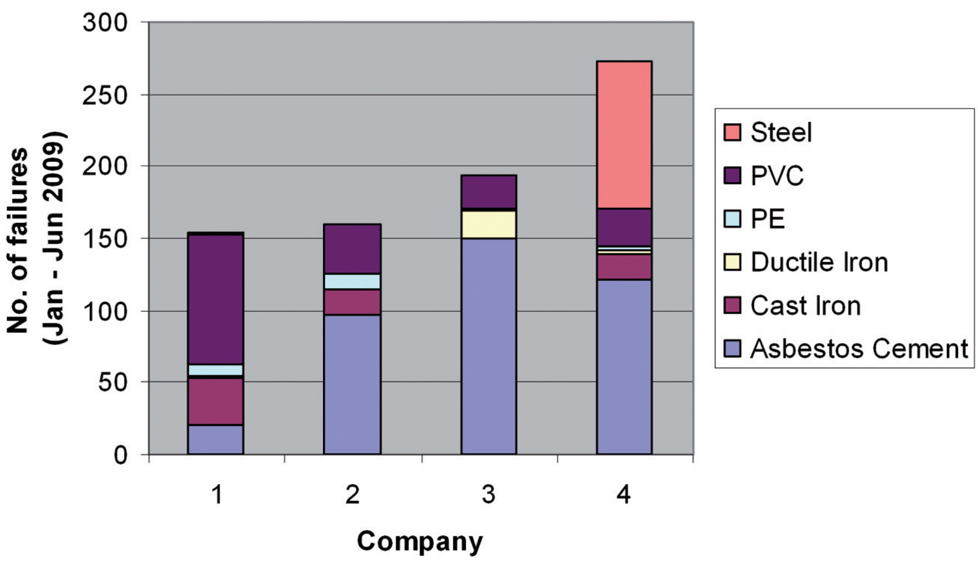
Taking the total network lengths into consideration, however, it can be seen that Company 4 does not perform much worse than the other companies (Table 3).

Table 3 also gives an indication of the performance of the pipe-materials over the past half year. High failure frequencies occur in asbestos cement and ductile iron in Company 3 and steel in Company 4. The problems with asbestos cement in Company 3 have been occurring for several years now. A number of possible explanations have been proposed, such as soil type and product quality, but further research in necessary. U-STORE is helpful and welcome in this respect. The high failure frequency in ductile iron is partly caused by the lead joints used that make up almost two thirds of the total number of registered failures. Another suggested cause is that less effort has been invested in the correct registration of the total length of installed ductile iron pipes than those of asbestos cement (because of the known problems in asbestos cement), resulting in a low total length and, with better failure registration, a higher failure frequency. The high failure frequency in steel assets in Company 4 is said to be caused by corrosion as a result of degradation. From Figure 5 it can be seen that so far, no failures have occurred in the steel assets of the other three companies. This illustrates the advantage of sharing data; Companies 1, 2 and 3 receive information on steel even if they do not have any failure data themselves. Moreover, excessive results due to company specific policies or actions are evened out in statistical analysis when multiple databases are merged.

When combining the received failure data with information on pipe lengths per installation year, the example in Figure 6 can be composed. In Figure 6 the failure frequencies of asbestos cement pipes of different ages are represented. Pipes younger than ten years of age have not been included because amongst these were a few extremely high failure frequencies (due to a few failures in limited pipe lengths) that would make the figure less clear. The failure frequencies in pipes aged 11 to 90 years show a bathtub curve. This result from six-month data of four companies leads to the belief that in a couple of years knowledge can be generated about the deterioration process of different materials in time and under certain circumstances.

The company representatives acknowledge that not 100% of all failures are registered (yet). They admitted that so far it has not been possible to register all failures. To improve the registration rate, the representatives regularly present the results to the employees involved in the gathering, recording and exchange of

Figure 5
The number of failures of each company distributed per material



	Total	Asbestos Cement	Cast Iron	Ductile Iron	PE	PVC	Steel
Company 1	0.07	0.06	0.08	0.03	0.05	0.08	0.00
Company 2	0.03	0.04	0.05	0.00	0.01	0.03	0.00
Company 3	0.08	0.23	0.00	0.19	0.02	0.01	0.00
Company 4	0.06	0.06	0.08	0.00	0.05	0.04	0.20
Total	0.06	0.07	0.07	0.02	0.02	0.04	0.17

Table 3
Failure frequencies per company and per material

the data. This has proved to have a positive effect on the registration rate and quality of the data.

Of the exchanged data, many did not yet fulfil the requirements. However, to encourage failure registration, some loose analyses can be performed on all the data to give an indication of what the data-exchange enables. It is important to show people their work is used, as an incentive to improve data quality and registration rate.

The results of the first six months, despite all shortcomings in the registration due to start-up problems, are promising. Based on the (incomplete) registration of four out of ten companies, and the affirmation of three others to start this year, estimates are that at the end of 2010 at least 5000 failures will be uniformly registered and exchanged.

Conclusions

This paper describes the development of U-STORE, a uniform failure registration system, which helps to improve the quality and quantity of registered failure data for statistical analysis. Statistical analysis of failure data can provide insight into network deterioration, which in turn is useful for asset management and, in particular, decision making on repair or replacement.

In this exercise a direct link is created between theory and practice – beautiful because of the opportunity for pure data, scary because of the obstacles on the way. As an example of putting theory into practice and the problems one encounters in doing so, the process of development and implementation of U-STORE has been described here, highlighting points of attention to share the knowledge this experience has provided. In conclusion the following is worth taking into consideration in similar undertakings: starting with seeking agreement amongst all parties and definition of common goals.

The development of a uniform failure registration system benefits from:

- Starting with seeking agreement amongst all parties and definition of common goals.
- Formulation of the questions that the results of the statistical analysis will have to answer (defining the goal of failure registration).
- Pursuing agreement on which parameters to register and which multiple-choice questions should be asked as less is better for quality assurance, but every aspect of a failure that is not registered will be lost.
- Writing down all decisions (and their reasoning) that have been made for each parameter and set of questions so when, at a later stage, changes seem necessary, decisions can be easily made based on arguments.

For the implementation the following points of attention can make the difference between success and failure:

- People are more prepared to help out with or carry out a task if the task is manageable and clear them.
- All processes should therefore be broken down in the smallest possible steps. For each step it is wise to consider who is responsible for it and in which way their daily routines are affected by the implementation of the U-STORE system.
- All individuals involved must be aware of the fact that his or her work is specific to his or her daily activities, and no person can assume that others know what it comprises of, why and how it is done, etc. Even within one department it is not guaranteed that all people understand the same when certain terms are used. The implication of this for communication is that enough time has to be invested to talk things through to make sure everybody understands the same.

Although the investments and the obstacles that may arise seem tremendous for individual companies to take and overcome, in the long run they are worth the effort. Had this been done ten years ago, then the water companies would now have had much more information about their buried assets. Each day that passes without registration of failures is another day to wait for the knowledge that is needed now. ●

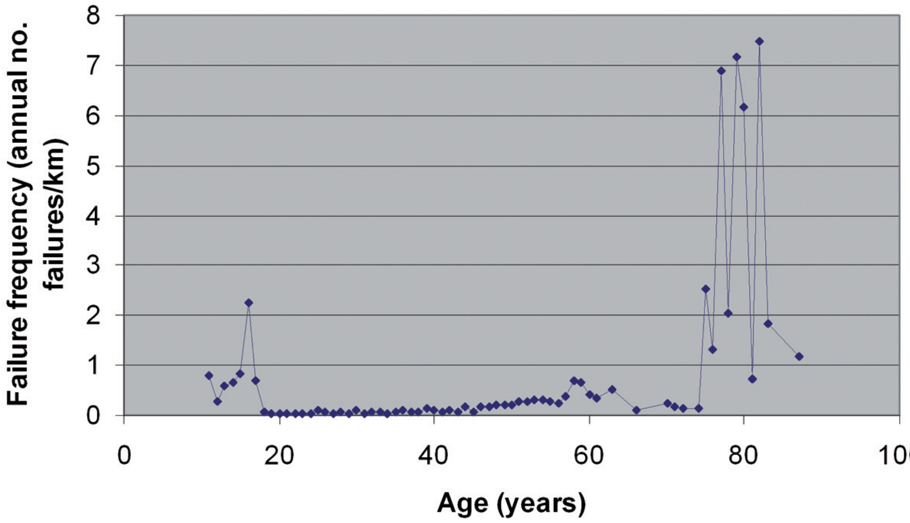


Figure 6
Failure frequencies in asbestos cement pipes per age

References

[1] *Vloerbergh, IN and Blokker, EJM (2007) Statistical analysis of failure data, BTO 2007.043, Kiwa Water Research Nieuwegein.*

[2] *Hu, Y and Hubble, DW (2007) Factors contributing to the failure of asbestos cement water mains, Canadian Journal of Civil Engineering, v. 34, no. 5, May 2007, pp. 608-621.*

[3] *Parker, J (2009) Collecting information to resolve the repair or replacement dilemma, Water21, June 2009, p. 46-48, IWA Publishing, UK.*

[4] *Sulmann, G (2009) Annual report Joint Research Programme 2008, BTO 2009.018, KWR Nieuwegein.*

[5] *Vloerbergh, IN and Blokker, EJM (2007) Failure data analysis – A Dutch case study, Proceedings of LESAM 2007, Lisbon 17-19 October 2009.*

[6] *Urbanus, J, de Kater, H, Rosenthal, L, van der Velde, J, Blokker, M and van der Boomen, M (2004) Performance measure Substandard Supply Minutes, BTO 2004.005, KWR Nieuwegein.*

[7] *van Daal, KHA (2008) The relationship between failures in asbestos cement pipes and the weather, BTO 2008.006, KWR Nieuwegein.*

[8] *Mesman, GAM (2001) Determination of the condition of joints – Possibilities for determination of the condition and failure registration of joints, BTO 2001.205(c), KWR Nieuwegein.*

Estimating and extending the remaining useful life of large diameter PCCP mains

Large diameter prestressed concrete cylinder pipe (PCCP) mains often form vital pieces of infrastructure for medium to large water and wastewater utilities. Much of the underground infrastructure in the US has been buried and forgotten about and, despite their criticality, PCCP mains often fallen into this category. Michael S Higgins focuses on providing a leading edge (but practical) approach to estimating remaining useful service life of these important assets, as well as presenting a method to extend their service life through state-of-the-art risk management practices.

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PCCP mains have traditionally been a durable pipe material for large diameter pressurized water transmission mains and sewer force mains, as statistically the number of failures per mile is very low. However, they often form the backbone of a water or wastewater utility and if a major PCCP main fails, the utility may not be able to meets its customer's demands. The social and environmental consequences of PCCP main failures are also significant in many instances.

One of the challenges associated with PCCP mains is that they do not deteriorate in a uniform fashion. Typically, even if a main has experienced failures in the past, only a small percentage of the pipe sections have deterioration problems (2 to 5% on average) (see Table 1). The remaining pipe sections usually only have limited, if any, deterioration. A successful asset management programme needs to identify pipe sections that are having condition-related problems, the extent of the problems, and estimate the remaining useful life of individual pipe sections. This type of programme will allow the utility to focus maintenance and capital improvement activities where needed so the service life of the main will be realized while its safety assured.

Historically, the conventional approach to mitigating risk with problematic mains has been replacement. However, due to the capital expenditure required and since many of these mains are now in developed areas, this approach is not practical. Furthermore, this approach involves discarding a major piece of infrastructure when the majority of it remains in safe, operable condition – not an ideal management approach. This paper describes an approach to identifying locations of PCCP mains that are at a high risk for failure, estimating the remaining service life of problematic pipe sections, and safely extending the service life of a PCCP main.

An estimate of remaining service life for each pipe section allows a utility to appropriately plan capital expenditures and make intelligent decisions regarding the future of a pipeline. If several pipe sections reach their remaining useful life within a particular year, it may be prudent to replace the main at that time. Alternatively, it may be such that the individual sections of pipe have to be periodically repaired/replaced and the pipeline can be proactively managed into the foreseeable future.

Condition assessment

There are several techniques that can be used to assess the condition of PCCP mains, either while the pipeline remains in service or while it is decommissioned. There are several technical papers in the industry documenting these techniques, including case studies. In general, the most widely utilized inspection methodologies include: electromagnetic inspection (see Figure 1); visual/sounding inspection; and acoustic monitoring. Due to the availability of technical papers covering these assessment methods, they are not covered by this paper.

The main focus of condition assessment programmes is the condition of the prestressing wire. This is the structural component that provides the strength of a PCCP section. If the prestressing wire breaks, the strength of the pipe is reduced and when numerous breaks occur in one area, the pipe's strength can be eventually reduced to a point of potential failure.

Interpreting condition assessment results

By collecting condition assessment data and performing structural analysis, each individual pipe section (usually 16 to 20 feet (4.8 to 6m) in length) can be divided into one of three categories:

- Minor or no damage: Pipe sections with little to no damage and pose little risk of failure. These pipe sections will often have a remaining service life up to several decades if they are properly operated.
- Moderate damage: Pipe sections that have some level of deterioration, measured in the number of broken prestressing wire wraps (wire breaks). By definition, these pipe sections do not pose a threat for imminent failure, but are deteriorating at an accelerated rate. The level of deterioration is measured by the number of wire breaks. However, risk and consequence of failure is not necessarily measured by the number of wire breaks and requires more detailed analysis.
- Incipient failure: These pipe sections already exhibit evidence of structural failure (numerous wire breaks, cracked core, delaminated lining, etc.) (see Figure 2). The service life on these pipe sections has already been realized.

Of the three categories above, deciding how to manage the first and third categories is straightforward. Pipes in the minor or no damage category should be operated without any significant risk management strategies. Pipe sections in the incipient failure category should be evaluated to determine the consequence of failure. If failure will place a burden on the utility, the pipe should be repaired/replaced immediately to avoid a catastrophic failure.

Making decisions regarding pipe sections in the moderately damaged category is a challenge and is often the determining factor of how a PCCP main should be managed. This is further discussed below.

Estimating remaining service life for moderately damaged pipe sections

Condition assessment of PCCP mains typically focuses on detecting and quantifying the extent of broken prestressing wire breaks on each pipe section. The number of wire breaks required to cause microcracking, cracking, and/or failure of the pipe varies depending on several design and loading variables. This can be modelled with three dimensional finite element analysis allowing prediction of the structural condition of a pipe section with a known level of wire break damage. By combining this analysis with the consequence of failure, the risk associated with a given pipe section can be determined.

Through this type of analysis, a maximum permissible number of wire breaks on a pipe section can be determined. In some cases, this may be as few as five wire breaks and in other cases more than 100 wire breaks may be tolerated. In either case, a maximum wire break threshold can be established in order to evaluate a pipe section. If the number of wire breaks is less than this threshold, service can continue in the pipe section. If it is greater than the threshold, the risk associated with the pipe section should be mitigated (e.g. replace or rehabilitate the pipe section).

For moderately damaged pipe sections that remain in place, the remaining service life can be estimated by determining the rate of wire breaks on a pipe section, typically measured as wire breaks per month using acoustic monitoring. This rate combined with the remaining quantity of wire breaks required to exceed the tolerable wire break total will provide the expected remaining service life of a pipe section, measured in months. This is better summarized in the following equation:

$$RS = (WB_{max} - WB_{est}) / WB_{rate}$$

Where:
RS = remaining service life of a pipe section (months)
WB_{max} = maximum permissible number of broken prestressing wire wraps
WB_{est} = estimated number of broken prestressing wire wraps determined by condition assessment
WB_{rate} = rate of increase in number broken prestressing wire wraps (wire breaks per month)

Accuracy of variables affecting service life estimates

Any model is only as accurate as the variables that are used to populate the model. The model presented in this paper is accurate and simple. However, assigning values to the three variables needed to complete the model is not simple and can be influenced by number of other factors.

The maximum permissible number of wire breaks is determined by evaluating structural modelling results and evaluating consequence of failure. Structural modelling has been performed on pipes of varying designs and loading conditions and has been found to be a fairly conservative approach. Specifically, the actual condition of an in-situ pipe is usually in better condition than the structural models predicted. This is because material strengths often exceed design requirements, soil contribution to the structural capacity of the pipe is often underestimated, loading conditions are usually not as harsh as predicted, and structural modelling requires conservative assumptions for model execution. Therefore, the maximum number of permissible wire breaks is often based on conservative models. This is a positive as it allows for a greater factor of safety. If a management approach can be implemented to ensure the actual number of wire breaks does not exceed the maximum permissible wire breaks, the safety of the pipe can be assured.

Estimating the number of a wire breaks in a pipe section is perhaps the most challenging variable to address. Condition assessment tools (electromagnetic inspection and acoustic monitoring) provide quantified data on the number of wire breaks for each section of PCCP but have limitations. In general, these technologies tend to overestimate the quantity of wire breaks, which is favourable when managing a pipeline. However, there are circumstances that can lead to an underestimation of wire breaks. It is important for those managing PCCP mains to understand the limitations of condition assessment tools so that the estimated condition of a pipe is known and safe management decisions are made.

Estimating the rate of wire breaks activity can be performed through one of three methods:

- Measuring rate of wire breaks: The application of acoustic monitoring can measure the rate or wire break activity. Acoustic monitoring involves electronically monitoring the acoustic activity in a pipeline to identify an acoustic event associated with a wire break. Acoustic monitoring determines

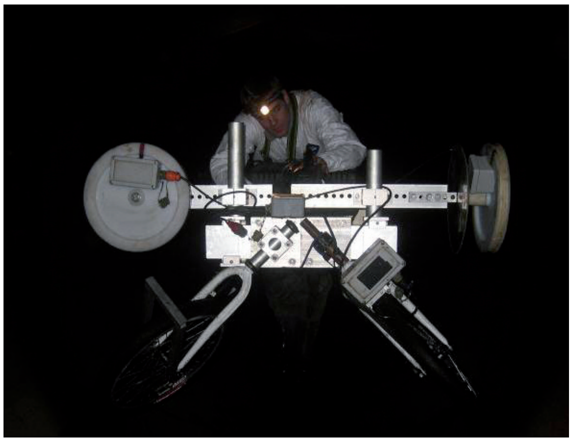

Figure 1
Electromagnetic inspection of 60-inch diameter PCCP main.

Table 1
Sample table from condition assessment project based on electromagnetic inspection

Inspection results

	Number of pipe sections	Percent of pipe sections in this category
Minor or no damage	1526	95.1%
Moderately damaged	76	4.7%
Incipient failure	3	0.2%
Total	1605	100%

which pipe sections are actively deteriorating and the rate of deterioration. This is the most accurate method of determining the rate of wire breaks.

- Estimating rate of wire breaks: Using the estimation of wire breaks currently in a pipe section, the age of the pipe section, and a distribution curve, the rate of wire break activity can be estimated. The simplest method of doing this is to divide the estimate number of wire breaks on a pipe section by the age of the pipe. For instance, if there are 60 wire breaks on a 20 year old pipe, the rate of wire break activity would be three wire breaks per year or 0.25 wire breaks per month. The accuracy of this method is unknown and when making decisions based on this information, only general conclusions should be considered.
- Reviewing wire break rates for similar mains: By reviewing the rate of wire break activity as determined through acoustic monitoring on other mains of similar vintage and design, a range of wire break rates can be determined. Using this range can provide either an optimistic or pessimistic outlook on the remaining service life of a pipe section.

No matter how the three variables affecting the service life of a pipe section are determined, a PCCP manager should understand that there are limitations to estimating service life. Given the limitations, it may be necessary to fix certain pipe sections prior to recognizing their full service life. However, by actually measuring the rate of wire breaks, estimating service life should provide adequate information to enable a PCCP operator to make intelligent decisions to mitigate risk and plan capital expenditures.

Extending service life

All water/wastewater managers are faced with the challenge of minimizing capital expenditures while ensuring that their customer's demands are safely met. Extending the service life of major, large diameter mains provides significant savings to an agency. Given that the replacement of a large diameter PCCP main in developed areas can cost tens of millions of dollars, if the service life of a PCCP main can be extended to avoid/defer a capital programme, the potential savings can be significant.

Safely extending service life relies on identifying and repairing the small percentage of damaged sections in a pipeline and relying on the pipe sections that are in good condition for more years of service. This approach often involves maintaining pipe sections that are classified as moderately damaged. Therefore, an approach to ensure the safety of moderately damaged pipes must be implemented. In general there are two approaches:

Figure 2
PCCP pipe section in a state if incipient failure

- Long-term structural monitoring: Long-term structural monitoring involves installing a permanent acoustic monitoring system on a pipeline that tracks wire break activity. Wire breaks detected by the system are added to those identified during a condition assessment. When managed in this fashion, the condition of the pipe is known in near real time and risk is continuously updated. Flags can be raised as individual pipe sections approach the maximum permissible number of wire breaks. This management approach is often warranted for critical pipelines, pipelines with multiple moderately damaged pipe sections, or pipelines that are difficult to inspect. This is the most reliable means to manage a pipeline with moderately damaged pipe sections.
- Periodic internal inspection: This involves periodically inspecting a pipeline perhaps every three to five years to ascertain an update on its condition. However, since the condition of a pipe can change quite significantly in this timeframe, it should be used for pipe sections that have relatively minor levels of damage and where consequence of failure is not significant.

In the author's opinion, long-term structural monitoring is the preferred approach for managing these types of mains. Long-term monitoring was first performed in the United States on a 102 inch (2m) PCCP main with an acoustic monitoring system that was installed in 2003 and continues to operate today. Data from inspections and the long-term monitoring system can be integrated into GIS and other asset management systems to allow for quick evaluation of data and subsequent assignment of risk. Figure 3 shows an example of a 96 inch (1.9m) PCCP main where this concept has been applied. In this case, the pipe has been plotted on an aerial photograph so that the operator can determine what above ground facilities would be affected by a pipe failure. A bar graph has been plotted on top of the pipe, providing wire break data and allowing for near real time assessment and risk evaluation for each pipe section. The height of the bar indicates the number of wire breaks and the colour of the bar provides an indication of risk associated with each pipe section. In addition, the PCCP operator receives an email each time a wire breaks on the pipeline and the risk has been re-assigned.

Conclusions

This paper described a management approach that has been implemented on approximately 500 miles (800km) of pipe that represents the state-of-the-art large diameter PCCP management. The management approach can safely extend the life of PCCP mains by relying on pipe sections in good condition or with moderate damage by managing risk through isolated repairs and long-term structural monitoring. The risk associated with each pipe section is updated as structural monitoring results are acquired. ●

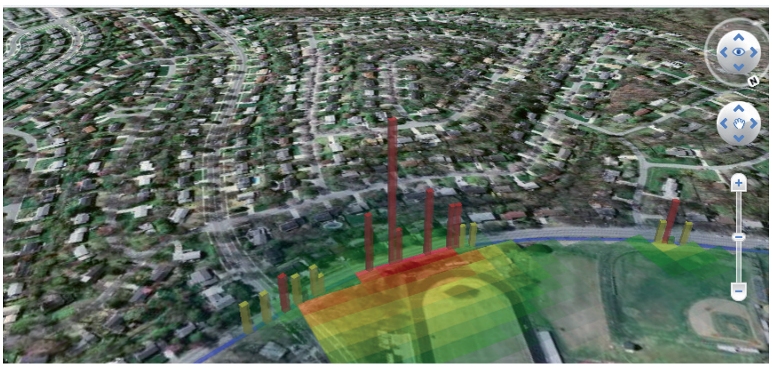

Figure 3
Near real time condition assessment and risk management data integrated with GIS and mapped. The columns indicate the number of broken prestressing wires on each pipe section (no bar indicates no broken wires) and the colour of the bar indicates the risk associated with a given pipe section.

The role of condition assessment and its application in asset management in North America – The Hillsborough County case study

Significant advances have occurred in the application of asset management strategies in North America in the last ten years, with condition assessment becoming a significant component in the process of determining residual asset lives. Although asset inventory and condition assessment of gravity sewer collection systems is well-established in the United States, protocols for the assessment of pressure pipe systems are relatively new and under development. The differences in methodologies for assessment, driven by the nature of these systems, makes the assessment of pressure pipe systems difficult. This is complicated by the continuing debate regarding the adoption of reactive and pro-active management strategies, with many authorities adopting an 'operate to failure' strategy for their non-critical mains. In contrast, Hillsborough County in Florida has undertaken a proactive approach to managing all its assets, including the pressure pipe/force mains in their water, wastewater and reclaimed (reuse) systems. The County's asset management programme includes all above and below ground assets, with the goal of prioritizing renewal and replacement of these assets as part of its capital improvements plan (CIP). In this paper, Stewart Burn, Will Williams, Sanjay Puranik and David Marlow describe a project undertaken with Hillsborough County that involved the application of condition assessment as a critical component of physical/probabilistic and statistical analysis to allow existing condition to be assessed for incorporation into the County's long term asset management strategy. They also detail how the risks and consequences of failure were determined and used to formulate a long term rehabilitation and replacement strategy to maximize the overall benefit to the County at optimal cost.

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One of the key issues to maintaining service levels is to understand the condition of the asset stock. Whilst there are many papers in the literature discussing condition assessment techniques[1,2,3,4,5,6], up until recently there have been no standardized guidelines for conducting condition assessment, nor have there been protocols to help utilities better understand asset condition, performance and the methodologies appropriate to different levels of sophistication in asset management.

In this context, the question arises as to how utilities should undertake condition assessment within an appropriate asset management framework to address the following:

- Meet customer service expectations as well as legislative requirements.
- Determine the risk of failure (probability versus consequence) associated with different assets, and therefore, prioritize spending within limited budgets.
- Understand asset condition and remaining life, allowing for proactive budgeting for renewal/replacement.
- Quantify the benefits of different management/operational strategies.
- Determine asset value and comply with accounting standards such as the Governmental Accounting Standards Board's Statement 34: Basic Financial Statements – and Management's Discussion and Analysis – for State and Local Governments (GASB 34).

The adoption of formal asset management processes by utilities has generally lagged behind the development of the asset stock. As such, asset management has commonly evolved and developed around existing utility systems and in light of existing assets, rather than being a planned process. The role of condition assessment as part of this strategy has generally been ignored and condition assessment has been applied in an unstructured manner.

As discussed by Marlow et al[7], Marlow and Burn[8] and Burn and Marlow[9], the development of asset management approaches can be characterized in terms of a succession of dominant philosophies. In reality, each successive approach builds on the previous one(s), so any explicit division is somewhat artificial. Nevertheless, for the purposes of this

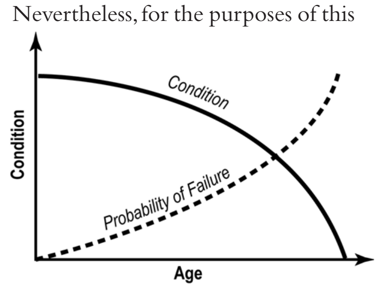


Figure 1
The relationship between asset condition, age and failure probability

discussion, it is useful to consider a distinct staged development of increasing asset management sophistication, namely:

- Condition-based asset management
- Performance-based asset management
- Service-based (service level driven) asset management
- Risk-based asset management
- Sustainability-based asset management

Since the more developed asset management philosophies do not focus on asset condition, it can be concluded that strategic asset management does not seek to manage asset condition or performance. Nevertheless, there remains a general relationship between the condition of an asset and its propensity to fail, as illustrated in Figure 1.

To maintain service into the future in an affordable way, the utility must therefore understand the change in structural condition, or the probability of failure of all its assets, both in space and in time[10]. Condition assessment can thus be used to develop or enhance this understanding in conjunction with assessments of performance undertaken at both asset-specific and system levels. In fact, the US Environmental Protection Agency (EPA)[11] noted that the best way to determine the remaining useful life of a system is to conduct periodic condition assessments, and that it is essential for utilities to complete periodic condition assessments in order to make the best life-cycle decisions regarding maintenance and replacement.

This is in direct contrast to the approach discussed by Burn et al[12], and illustrated in Figure 2, where condition assessment is generally utilized for proactive assets, with

Figure 2
Asset management strategies for assets with different probability and consequence combinations

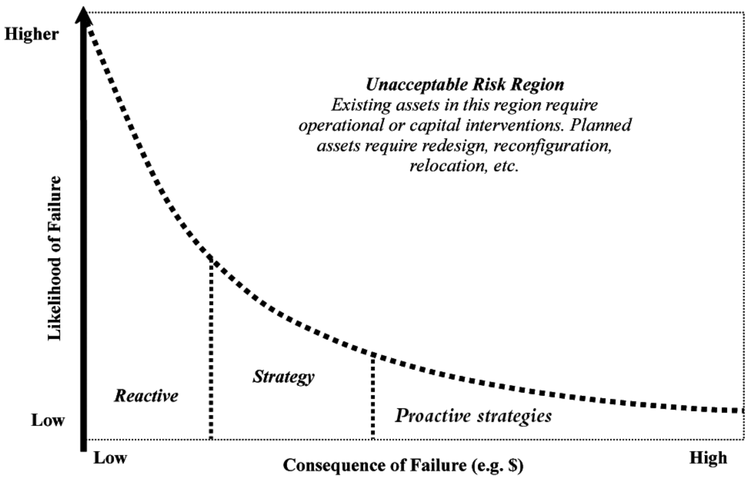
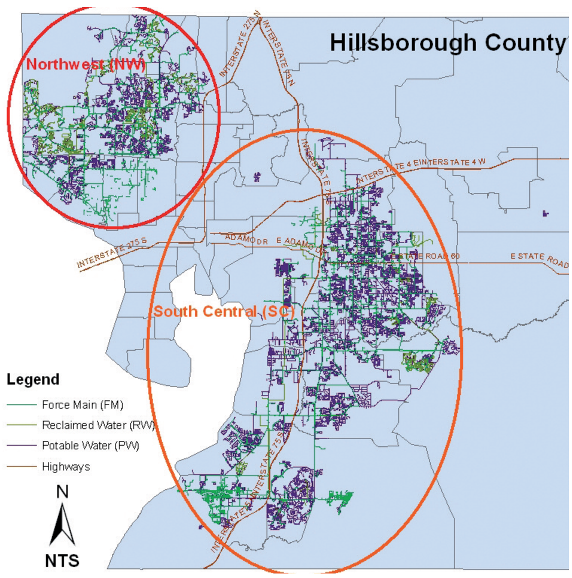


Figure 3
Hillsborough County Water Resource Services pipeline networks showing study areas North-West and South-Central



reactive assets left to operate to failure, using probabilities of failure determined from lifetime modelling to feed into the asset management approach. In this approach, condition assessment can still be used in a reactive strategy, but generally only to fill in data gaps left by the statistical and physical/probabilistic modelling. The approach discussed by Burn et al[12] is proposed because analysis using Net Present Value assessment indicates it is generally not financially viable to perform condition assessment on all assets, and thus the argument for run-to-fail on low risk assets.

As shown in Figure 2, proactive strategies are generally applied to assets when the consequences associated with failure are large, and there is the potential for authorities, municipalities and other segments of society to incur high costs (tangible and/or intangible). For such assets, the economics of preventing failure are advantageous and in these cases the application of condition assessment is generally warranted. While proactive strategies tend to be more justifiable at the high consequence end of the spectrum, they may also apply to lower consequence assets if the economics of this are favourable, for example, if low-cost condition assessment is available or if uninterrupted water supply is critical, e.g. for dialysis patients.

The challenge is thus when to consider the application of condition assessment for the whole range of asset management approaches currently in use; from simple asset management approaches through to strategic asset management approaches based on risk and sustainability paradigms. We therefore need to determine what an ideal practice for specifying the need for condition assessment is, while allowing for the fact that a significant proportion of utilities will not be in a position to adopt this ideal.

It is thus proposed that condition assessment should only be used where it is the most cost effective way to fill the required data gaps. High level monitoring of utility performance can be a corner stone of asset management, where routine activities do not generate all the data that is needed to manage the asset stock and support decision-making. This is especially true for below ground assets that are hidden from view and can operate for many years before deterioration is sufficient to cause operational issues. As such, even when strategic performance management is undertaken effectively, there is still a gap in the information required to manage the assets, which may be filled by undertaking asset-level condition and performance assessments.

This paper presents an overview of the techniques and processes used in the condition assessment of a pipe network in Hillsborough County, Florida, USA, where a significant condition assessment analysis has been undertaken in order to fill the information gaps with regards to asset condition. It could be argued that Hillsborough County could have used the current state of physical/probabilistic modelling to determine condition grade across the network and used limited condition assessment to confirm this. However, due to a number of the drivers discussed above, it chose to undertake a major condition assessment exercise to determine the current state of all of its assets. Whilst this exercise has shown that certain asset types should be treated in a pro-active mode, it has also shown that certain types can be treated in a reactive mode as discussed above.

Application of condition assessment in Hillsborough County

In the 1990s, Hillsborough County's Water Resource Services (WRS) identified the need for a proactive plan for renewal and replacement (R&R) of its assets. In order to implement the plan, a comprehensive asset management system was required, including an asset management strategy and a computerized maintenance management system (CMMS).

System	2007 length (ft)	2007 length (miles)	Number of pipes	Average failure rate (failures/mile/year)
PW – Potable water	11,296,790	2140	45,060	0.065
FM – Force main	3,609,414	684	6224	0.036
RW – Reclaimed water	1,705,868	323	1542	0.025

Table 1
Pipe lengths for individual pipe classification

The CMMS system was implemented by the County to provide the necessary support for the decision making process to prioritize the R&R of assets. However, to achieve this, a complete and accurate inventory of asset condition was needed. The condition assessment was undertaken utilizing the following process:

- Field inventory and initial condition assessment
  - Define geographic sub-areas for data collection and develop a data collection protocol
  - Data collection and update
  - Determine representative sample for condition assessment
  - Develop condition/useful life model for sample surveyed
  - Advanced condition assessment
- Determine sample sets for advanced condition assessment
  - Perform advanced condition assessment
  - Predict future failure from condition assessment information

Network details

As shown in Figure 3, the pipe network in Hillsborough County consists of two pipe clusters based around Tampa, Florida in the United States. Analysis of the network system utilizing the Geographic Information System (GIS) and pipe inventory database identified three distinct pipe types: potable water (PW); force wastewater main (FM) and reclaimed water (RW), with PW having the most installed length, as detailed in Table 1. Also detailed are the failure rates, which reflect the different pipe materials and pipe ages in these classifications.

Based on the knowledge gathered, a set of cohorts (groups of pipes exhibiting similar condition, performance and other characteristics that should be grouped for rehabilitation planning) was selected for the three pipe systems and subsequently used as input to the financial analysis. These cohorts were:

- Asbestos cement (AC)
- Cast iron (CI)
- Ductile iron (DI)
- Galvanised
- High density polyethylene (HDPE)
- Polyvinyl chloride (PVC)
- Pre-stressed concrete cylinder (PCCP) – (RCP in the figures)
- Other (remaining assets)

As shown in Figure 4, the majority of the potable water system consists of PVC with smaller percentages of DI, CI and AC, with a large percentage of the pipes being installed in the 1980s, as shown in Figure 5. Summaries of the PW, FM and RW networks are given below.

- In the case of the PW system, the predominant material is PVC and there is a dominance of 6 and 8 inch (152 and 203mm) diameter pipe.

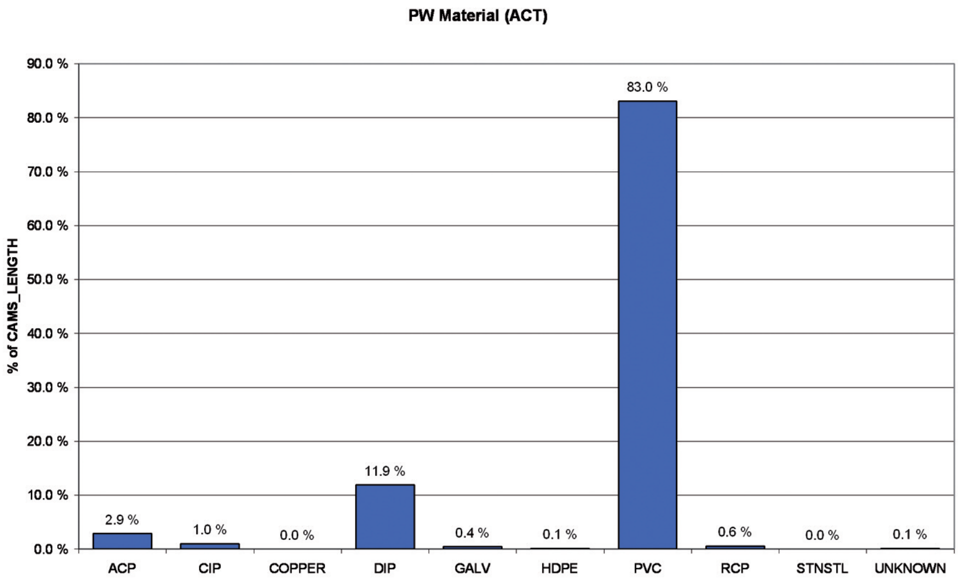


Figure 4
Material distribution, potable water

DI is also significant, and this tends to be for the larger diameter pipes (>8 inch). The installation of PVC has been significant from 1970 to current date, and the average age of the PVC and DI is approximately 20 years; this is a relatively young system.

- The RW system shows a similar characteristic to the PW system. The key difference is that the PVC installation has tended to be more recent (predominating from the 1980s onward) and this is reflected in the average age of the PVC, and DI, being approximately ten to 15 years.
- The FM system also has a large proportion of PVC, though the typical size range is greater (4-12 inch (102-305mm)) in comparison to the PW and RW networks. The amount of PVC installed has increased each decade since the 1970s.

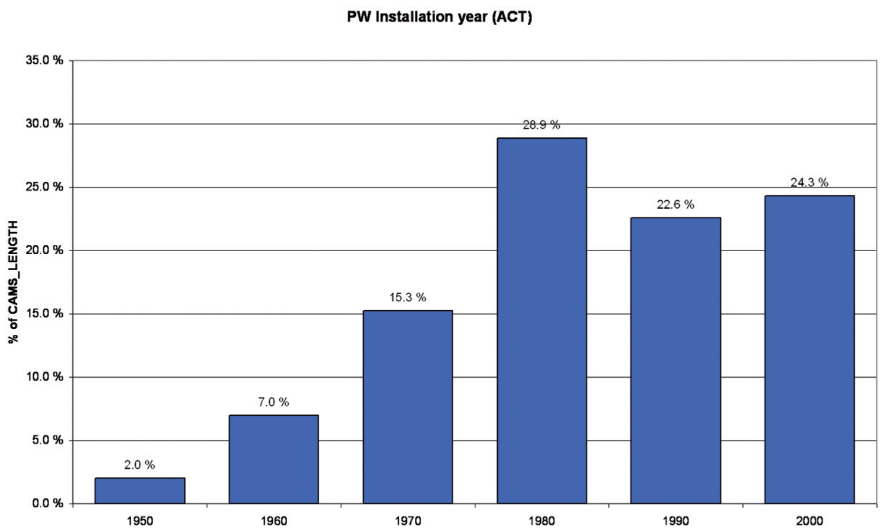


Figure 5
Material distribution, potable water

Based on this analysis, it can be observed that the properties and behaviour of PVC will be a major factor in determining the future rehabilitation strategy. The failure figures detailed in Table 1 are similar to failure results experienced to many utilities around the world[13, 14], with average failure rates in the United Kingdom being similar to the PW system at around 0.06 failures/mile/year[13]. As can be seen, the majority of the failures occur in the potable water system, with DI and PVC having the lowest failure rates as shown in Figure 6.

Results of the cohort analysis were used to make an initial assessment of rehabilitation needs of the system. This highlighted a number of areas where the potentially large cost of rehabilitation would justify a proactive management approach and where detailed condition assessment was therefore appropriate. It is interesting to note, however, that there were two conclusions from this analysis which were questioned, namely that there was apparently a significant amount of AC pipe that needed rehabilitation and that there were apparently two distinct failure rates observed in PVC pipe installed pre and post 1980. These are discussed in more detail below.

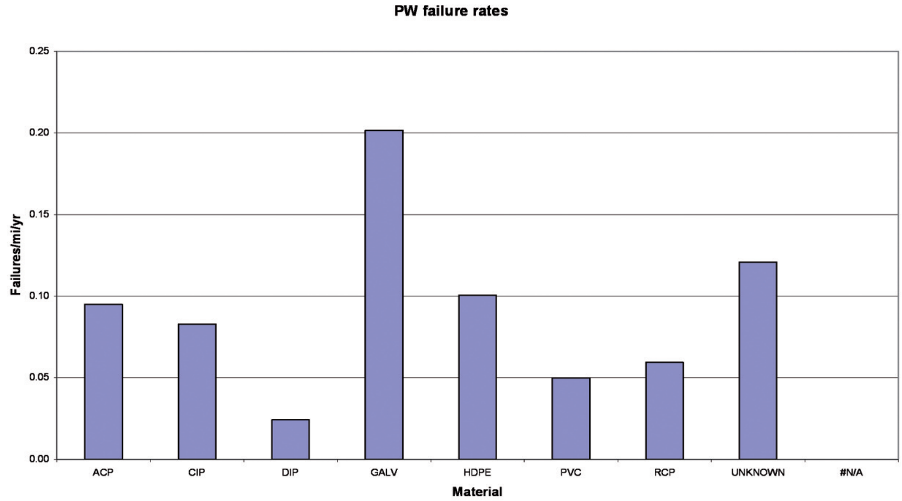


Figure 6
Failure rates for material cohorts – potable water

Advanced condition assessment

Pipes from the cohorts detailed above were selected for advanced condition assessment based on a statistical sampling procedure that took into account the risk/consequence of failure, pipe type, age, diameter, operating pressure and failure history.

Table 2
Relationship between condition grade and remaining asset life

Condition grade	Remaining life, years
1	> 50
2	>25 to 50
3	>15 to 25
4	> 5 to 15
5	≤5

A total of 258 pipe samples (21 CI, 65 DI, 160 PVC and 12 AC), representative of the pipeline systems, were selected and assessed using standard test procedures specific to each material type to allow prediction of residual lifetime. The findings were used to develop predictive condition models for all similar assets in the network using a five point condition grade index, as detailed in Table 2.

Condition assessment of CI and DI pipes

All CI and DI pipes selected for condition assessment were exposed in a trench to allow in situ inspection and pit depth measurement over the full circumference and for a length of approximately 3ft (approx. 1m). Pipes were sand blasted before inspection and measurement, although not all the pipes could be fully exposed around the pipe for reasons including: wet conditions, soils sticking to the pipe; and it being considered inadvisable to sand blast the pipe (due to its apparently poor condition). The depth of external pitting was measured using a pit depth gauge whilst the remaining wall thickness was measured using an ultrasonic device.

The ages of the pipe ranged from two years to 53 years. The pitting depths, external and internal (internal measurements were carried out on samples removed from the field), were highly variable between samples, as shown in Figure 7, with a trend for increasing pit depths with pipe age (both internal and external). Corrosion rates (combined internal and external) were highest for recent pipes (decade laid 2000s and average age three years), with a reducing trend to higher ages. This suggests that the corrosion rates are not linear but are higher for the initial burial period, gradually reducing with time.

It is of note that this is a typical observation for cast and ductile iron buried pipelines. There was no evident relationship between corrosion rate and pipe diameter for the samples examined.

Soil information indicated that the series of pipes examined were generally from sandy bedding. There were a small number of samples (eight) where clay was noted in the bedding, but these did not have significantly different external corrosion rates from other pipes. The difference in soil environment over all the pipes was felt to be too small to register as an influencing factor for these samples. Furthermore, a series of 18 samples experience brackish conditions with the seasonal high water table. An assessment of these samples showed no significant difference in external corrosion rates compared with other pipes.

Taking variability of corrosion rates into account, as well as the accelerated corrosion rate for younger pipes, an average corrosion rate model based upon calculated internal and external corrosion rates was calculated, as shown in Table 3. Estimations of remaining life were made by calculating both time to through wall corrosion and time to corroding to minimum wall (W_{min}), necessary to sustain system pressure, using the average combined pitting depth and using the lowest value to calculate the lifetime estimation. The trends observed tend to suggest that the most recently laid pipes will have shorter

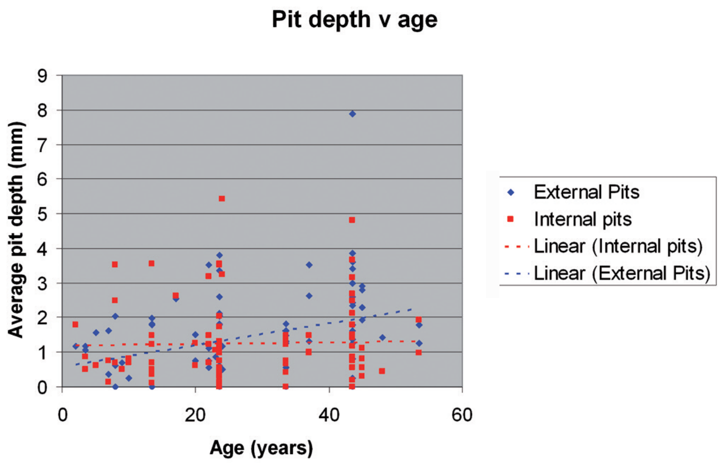


Figure 7
Pitting depths (average of five highest values) recorded on pipes of ages between two and 53 years

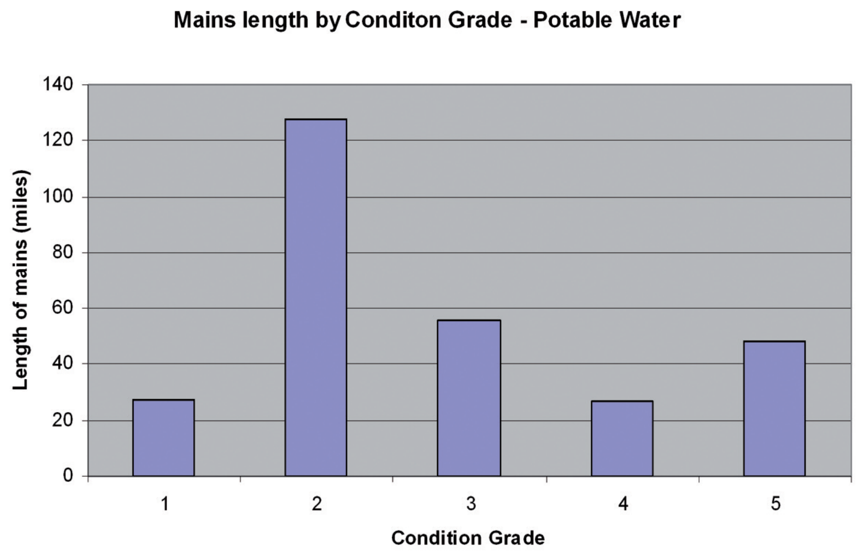


Figure 8
Pitting depths (average of five highest values) recorded on pipes of ages between two and 53 years

remaining lives than older pipes. Condition grades as shown in Table 2 were assigned to all assets based upon these remaining life estimations as shown in Figure 8 for the potable water assets.

Condition assessment of PVC pipes

The condition assessment work conducted on 160 exhumed PVC pipes focused on the measurement of the fracture toughness for PW, RW and FM pipes exhumed from the Hillsborough network and the calculation of residual life and thus condition based on these measurements.

A review of PVC pipe performance in North America[13] indicates that, although the failure rates of PVC are low, the majority of failures that do occur are reported as 'longitudinal fracture'. Figure 9 shows typical longitudinal fractures as seen in PVC pipe.

Since brittle fracture is expected to be the main failure mode for PVC pipes, condition assessment should target those properties that influence this failure mode. Therefore, advanced condition assessment for PVC pipes in this case consisted of defect size assessment and material fracture toughness assessment.

Due to the low number of inherent defects measured from the samples, a Hillsborough-specific distribution to describe defect sizes could not be created. As a distribution of this type is required for modelling pipe lifetimes, the values measured in the field were incorporated into an existing 2-parameter Weibull probability distribution[13] . The resulting distribution was found to represent all data and has the form as shown in Figure 10.

The material fracture toughness gives a measure of the resistance to fracture from defects for PVC pipes in service and can be used to estimate remaining life if the defect distribution and stress levels in the pipe are known. Using the International Standards Organization ISO 11673[15] C-Ring test method for fracture toughness, this property was assessed for 158 samples exhumed from the Hillsborough network with the results being shown in Figure 11 for the PW pipes.

The results show no significant variation in fracture toughness of the tested specimens based on 97.5% confidence limits. This contradicts the results of the cohort analysis, which saw two different failure rates, pre and post 1980. The lack of an age-related cohort is, however, in qualitative agreement with information supplied by Unibell indicating that PVC development over time in the USA has been incremental. The apparent difference in failure rates has been attributed to changes in reporting of failures and operational improvements as the system has expanded. The results generated indicate that PVC pipes can be represented by a single empirical fracture toughness curve for each of the PW, RW and FM pipe type, rather than a single cohort, because the manufacturing techniques will differ between these pipe types, due to the levels of recycled material used. Fracture toughness with time of these cohorts are given below:

Fracture toughness equation for PW PVC cohort

$K_I = 3.58t^{-0.007}$

Fracture toughness equation for RC PVC cohort

$K_I = 3.57t^{-0.004}$

Fracture toughness equation for FM PVC cohort

$K_I = 3.50t^{-0.006}$

Using these fracture toughness results and representative defect sizes, a physical/probabilistic model was developed following a previous study conducted by AwwaRF and CSIRO[13], where the time to failure in PVC pipes was predicted based on fracture mechanics theory. To account for realistic uncertainty in the failure process, a probability distribution was used to represent the variation in defect size in PVC pipes in service as shown in Figure 10. The details of the models are explained in Burn et al[13].

System Type	Material Type	Corrosion Rate (mm/year)
Potable	Cast	0.069
	Ductile	0.190
Reclaimed	Cast	0.157
	Ductile	0.157
Force main	Cast	0.120
	Ductile	0.109

Table 3
Summary of corrosion rate (mm/year) data – grouped by system type/pipe material combination

Running the model on individual pipes proved to be a computationally intensive task, and the simulation was thus run on cohorts of pipes for different values of pressure and diameter. From the simulated expected lifetime of pipe cohorts, the Weibull parameters of the distribution were defined and assigned to each pipe in the network, in order to estimate the remaining service lifetime of each pipe. From the calculated remaining service lifetime, the expected condition grades were assigned according to the classification detailed in Table 2 and shown in Figure 12 for potable water pipes. Analysis of the wastewater pipes showed a greater percentage of assets in condition 4 and 5 than shown in Figure 12.

Condition assessment of AC Pipes

Condition assessment of a limited number of AC pipes was carried out through determination of the indirect

Figure 9
Examples of reported 'longitudinal fracture' failures in PVC pipes.
(Note: These pipes are not from the Hillsborough network).

tensile strength of pipe wall core specimens, as shown in Figure 13.

The results were used as input to a model[16,17], to estimate the remaining service lifetime based on the rate of deterioration since installation, current operating parameters and loading conditions. Twelve core samples (one per pipe) were tested; these cores had been extracted from the wall of in-service pipes during normal operational activities. The core samples were extracted from pipes with a range of sizes from 4 inch to 18 inch diameter (100 mm to 457 mm nominal internal diameter), with differing installation years (to the closest decade), depths and operating pressures. The indirect tensile strength of these samples and the degradation rates calculated are shown in Table 4.

Variations in degradation rate can be attributed to the changes in water quality at the inner surface of the pipe (and hence cement leaching rates) and the inherent variation in the cement matrix structure produced during pipe manufacture. Since these processes (and their effect on strength loss) cannot be described completely, the best approach is to accept that uncertainty in degradation rate exists and incorporate this into a failure model. Therefore, a lifetime prediction model will not rely on single-valued deterministic measures, but will rely on a probability distribution function for degradation rate.

To quantify variation in degradation rates in AC pipelines, the Weibull Probability Density Function (PDF) has previously proven useful[16]. The Weibull probability density functions for degradation rate in pipes 1 to 12 are shown in Figure 14.

Monte Carlo simulation in conjunction with the physical/probabilistic failure model for AC pipes, as described in Davis et al[16,17] was used to estimate the expected time to failure in each pipeline. The Monte Carlo simulation allows determination of sample failure times by repeatedly generating random numbers for degradation rate (based on their probability distribution) and using these in the failure model to determine the time to failure for a set of trials. A number of lifetimes are predicted, which then allows the mean and standard deviation lifetime to be estimated.

A procedure was developed to extrapolate the results from the 12 test samples to estimate the expected failure lifetimes for the 851 AC pipes in the Hillsborough network. The procedure was based on the empirical degradation rate for each pipe determined by analysis of the 12 samples. In order to extrapolate the degradation rate results to obtain the remaining expected lifetime for each pipe of the network, a generalised linear model was defined. The model expressed the degradation rate of a pipe as a function of its internal pressure, diameter and the decade in which it was laid. This was done using the normal distribution applied to the 12 sample dataset. Once the coefficients of this model were defined and the degradation rate for each pipe calculated, they were used as inputs in the Monte Carlo simulation to assess the lifetimes of the 851 AC assets.

From the simulated expected lifetimes the Weibull parameters of the distribution were defined and the remaining service lifetime calculated for each pipe in the network. These were then assigned their expected condition grades according to Table 2. The results of this analysis disagreed with the cohort analysis, which had shown a significant amount of rehabilitation was required immediately. Discussion with County personnel identified that the high historic failure rate had in fact been caused by third party damage rather than material degradation.

Figure 15 shows the distribution of lengths of pipes in the network depending on their condition grade.

Condition assessment of other materials

Sections of other materials are present within the three systems totaled only 15 miles (24km) and were thus not considered to have a significant effect on the overall performance of the system. These materials comprised a mixture of legacy (e.g. galvanized iron, wood) and modern materials (e.g. PE). From an assessment of historical performance and using expert judgment, remaining life values were assigned to these materials. Pipes made of galvanized iron, copper and wood were considered to have effectively zero years remaining life. These are therefore included in the investment

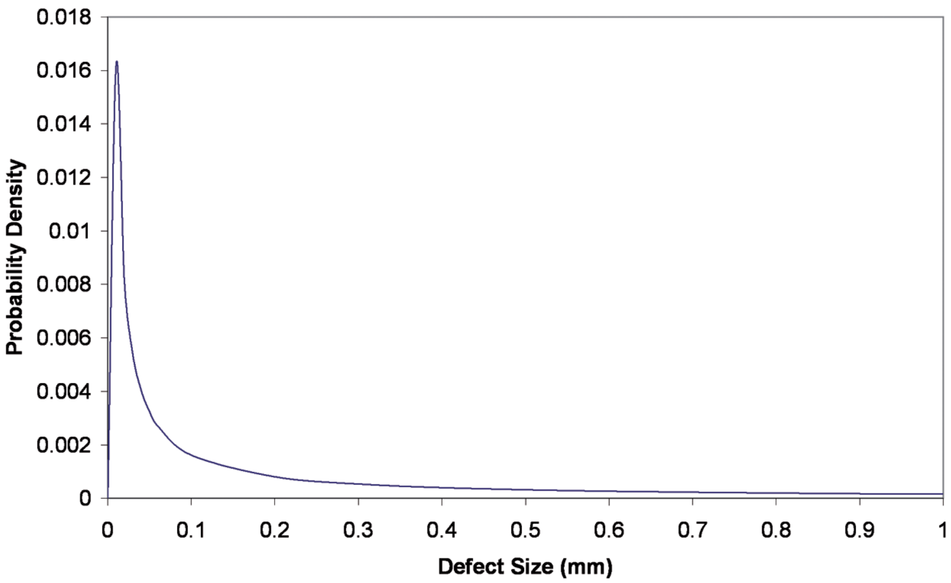


Figure 10 Weibull probability distribution for inherent defect size incorporating Hillsborough data

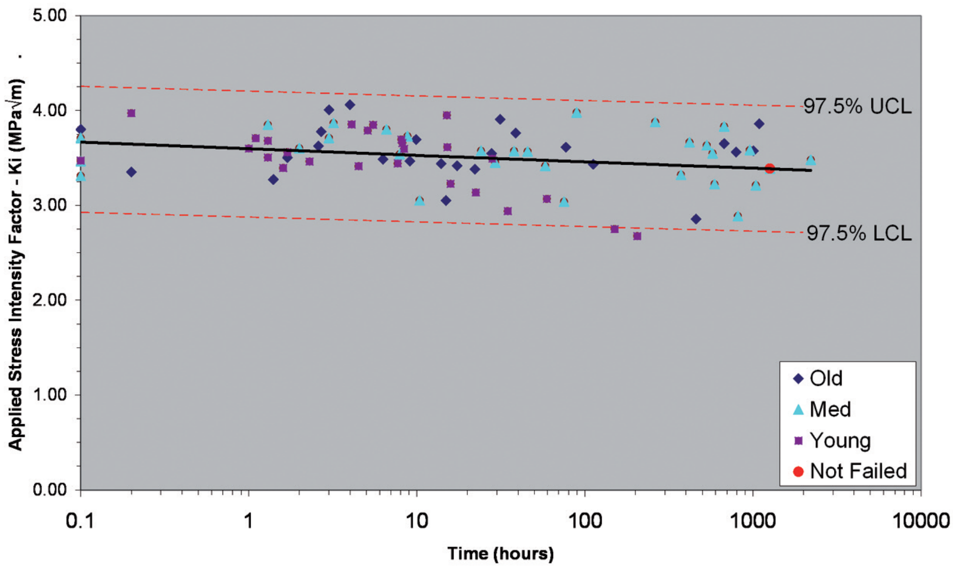


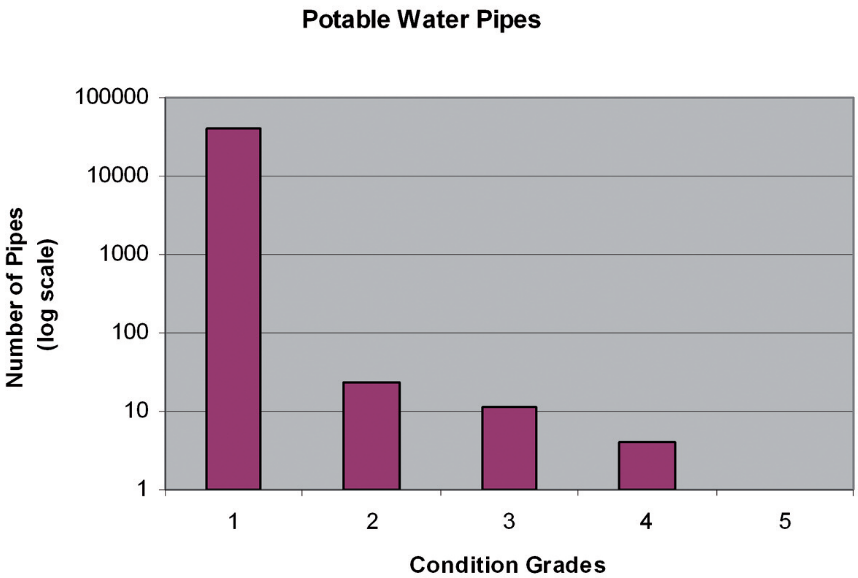
Figure 11 C-Ring fracture toughness test results for Potable Water (PW) PVC pipes from the Hillsborough network

Pipe Sample #	Pipe Age	Indirect tensile strength (MPa)	Degradation rate (sR) (MPa per year)
1	58	12.49	0.250
2	38	23.67	0.087
3	48	21.60	0.112
4	48	19.69	0.152
5	38	15.83	0.293
6	38	13.48	0.356
7	58	17.71	0.160
8	38	17.62	0.247
9	38	22.85	0.109
10	48	16.42	0.220
11	38	9.43	0.462
12	38	9.76	0.453

Table 4
Measured degradation rates (SR) in pipe samples

estimates. Other material types e.g. VC (vitrified clay), steel and PE were considered to have a remaining useful life of 60 years or better and therefore are not included in the 25-year time-frame for the investment budget.

Figure 12
Potable water pipe numbers by condition grade (log scale)



Financial modelling

Financial planning is a critical component of any asset management system, especially forward planning to allow adequate budgets to be set for asset renewal. This planning helps utility managers appraise the potential impacts of different long term rehabilitation scenarios, given a stock of pipes and their degradation characteristics. Financial planning should be based on the provision of certain levels of customer service and customer's willingness or ability to pay for such a service, e.g. no more than two water outages in any financial year, or no household shall be without water for more than 24 hours in any financial year. However, this requires a detailed understanding of the potential failures in each individual pipe, the effect that these have on customer service levels and an analysis of the costs associated with the failure and renewal of each asset.

Planning systems, such as the PARMS model[18,19,20] are currently available to allow this level of sophisticated analysis to be carried out, however, in this case the level of data was not high enough to allow the use of PARMS, so the CARE-W LTP (long-term planning) tool was utilized[21]. The CARE-W LTP tool is a tool for rehabilitation planning at the whole system level (it is not pipe specific so is not suitable for pipe level analysis and decision making). The tool determines long-term rehabilitation needs and associated cost, depending on the condition of the pipe system, local cost for repair and replacement, and different rehabilitation schemes.

CARE-W LTP uses the concept of pipe cohorts and survival functions to describe degradation. In this case, cohorts are groups or sub-families of pipes (organized by material, date of installation and total length of each sub-family) that are expected to age (deteriorate) in the same way (i.e. follow the same survival function). Material properties are always included in the definition of cohorts, but other properties (e.g. soil type) can be used as well. The input file for the model is normally created from a detailed database of network segments, such as a pipe GIS. Cohort definitions were confirmed with the help of local expert judgment and an analysis of failure data.

A number of cohorts were selected to describe the network's ageing and typically, a set of five to ten cohorts would be chosen for network analysis. For this project, fewer cohorts were sufficient for reclaimed water and force main, as these networks have a uniform composition with respect to materials, and in addition have a relatively shorter total length than potable water, where the cohorts were more detailed.

Figure 16 illustrates the survival function, failure rate, distribution and residual service life for a cohort of small AC pipes. The red curve is the pessimistic (short life expectancy), the

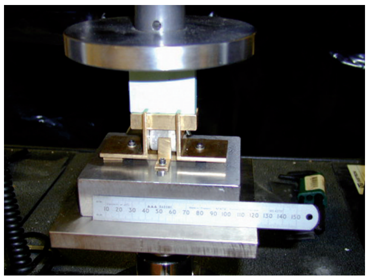


Figure 13
Testing core samples to determine indirect (splitting) tensile strength

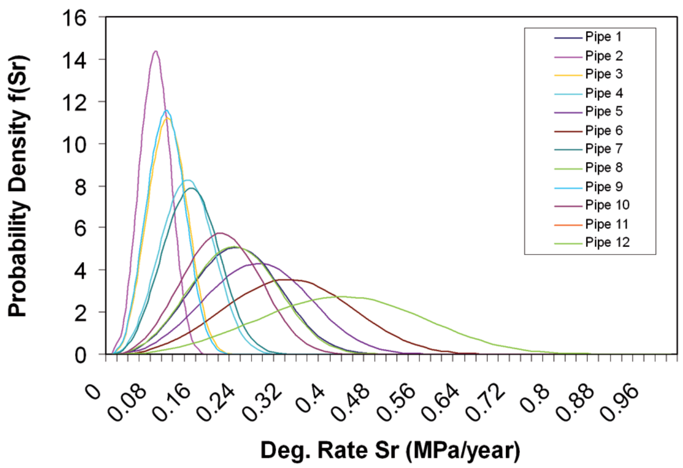


Figure 14
Weibull probability density functions for degradation rates in pipes 1 to 12

green curve is the optimistic (long life expectancy), while the black is the most likely expected survival function (derived from the red and the green).

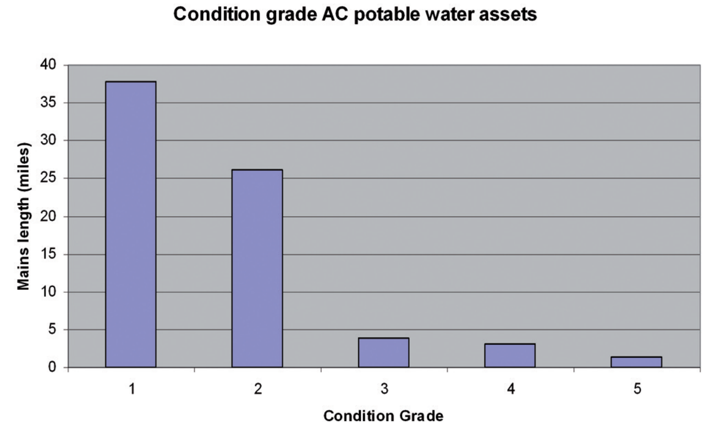
In this case 50% of the cohort will fail after approx 25 years following the pessimistic life expectancy, while according to the optimistic life expectancy this will take approx 45 years. Table 5 gives a more detailed analysis of the failure rates that can be expected for different survival functions.

Using the CARE-W LPT[21] tool the future network rehabilitation rates for each cohort were determined as shown in Figure 17 for the potable water network. This figure was used to calculate the length and percentage of pipe that will be replaced as it reaches the end of its life.

Using this procedure, an analysis of all assets was carried out to provide predicted levels of investment as shown in Table 6, based on the replacement of specific lengths of different pipe types as shown in Table 7. The investment model identified as 'Recommended' in Table 6 is the proposed strategy. The alternative 'Risk-averse' model is presented so that consideration can be made of an option with a lower level of risk (at greater cost), thus allowing for the outlier in the corrosion rates for metal pipes, thus allowing an informed decision during the budget setting process.

Based upon a detailed analysis of the cohorts and their condition grades, it was observed that the majority of replacements were to occur in the CI and DI pipes and thus it was recommended that these assets be managed pro-actively for early replacement. Conversely it can also be observed that few replacements would occur in PVC, AC and other materials and thus these materials should be managed reactively with pipe replacement on the basis of high levels of repeat breaks (when repair was uneconomic), it being understood that failures with these materials are predominantly due to third parties and failure at joints. The outcome of this analysis comes to essentially the same conclusion as discussed by Burn et al[12] and shown in Figure 2.

Figure 15
Lengths of assets by Condition Grade



be determined.

In this paper the role of condition assessment in asset management is discussed and a detailed analysis of condition assessment as applied to a water network in Tampa, Florida is carried out. Condition assessment in this case was used as a cost effective way to fill data gaps in the asset management methodology being applied by this utility.

Figure 16
Survival function, distribution, failure rate and residual service life for the AC pipe cohort.

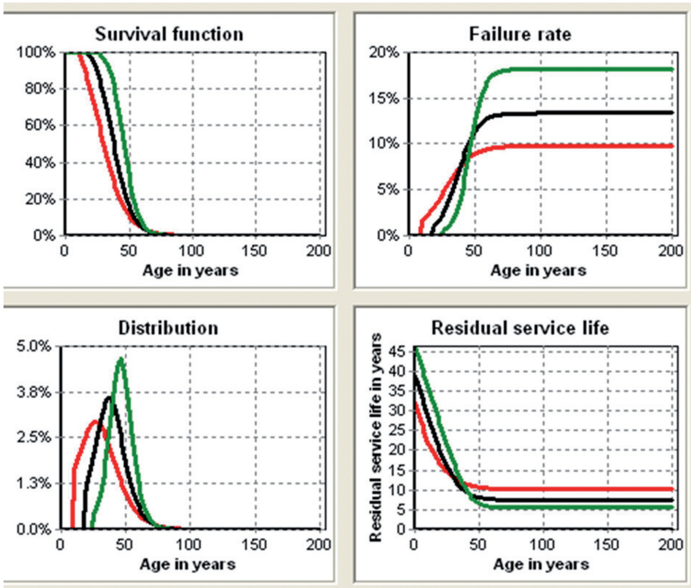


Table 5
Example of survival function input data

% of pipes that have survived	% of pipes that have failed	Lower Range (red line) Number of years that % of pipes would have survived	Upper Range (green line) Number of years that % of pipes would have survived
100	0	20	26
50	50	40	50
10	90	47	60

Conclusions

Condition assessment as a component of asset management is increasingly becoming a major consideration for water utilities wishing to implement a comprehensive asset management plan. Its role in determining the residual lifetimes of assets is, in many instances, a critical component, which allows the associated planning and rehabilitation costs associated with pipe repair or renewal to be determined.

Assessment of the network and its condition, using a range of assessment techniques found that failure rates are generally low, which reflects the fact that the system is relatively young and a primary composed of PVC, a material that is expected to perform well and not to deteriorate provided it had been manufactured, installed and operated correctly. Detailed analysis of the predicted failure rates of PVC, DI, CI and AC, indicated that the majority of failures were expected to occur in DI and CI, and that the majority of future costs would be associated with repairs to failures in these two materials.

The analysis reinforced a previously proposed strategy of dividing assets into reactive and proactive categories, and limiting condition assessment to the proactive category of assets unless there are significant reasons, such as data gaps for deviating from this strategy. In this strategy, for assets with a low consequence of failure, regular condition assessment cannot normally be justified and these assets should be operated to failure. For higher consequence assets condition assessment can be justified and should be applied using decisions based on the most suitable process for determining condition as discussed by Burn and Marlow[9].

The approach of undertaking a

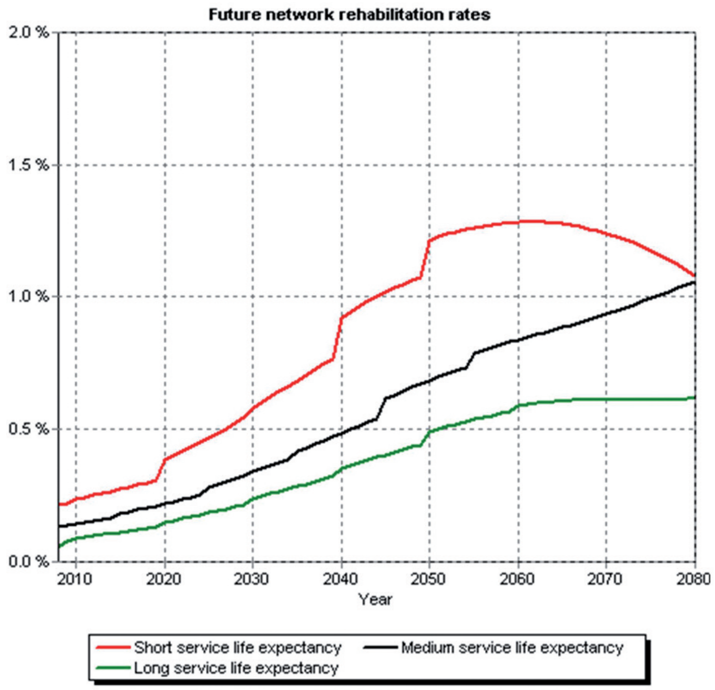


Figure 17
Example of CARE-W LTP output: future rehabilitation for a network

cohort based analysis and using the results to focus a more detailed assessment of condition was seen to be very cost effective. The detailed condition assessment phase contradicted some of the conclusions drawn from the cohort analysis, especially relating to AC pipes and PVC pipes and allowed the development of a more robust predictive model for rehabilitation planning. ●

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Model	**Investment period**		
	2009 to 2013	**2014 to 2023**	**2024 to 2034**
Recommended	38.9	22.9	41.9
Risk-Averse	64.2	53.1	73.8

Table 6
Investment Costs ($ million) (all assets) – recommended and risk averse models

Material	**Miles of pipeline replaced per year (in period)**		
	2009 to 2013	**2014 to 2023**	**2024 to 2034**
CIP + DIP	10.56	2.81	6.84
PVC	0.21	0.11	0.19
AC	0.28	0.32	0.39
Other	2.54	0.00	0.00

Table 7
Replacement rates (miles per year) for pipeline (by material) in period indicated

References

Burn, LS, Eiswirth, M, DeSilva, D and Davis, P (2001) Condition Monitoring and its Role in Asset Planning. Pipes Wagga Wagga, 15-17 October, Wagga Wagga, Australia.

Davis, P, Moglia, M, Burn, LS, and Farlie, M (2004) Estimating failure probability from condition assessment of critical cast iron water mains, Proceedings 6th National Conference, Australasian Society of Trenchless Technology (ASTT), Melbourne, Vic., 27-29 September 2004.

DeSilva, D, Moglia, M, Davis, P and Burn, LS (2002) Condition assessment and probabilistic analysis to estimate failure in buried pipelines. Australasian Society for Trenchless Technology, 19-21 August 2002, Sydney, Australia.

Dingus, M, Harven, J and Austin R (2002) Non-destructive, Non-invasive Assessment of Underground Pipelines. AwwaRf, Denver Co.

Eiswirth, M and Burn, LS (2001) New Methods for Defect Diagnosis of Water Pipelines. 4th International Conference on Water pipeline Systems, York UK, 28-30 March 2001.

Sadler PA, Davis P, Burn S, and Farlie M (2003) Benefits and Limitations of Non-destructive Broadband Electromagnetic Condition Monitoring Techniques for Ferrous Pipes, Pipes Wagga Wagga, 20-23 October, Wagga Wagga, Australia.

Marlow, D, Heart, S, Burn, S, Urquhart, A, Gould, S, Anderson, M, Cook, S, Ambrose, M, Madin, B, and Fitzgerald, A, (2007) Condition Assessment Strategies and Protocols for Water and Wastewater Utility Assets, (WERF Report 03-CTS-20CO).

Marlow, D and Burn S (2008) Effective use of condition assessment within asset management. Journal AWWA, (100.1) 54-63.

Burn, S and Marlow, D (2009) Strategic Asset Management and the Role of Condition Assessment. Singapore International Water Week – Water Convention, Singapore. 23-25 June 2009.

Burn, S, Marlow, D, and Tran, D (2009) The role and prediction of remaining service life in Strategic Asset Management . The 8th International Symposium on Water Supply Technology in Kobe 2009. 10-12 June, Kobe, Japan, Japan Water Research Centre.

US EPA (2002) The clean water and drinking water gap analysis. United States Environmental Protection Agency. Office of Water (4606M). EPA-816-R-02-020. September 2002.

Burn, S, Marlow, D, Moglia, M, and Buckland, P (2007) Asset Management for Water Infrastructure. Water Asset Management International 3.2, pp 12-18.

Burn, S, Davis, P, Schiller, TL, Tiganis, BE, Tjandraatmadja, GF, Cardy, M, Gould, S and Sadler, PA (2005) Long term performance prediction for PVC pipes, AwwaRF publication, AwwaRF.

Davis, P, Burn, S, Gould, S, Cardy, M, Tjandraatmadja, G, and Sadler, P (2007) Long term performance prediction for PE pipes AwwaRF publication, AwwaRF.

ISO (International Organization for Standardization) (2005) Unplasticized poly(vinyl chloride) (PVC-U) pressure pipes – Determination of the fracture toughness properties. ISO 11673. Geneva, Switzerland: International Organization for Standardization.

Davis, P, De Silva, D, Gould, S and Burn, LS (2005) Condition assessment and failure prediction for asbestos cement sewer mains, Proceedings Pipes Wagga Wagga 2005 Conf., Charles Sturt University, Wagga Wagga, NSW, Australia, 17-20 October.

Davis, P, De Silva, D, Marlow, D, Moglia, M, Gould, S, and Burn, S (2008) Failure prediction and optimal scheduling of replacements in asbestos cement water pipelines. J Water Supply Research and Technology – AQUA (57.4) (239-252).

Burn, S, Tucker, S, Rahilly, M, Davis, P, Jarrett, R, and Po, M (2002) Asset Planning for water reticulation systems – The PARMS model, IWA 3rd World Water Congress, Enviro 2002, Melbourne, Australia, 7-12 April 2002.

Burn, S, Ambrose, MD, Moglia, M and Tjandraatmadja, GF (2004) PARMS – an approach to strategic management for urban water infrastructure, IWA Leading-Edge Conference on Strategic Asset Management, San Francisco, 26-27 July 2004, 155-164., IWA, London.

Moglia, M, Burn, S and Meddings, S (2006) Decision support system for water pipeline renewal prioritisation, ITcon Vol. 11, Special Issue Decision Support Systems for Infrastructure Management, pg. 237-256, www.itcon.org/2006/18

CARE-W, Computer Aided Rehabilitation for Water Networks. Editor: Sveinung Saegrov, ISBN: 9781843390916. IWA Publishing, London, UK.

Strategic Asset Management: The Quest for Utility Excellence
Author: Clive Deadman
Utility providers are under pressure from all sides to reduce costs, while improving availability, reliability, safety and sustainability. As economies battle to recover from the 2008-2010 recession, utility company spending and results will be under closer scrutiny than ever to deliver more performance for less. This book explores the new techniques which are being used by leading utilities

While relevant to everyone regulating, supplying or working in the utility sector, this book is important for us all. As the assets employed by utilities account for 5% of global GDP the cost of replacing our aging utility infrastructure is unaffordable. However, utility services are essential to civilisation.

This book answers the key question of how utilities can select the right goals, organisational design, culture and engineering tools, which allow them to manage their complex asset bases and deliver truly excellent performance.

With 37 case studies and 50 diagrams, it illustrates the snakes and ladders that leading utilities have experienced on the path to excellence.

Troubador Publishing March 2010
ISBN: 9781848763661
Price: £28.00
For more information, visit: www.troubador.co.uk

Inspection Guidelines for Wastewater Force Mains
WERF Report 04-CTS-6URa
Authors: James Thomson, Robert S Morrison and Tom Sangster
This report brings together a body of information on the characteristics of the wastewater force main network and the most common defects encountered. The technologies and methods used by utilities to inspect the force mains to identify and locate these defects are identified together with what are the perceived unmet needs. This report provides a comprehensive review of the current state-of-the-art in inspection technology for pressure pipelines. It also reviews the data management and processing and considers the application, effectiveness, and suitability of the technologies reviewed for use in force mains. The report also provides a risk-based failure evaluation.

Innovative inspection technologies and methods for force main inspection are reviewed under five categories: external inspection of ferrous force mains; internal inspection of ferrous force mains; inspection of asbestos cement force mains; inspection of prestressed concrete cylinder pipe force mains; and inspection of plastic force mains.

The study includes ten case studies of actual inspections undertaken on pressure mains using technologies reviewed in the report. It proposes a structured approach to force main investigation driven by information need and cost-effectiveness within a condition assessment and asset assessment programme. It provides guidelines for developing and implementing force main inspection programmes.

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ISBN: 9781843392866
330pp. PDF
Price: £98.70
IWA members price: £74.03
Only available as an online PDF
For more information, visit:
www.iwapublishing.com

Remaining Asset Life: A State of the Art Review
WERF Report SAM1R06d
Author: Anthony Urquhart
This report is an output of the fourth research track (Track 4) of WERF's strategic asset management research programme 'Asset Management Communication and Implementation' (SAM1R06). Track 4 addressed 'remaining asset life', and had the overall objective of contributing to the development of techniques, tools and methods for estimating residual life of wastewater assets. Track 4 research was planned to be undertaken in a staged manner, so as to provide a stepwise development of concepts and protocols.
To this end, the research team has produced a synthesis of knowledge in relation to 'end of life' and 'remaining asset life', which is the subject of this report.

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188pp. Paperback
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Water Utility Benchmarking
Measurement, Methodologies, and Performance Incentives
Author: Sanford Berg
Benchmarking is essential for those developing and implementing water policy. If decision-makers do not know where they have been or where they are, it would seem to be impossible to set reasonable targets for future performance. Information on water/sewerage system operations, investments, and outputs is essential for good management and oversight. This book is designed to help decision makers identify the data required for performance comparisons over time and across water utilities, to understand the strengths and limitations of alternative benchmarking methodologies, and to perform (or commission) benchmark studies.

This book provides an overview of the strengths and limitations of different methodologies for making performance comparisons over time and across water utilities (metric benchmarking). In addition, it identifies ways to determine the robustness of performance rankings.

Current benchmarking activities in Latin America, Asia, Africa, Central Europe/Asia, and OECD nations are summarized.

Five basic approaches to benchmarking characterize current studies:

- Core indicators and a summary or overall Performance Indicator (partial metric method)
- Performance scores based on production or cost estimates ('total' methods)
- Performance relative to a model company (engineering approach)
- Process benchmarking
- Customer survey benchmarking

This volume is of interest to the water professionals, water utility managers and senior staff of regulatory agencies, professionals in related government agencies, and consultants.

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For more information, visit:
www.iwapublishing.com

Integrated High Resolution Imaging Radar and Decision Support System for the rehabilitation of WATER PIPElines
Editors: Matthaios Bimpas, Angelos Amditis and Nikolaos Uzunoglu
Many EU cities are experiencing increasing problems with their water pipeline infrastructure. The cost of replacing these old, worn-out systems, if left to deteriorate beyond repair, is astronomical and clearly beyond the resources of many communities. Replacement, however, is not the only choice as many of these systems can be rehabilitated at 30 to 70 percent of the cost of replacement. Accordingly, resources are now increasingly being allocated to address pipeline rehabilitation management issues.

Due to the emphasis on sustainable management, risk-based approaches for the rehabilitation management of the water supply network need to be developed. Rehabilitation decisions should be based, interalia, on inspection and evaluation of the pipeline conditions. Yet, utilities cannot locate a number of their old pipes and current inspection technologies typically do not provide the needed detailed information on pipeline damage.

The objectives of this book are to describe the research work carried out in the framework of WATERPIPE project, aiming to: develop a novel, high-resolution imaging ground penetrating radar for the detection of pipes, leaks and damages and the imaging of the damaged region and evaluate it at a test site; produce an integrated system that will contain the equipment and a Decision Support System (DSS) for the rehabilitation management of the underground water pipelines that will use input from the inspections to assess, probabilistically, the time-dependent leakage and structural reliability of the pipelines and a risk-based methodology for rehabilitation decisions that considers the overall risk, including financial, social and environmental criteria; and field test the equipment and the DSS.

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Benchmarking Water Services

Guiding water utilities to excellence

Authors: Enrique Cabrera Jr., Peter Dane, Scott Haskins, Heimo Theuretzbacher-Fritz

Benchmarking has become a key tool in the water industry to promote and achieve performance targets for utilities. Utilized as an 'instrument for performance improvement through systematic search and adaptation of leading practices', benchmarking activities have expanded globally. Nowadays, many projects are being carried out worldwide to meet different needs and objectives, in varying contexts, with outstanding results and impact. However, despite the many projects, published papers and ever growing interest in this field, the terms and concepts used by the industry are far from being consistent.

This Manual of Best Practice is edited by the IWA Task Group on Benchmarking (a joint effort of the IWA Efficient Operation & Management Specialist Group and IWA Statistics & Economics Specialist Group) and co-published by AWWA and IWA Publishing. The manual provides valuable information to those planning to get involved in a benchmarking project and even to experienced practitioners.

The objectives of this manual are to define a new framework in which the traditional benchmarking concepts can be clearly distinguished, guaranteeing more fluent and efficient communication. The manual intends to be a hands-on document, with a practice oriented approach, both from the perspective of those organizing a project, as well as the needs of potential participants and even beginners in the topic. This practical how-to information originates in the experiences gathered in some of the most relevant benchmarking projects in the water industry to date, including the IWA-WSAA benchmarking efforts, the European Benchmarking Co-operation and the several benchmarking projects carried out in Austria and Central Europe.

This title belongs to Manual of Best Practice Series.

AWWA and IWA Publishing 1 September 2010
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IWA members price: £60.00/US$108.00/€81.00
For more information, visit: www.iwapublishing.com

Water Infrastructure for Sustainable Communities

China and the World

Editors: Xiaodi Hao, Vladimir Novotny and Valerie Nelson

A new model for water management is emerging worldwide in response to water shortages, polluted waterways, climate change, and loss of biodiversity. Cities and towns are questioning the ecological and financial sustainability of big-pipe water, stormwater, and sewer systems and are searching for 'lighter footprint' more sustainable solutions. Pilot projects are being built that use, treat, store, and reuse water locally and that build distributed designs into restorative hydrology.

This book has been developed from the conference on Sustainable Water Infrastructure for Villages and Cities of the Future (SWIF2009) held in November 2009 in Beijing (China) that brought together an international gathering of experts in urban water and drainage infrastructure, landscape architecture, economics, environmental law, citizen participation, utility management, green building, and science and technology development.

Water Infrastructure for Sustainable Communities China and the World reveals how imaginative concepts are being developed and implemented to ensure that cities, towns, and villages and their water resources can become ecologically sustainable and provide clean water. With both urban and rural waters as a focal point, the links between water quality and hydrology, landscape, and the broader concepts of green cities/villages and smart development are explored.

The book focuses on decentralized concepts of potable water, stormwater, and wastewater management that would provide clean water. It results in water management systems that would be resilient to extreme events such as excessive flows due to extreme meteorological events, severe droughts, and deteriorated water and urban ecosystem quality. A particular emphasis is placed on learning lessons from the many innovative projects being designed in China and other initiatives around the world.

The principal audience for the book is university faculty and students, scientists in research institutes, water professionals, governmental organizations, NGOs, urban landscape architects and planners.

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AM DIARY

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

Water Loss 2010
6-9 June 2010, Sao Paolo, Brazil
Email: committee@waterloss2010.com
Web:www.acquacon.com.br/waterloss2010/en

7th International Conference on Sustainable Techniques and Strategies for urban Water Management
28 June-1 July 2010, Lyon, France
Contact: Novatech Secretariat
Tel: +33 (0)4 72438368
Email: novatech@graie.org
Web: www.novatech.graie.org

Singapore International Water Week
28 June-2 July 2010, Singapore
Contact: Samantha Shoo
Tel: +65 6346 4402
Email: waterconvention@siww.com.sg
Web: www.siww.com.sg/water-convention

Sustainable Water Resource Conference and Exhibition
27-28 July 2010, CSIR International Convention Centre, South Africa
Tel: 021 447 4733
Email: sales@waterresource.co.za
Web: www.waterresource.co.za

9th International Conference on Hydroinformatics 2010
7-11 September 2010, Tianjin, China
Contact: Ivan Boo, Conference Manager, Singapore
Tel: +65 6356 47272
Email: confmgr@hic2010.org
Web:www.hic2010.org

12th Annual Water Distribution Systems Analysis Conference - WDSA 2010
12-15 September 2010, Tucson, Arizona, USA
Web: http://wdsa2010.org

IWA World Water Congress
19-24 September 2010, Montreal, Canada
Tel: +31 703 150 793
Email: 2010montreal@iwahq.org
Web:www.iwa2010montreal.org

2nd WaterLoss Asia 2010 Conference and Exhibition
14-15 October 2010, Kuala Lumpur, Malaysia
Web: www.waterlossasia.com

6th International Conference on Sewer Processes and Networks
7-10 November 2010, Surfers Paradise, Australia
Web: www.iwahq.org

International No-Dig 2010
8-11 November 2010, Singapore
Tel: +44 (0) 845 0948066
Email: trenchless@westrade.co.uk
Web: www.nodigsingapore.com

Vietwater 2010 Water and Wastewater Industry Show
10-12 November 2010, Saigon Exhibition and Convention Centre, Ho Chi Minh City, Vietnam
Tel : +603 40454993 (Malaysia Office),
+84 4 62872679 (Vietnam Office)
Email: richard@ambexpo.com / support@ambexpo.com
Web: www.vietwater.com

Aquatech India
2-4 March 2011, Mumbai, India
Web: www.india.aquatechtrade.com/in/en/Pages/default.aspx