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PAPERS

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Bank-led group establish water centre

The Inter-American Development Bank (IADB), Fundación FEMSA and the Tecnológico de Monterrey have entered an agreement to create the Latin American and Caribbean Water Centre, with an initial investment of $11 million.

Fundación FEMSA, founded by beverage company FEMSA, is starting its work with this project. The foundation plans to develop projects in cooperation with institutions committed to community welfare around the world.

The Water Centre will be operated by the Tecnológico de Monterrey and will jump-start programmes and projects that support initiatives related to the use, management and conservation of water resources in Latin America and the Caribbean.

The IADB notes that it considers the proper management and distribution of water resources to be a key prerequisite to health and economic growth in the region's countries.

IADB president Luis Alberto Moreno said: 'Some 85 million people in Latin America and the Caribbean still do not have access to potable water, and more than 115 million do not have access to sanitation services. This Centre is a call to think big and to seek ambitious, definitive solutions to these problems.'

The Centre will offer training, research and information management for the conservation and sustainable use of water, promote strategic alliances, and offer world-class technical expertise and innovative approaches to the sector's problems, based on a broad understanding of the major issues affecting the countries in the region, he added.

Its programmes will be aimed at professionals in national and regional government agencies, and companies involved in managing and using regional water resources.

Mr Moreno added: 'Every country in Latin America and the Caribbean urgently needs trained professionals, and launching the Centre is a very important step in that direction. The Centre will be an invaluable platform for developing the abilities and knowledge that will move us toward better management and use of the region's water resources.'

IADB approves water and sanitation loan for Buenos Aires

The Inter-American Development Bank (IADB) has approved a $200 million loan to expand potable water and sanitation services in the Buenos Aires metropolitan area and suburbs.

The project is part of a wider programme that aims to add 1.5 million users to the water service and 1.4 million to the sewer system between now and 2011.This is the first loan within a $720 million conditional credit line for investment projects approved by the IADB.

The expansion of potable water and sanitation services includes the construction of a collector sewer and pumping stations in the municipality of Tigre, which will enable the system to serve an extra 220,000 residents and the construction of sewage networks in the municipalities of Tres de Febrero, Hurlingham and Ituazingó, which will serve 108,000 residents.

The project also includes a plan to reduce unaccounted-for water in order to reduce losses and make the best use of the distribution system, saving nearly 100,000m^3/day of water, and improvements to the San Martín potable water plant, which supplies 4.8 million people. Utility Agua y Saneamientos Argentinos will carry out the work.

ADB provides extra funding for Kyrgyz Republic watsan project

The Asian Development Bank (ADB) is granting an additional $30 million to a project that will provide cleaner drinking water and better sanitation for 1.5 million people in the provinces of Chui, Jalal-Abad, Osh, and Batken in the Kyrgyz Republic. The community-based infrastructure services sector project was initially approved in 2000, with ADB extending a $36 million loan. The additional Asian Development Fund grant will ensure completion of the project following sharp increases in the prices of various basic commodities such as steel and cement during project implementation.

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EDITORIAL

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Application of a DPA method for asset management in small water distribution systems

This paper describes a decision support algorithm for assisting with the establishment of infrastructure investment plans for small water systems. It describes the methodology adopted, the key features of the prototype computer application developed, and refers to an academic study that was carried out in collaboration with a Portuguese research centre and a private water supply service provider. A deterioration point assignment (DPA) method was adopted because DPA methods are particularly suitable for application to systems characterized by a lack of pertinent information, which is typically the situation in small utilities. The water distribution network of a Portuguese village, Marco de Canaveses, is presented as a case study, serving as a basis for discussion and demonstration of model applicability.

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Introduction

Asset rehabilitation is a topic of paramount importance for the optimal management of drinking water infrastructures.

The importance of the benefits that an efficient and effectively managed infrastructure network provides to the overall society is obvious. It is no less true that if some infrastructures bring competitive advantages, others like drinking water distribution and the wastewater collection systems are the cornerstone of the public health system, and define the society development standards.

The unstoppable increase in the infrastructure network, combined with its ageing and the impossibility of permanent and continuous replacement, brings out the need for improving the infrastructure asset management methods.

This requires a theoretical and practical effort to find new models beyond the traditional economical ones. The main goal is clearly to develop models that allow a resource rationalisation and minimise costs (especially re-investment ones).

Recently, sophisticated and powerful algorithms and decision support tools have been made available. However, most of them are too data-demanding to be applicable to small water systems. The European R&D network COST C18 – Performance assessment of urban infrastructure services: the case of water supply, wastewater and solid waste (www.costc18.org) identified the 'Efficient management of small community systems' as a top research priority. In fact, these utilities are typically characterised by constraints in terms of number and degree of expertise of their staff, of the technical and financial resources available. Consequently, small systems tend to lack good data, which is a shortcoming for the implementing of advanced asset management programmes. Most countries, including the most developed ones, face this problem. Norway, Germany and Austria are just three good examples of industrialised and wealthy countries where the number of small utilities is very high. In Portugal, most systems are small sized: an estimate of about 18% of the Portuguese population receives drinking water from small or very small supplies (population ≤5000 inhabitants), representing 92% of the total number of drinking water systems. In recent years, especially after Portugal joined the EU in 1986, large investments were made in the water distribution systems, leading to an average of 93% of the total population being served by public systems providing safe drinking water. The priority now is to manage these assets in a sustainable way.

This paper focuses on a study that aimed at designing a decision support algorithm for assisting in establishing infrastructure investment plans of small water systems. It describes the methodology adopted and the key features of the tool developed. This is an academic study that was developed with a Portuguese research centre and a private water supply service provider.

A sound technical and scientifically-based decision support tool was developed to assist in the implementation of water infrastructure asset management, at a basic level.

A model based on a deterioration point assignment (DPA) method was adopted because DPA methods are particularly suitable for application to systems characterized by lack of pertinent information.

The need for this study was identified in a research programme on water infrastructure asset management (Alegre, 2007), recently concluded at the National Civil Engineering Laboratory (LNEC), in Lisbon. The study was carried out in the scope of a master thesis at the University of Minho. The team also included two senior engineers from AGS, a private holding, and the executive manager of Águas do Marco, SA, a subsidiary company of AGS that has a 25 years concession contract to run the water supply systems of Marco de Canaveses, a village located in the North of Portugal.

The water distribution network of Marco de Canaveses is presented as a case study, serving as a basis for discussion and demonstration of the model applicability.

Underlying assumptions

The main assumption made was that the starting point is poor in terms of available data and information systems, but there is a corporate will for change in terms of the asset management (AM) practices. This corresponds to the following specific underlying assumptions considered:

(i) inexistence of reliable and well structured failure records;
(ii) inexistence of other reliable and well structured data on asset condition;
(iii) availability of qualitative information about construction quality;
(iv) knowledge of the order of magnitude of asset age;
(v) availability of asset inventory (i.e. preliminary work to create an updated asset inventory must be carried out if an asset management strategy is going to be implemented);
(vii) availability of a Geographic Information System (GIS);
(vi) inexistence of accounting information at the individual asset level;
(viii) need for an easy to use tool, not too demanding in terms of data collection and input;
(ix) need to accommodate a potential further migration to a more sophisticated asset management system.

The case study of Águas do Marco complies with all these requirements. Although the inventory available when the concession started was rather incomplete and outdated, a detailed mapping was elaborated and loaded into a GIS. There were no records of failures or interventions. This information has in the meantime started to be collected in a structured way and stored in the GIS. The accounting data is not sufficiently detailed to be used to support an AM approach. Due to the way the concession contract is set up, it is not foreseen that intervention costs are going to be accounted for in a way that can be allocated to individual assets. There is no recorded information about the asset construction quality and current condition. However, some of the field workers know the network well, as well as the construction companies who built it. They have a good qualitative knowledge of the situation.

Objective of the study

The objective of the study is:

- To identify the core information necessary to support an asset management strategy in small water utilities complying with the underlying assumption presented;
- To develop an algorithm that makes the most of the available information and mitigates the effects of the lacking data;
- To develop algorithms to assess global rehabilitation needs, current asset values, intervention priorities and corresponding asset needs, based on a whole of asset life costs approach;
- To develop a simplified computer application, in the form of a worksheet, that supports data collection, implements the methodology proposed and can be used directly by decision makers, or as a prototype for the development of a professional information system.

Looking for simplicity as a key requirement, this methodology was developed on the widely spread Microsoft Excel software. In its current form, it is applicable to mains and service connections of water distribution networks. However, the approach can be adapted to other type of assets. The case of water mains was chosen because:

- they represent the most valuable type of assets in an typical water supply system;
- they are a challenging type of asset because they are buried and not easily inspected.

Key references of the model developed

The algorithm adopted is inspired in the procedure recommended in the asset management workshops run by the Environmental Protection Agency (EPA) (Parsons-GHP, 2006) and in the Deterioration Point Assignment (DPA) model.

Parsons-GHP (2006) is a Microsoft Excel application structured in the following main sections:

- Asset register and hierarchy.
- What is the state of my assets?
  - Installation date;
  - Asset class;
  - Original cost;
  - Estimated service life;
  - Condition rating;
  - Effect life adjust factor;
  - Calculated residual physical life;
  - Judgment residual life;
  - % asset consumed (physical);
  - Annual depreciation;

Table 1 Performance rating as defined in Parsons-GHP (2006)

Performance rating	Global relative benefit
1	Exceeds / Meets all Performance Targets
2	Minor Performance Deficiencies
3	Considerable Performance Deficiencies
4	Major Performance Deficiencies
5	Does not meet any Performance Targets

- Accumulated depreciation;
- Current performance;
- Current reliability.

• Required levels of service (LOS)?
- Current LOS?
- Minimum Condition.

• Which are most 'Critical'?
- Backup Reduction (Redundancy);
- Probability of Failure;
- Consequence of Failure;
- Business Risk Exposure Rating.

• What strategies?
- Renewal strategy;
- Maintenance strategy;
- % Change of future maintenance;
- Cost of renewal option;
- Recommended renewal date;
- Present value of renewal cost.

• What Funding Strategy?

pipe by adding the failure scores of the individual factors. If the total failure score exceeds a threshold value, the pipe is considered a candidate for replacement/repair. The model allows fully customisable numerical scores, so that it can be adjusted to the particularities of each water distribution system. Factors may include pipe age, pipe material, pipe diameter, type of soil, service pressure, history of previous breaks, or any other relevant explanatory aspects factors (Deb et al., 1997; Loganathan et al., 2002; Park & Loganathan, 2000).

Model description

An hierarchical structure is adopted for the assets. Four levels are considered:

Table 2 Grading scheme for expressing the asset installation quality

Installation quality	Global relative benefit
1	Excellent
2	Good
3	Average
4	Poor
5	Very poor

Many of these aspects are specified as grades of predefined classes. For instance, current performance shall be expressed according to the definitions of Table 1.

In a way, Parsons-GHP (2006) is partially based on a DPA scheme. In the DPA schemes, a set of factors which are known to contribute to the pipe failure rate are identified. These factors are split into categories and then assigned numeric scores (weights). Once the scores for each factor are established, a total failure score is obtained for every

Level 1: System;
Level 2: Main component of the system (abstraction, treatment plant, transmission mains, pumping stations, distribution network);
Level 3: Subcomponent (e.g. for the distribution network, service reservoirs, distribution mains, service connections, etc.);
Level 4: Type of individual assets (e.g. for the mains: pipes, hydrants, valves, etc.).

The algorithm was completely developed and implemented for the case of pipes, but is thought to be expanded to other types of assets and systems. Each pipe corresponds to a line in the spreadsheet application.

The decision of what is an 'elementary asset' was a matter of detailed discussion with the utility managers. A higher degree of aggregation means less input data and therefore simplicity; desegregation apparently provides more information to the decision maker, but increases exponentially the input data volume and handling needs. Taking the various data sources available into account, decision was to keep the same definitions as in the GIS: one pipe in the GIS is one pipe in the AM application. In fact, in small systems complying with the assumptions made, most AM data comes from the GIS.

For each pipe, the data required is:

• Basic data:
- Assessment year
- Installation year
- Pipe material
- Material pressure class
- Pipe diameter
- Pipe length
- Static pressure (expressed in classes).

• Installation and ease of intervention information:
- Number of service connections with diameter < 1inch (2.54 cm) (affects easiness and cost of intervention)
- Number of service connections with diameter > 1inch (2.54 cm) (affects easiness and cost of intervention)
- Failure rate class (affects performance and expected residual useful life)
- Installation quality class (affects performance and expected useful life);
- Type of pavement class (affects the cost of intervention);
- Traffic load class (affects the consequence of a burst and the easiness cost of intervention);
- Replacement material (e.g. asbestos cement pipes are replaced by other material pipes).

• Complementary qualitative information (if available and relevant):
- Asset redundancy class (affects the consequence of a failure and the priority of intervention);
- Social importance class, defined in terms of the relevance of the pipe for the service to specially relevant customers (e.g. hospitals);
- Current condition class;
- Class of area in terms of constraints to interventions (e.g. protected historical area);
- Need of coordination with other infrastructure intervention.

Table 3 Driving factors and weights used to assess the indices

	Indices		
Driving factors	Difficulty of Intervention	Demand for Intervention	Importance of the asset for the service
Static pressure/pressure class		10%	
Pipe diameter	10%		50%
Installation quality	5%	20%	
Number of service connections (>1 inch => double weight)	25%		5%
Social importance			20%
Type of pavement	30%		
Traffic load	30%		
Failure rates		35%	
Current asset condition		35%	
Asset redundancy			25%
TOTAL	100%	100%	100%

Basic data can be imported directly from the GIS system. The other two sets of input data are likely to require manual input, depending on the existing information systems in each specific utility. This was the situation for the case study of Águas do Marco, SA. Once collected, it is recommended that, whenever feasible, the new data collected is archived back into the GIS.

Pipe diameter, installation quality, ratio between static pressure and pressure class, service connection density, failure rates, traffic load, asset redundancy, social importance, current asset condition and type of pavement are used as driving factors to be taken into account in the rehabilitation planning. As in the DPA models, they are converted into a 1-5 grading scheme, 3 corresponding to the average situation or to unavailable information.

Some of these data are inputted directly into five qualitative categories, directly converted into a 1-5 grading scheme. Table 2 presents the example of installation quality.

For the remaining data items (diameter, service connection density and asset redundancy), the following conversion methodology is adopted:

- For each factor, the set of values corresponding to every elementary asset are taken and the 20, 40, 60 and 80 percentiles are assessed;
- Values below the percentile 20 are graded 1;
- Values between percentiles 21 and 40 are graded 2;
- Values between percentiles 41 and 60 are graded 3;
- Values between percentiles 61 and 80 are graded 4;
- Values above the percentile 81 are graded 5.

Driving factors, constraints to interventions and need of coordination with other infrastructure interventions are used to assess three indices:

- **Difficulty of Intervention Index,** which provides information on the relative difficulty associated to the rehabilitation of each elementary asset;
- **Demand for Intervention Index,** that takes into account the quality and the condition of the current asset, and therefore its need for intervention based on its conditions, regardless of serviceability;
- **Importance of the Asset for the Service Index**, that aims at assessing in a simplified way the contribution of the asset for the global service provided by the infrastructure; it assumes that an interruption in a pipe with a larger diameter will have more of an effect on the service, and takes into account critical customers served (in the 'social importance' driver), the number of properties directly supplied by the pipe, and the redundancy of the link.

These indices are assessed as a weighed average of the driving factors, after their conversion into the 1-5 grades, and as indicated in Table 3. Weights can be customised by the user.

These indices are used to assess the Rehabilitation Priority Index of each asset, as explained further on in this paper.

Table 4
Pipe average useful life

Pipe material	Material code	Average useful live (years)
Ductile iron mains	FFD	60
Polyvinyl chlorine mains	PVC	45
High density polyethylene mains	PEAD	45
Other types of polyethylene mains	PE	40
Polypropylene mains	PP	50
Asbestos cement mains	FC	30

Another feature of the model is the assessment of the 'expected residual useful life':

Expected residual useful life = (Default useful life corrected with the quality of construction and condition information) - (Assessment year – Installation year)

The default useful life can be customised by the user. The values adopted in the case of Águas do Marco are presented in Table 4.

The 'Corrected expected residual useful live' is:

Corrected expected residual useful live = corrective factor x default expected residual at the assessment date - (current date - condition assessment date)

Table 5 shows the corrective factors adopted in the case of Águas do Marco.

Table 5
Corrective factor of the residual useful life expectancy

Asset condition	Corrective factor
Perfect/Excellent condition	120%
Good condition	110%
Normal condition	100%
Poor condition	50%
Very poor condition	0%

The model also allows for assessing the replacement cost and the current value of each asset.

In the case study of Aguas do Marco, the unit replacement cost was established by the utility as a function of the pipe material and diameter (Table 6), in the case of the pipes, and as a function of the diameter, in the case of the service connections (Table 7). The total replacement cost is assessed as the sum of:

- Unit replacement cost for the replacement material x pipe length;
- Linear pavement replacement cost x pipe length;
- (Number of service connections with diameter <1 inch) x (respective unit service connection costs);
- (Number of service connections with diameter $\geq$1inch) x (respective unit service connection costs).

As the individual construction costs are not known, replacement costs are also used to assess the current values. Constant costs and linear depreciation are adopted. Technical service lives, resulting from the correction of the default values (Table 4) taking into account the construction quality and the information about the condition, are used to assess the asset current level:

Asset current value = Annual depreciation x Expected residual life

Table 6
Unit pipe replacement costs (extracted from the complete table)

Type of material and diameter	Linear replacement cost
Ductile iron DN 100	70 €/m (88 $/m)
Ductile iron DN 125	75 €/m (94 $/m)
Ductile iron DN 150	80 €/m (100 $/m)
Ductile iron DN 180	85 €/m (106 $/m)
Ductile iron DN 200	100 €/m (125 $/m)
Ductile iron DN 250	150 €/m (188 $/m)
Ductile iron DN 300	200 €/m (250 $/m)
…	…
PEAD-DN 315	75 €/m (94 $/m)
PE	40 €/m (50 $/m)
PP	50 €/m (63 $/m)

Table 7
Service connection replacement costs

Service connection diameter connection	Average replacement cost per service
DN < 1 inch	€175 ($219)
DN ≥ 1 inch	€125 ($157)

where:
Annual depreciation = Replacement cost / default service life

and the 'expected residual life' is the value previously referred.

Model outputs

Main outputs

Based on the input data and on the calculations described in the previous section, the model produces several types of results:

- A 'Rehabilitation Priority Index' for each elementary asset that may range from 0 to 100, which allows for sorting the assets in terms of its global rehabilitation priority;
- A preliminary rehabilitation planning;
- Two global network indices: the 'Average Asset Age' and the 'Infrastructure Value Index'.

Rehabilitation Priority Index

The Rehabilitation Priority Index (RPI) ranges from 0 to 100 and is assessed for each elementary asset, taking into account the partial indices 'Difficulty of Intervention' (DOI), 'Demand for Intervention' (DFI) and 'Importance of the Asset for the Service' (IAS). It assumes that a high difficulty of intervention may contribute to defer the intervention, particularly if the asset is located in an area where interventions are highly constrained. Therefore, DOI contributes negatively to RPI. It also assumes that high values of the 'demand for intervention' and 'importance of the asset for service' contribute to anticipate the intervention, particularly if there is a higher priority of intervention due to external factors, such as the need to coordinate it with the intervention in other type of infrastructures in the same location. Consequently, DFI and IAS contribute positively to RPI.

RPI is assessed in two stages. In the first stage, the non-standardised Rehabilitation Priority Index is assessed as follows:

$NS\_RPI = DOI \times W_{DOI} \times LCF + DFI \times W_{DFI} \times EPF + IAS \times W_{IAS}$

where:

NS_RPI: Non-standardised RPI
W_{DOI}: Relative weight of DOI to RPI
W_{DFI}: Relative weight of DFI to RPI
W_{IAS}: Relative weight of IAS to RPI
LCF: local intervention constraints factor (default = 1; high constraints = 2)
EPF: External priority factor (default = 1; high priority of intervention due to external factors = 4)

Table 8
Weights used to assess the Rehabilitation Priority Index

Index	Relative weight		
	Difficulty of Intervention	Demand for Intervention	Importance of the asset for the service
Rehabilitation Priority Index	-50%	80%	70%

Table 8 shows the relative weights adopted in the case of Águas do Marco.

Considering that there are advantages of using standardised measures with a well known range, the second sage of this process consists of converting NS_RPI into RPI, as follows:

$RPI = (NS\_RPI - MIN_{NS\_RPI}) \times (100 / (MAX_{NS\_RPI} - MIN_{NS\_RPI}))$

where:

MIN_{NS_RPI} = minimum value that NS_RPI can assume
$= \text{Max}\{DOI\} \times \text{Max}\{LCF\} \times W_{DOI} + \text{Min}\{DFI\} \times \text{Min}\{EPF\} \times W_{DFI} + \text{Min}\{IAS\} \times W_{IAS}$
MAX_{NS_RP} = maximum value that NS_RPI can assume
$= \text{Min}\{DOI\} \times \text{Min}\{LCF\} \times W_{DOI} + \text{Max}\{DFI\} \times \text{Max}\{EPF\} \times W_{DFI} + \text{Max}\{IAS\} \times W_{IAS}$

Sorting the assets in descending order of the RPI assists the decision maker to prioritize interventions. This information should be combined with the preliminary plan of interventions.

Preliminary rehabilitation plan

The preliminary plan of interventions results from the assumption that any asset is replaced when it reaches the end of its expected corrected useful life and that any intervention corresponds to the replacement costs (Table 9). For simplicity of the model, it does not go into detail in terms of the rehabilitation technique adopted (e.g. dig or no dig). Average replacement costs are adopted. Techniques that may expand the useful life but does not reset the clock to zero are not considered. This simplifying assumption is acceptable for the case of pipes when the use of relining is not relevant. This is the case in Portugal.

Table 9
Example of preliminary investment plan (extracted from the complete table) (in €)

Asset:	2008	2009	2010	2011	2012	2013	2014	2015
A0255	13,135							
A0280		1089						
A0300				2841				
A0355					3888			
B0205				12,518				
B0255						11,426		
C0435		2915						
C0551								
…	…	…	…	…	…	…	…	…
Total	42,738	40,563	32,546	12,518	19,394	20,560	45,576	33,568

Global network indices

The model also produces two global network indices: the 'Average Asset Age' and the 'Infrastructure Value Index'.

The 'Average Asset Age' is a weighed average of the individual elementary assets age, using the pipe length as weight. This index, which is frequently used in the literature, may be useful if the unit replacement costs are roughly the same for every asset.

The 'Infrastructure Value Index' (IVI), set up by Alegre (2007), is assessed as:

IVI (%) = current infrastructure value / infrastructure replacement cost

Or:

$$IVI(t) = \frac{\sum_{i=1}^{N} \left(cs_{i,t} \cdot vr_{i,t} / vu_i \right)}{\sum_{i=1}^{N} cs_{i,t}}$$

where:

t : assessment time;
$IVI(t)$: 'Infrastructure Value Index' at time t;
N : total number of elementary assets;
$cs_{i,t}$: replacement cost of asset i at time t;
$vr_{i,t}$: residual useful life of asset i at time t;
vu_i : total useful life of asset i.

It can be demonstrated that IVI (Alegre, 2007) tends to reach a value of the order of 50% in mature infrastructures, where assets are systematically replaced by the end of their useful lives. Figure 1 shows the

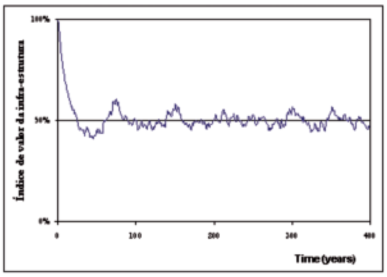

Figure 1 Structure of the operational model (Alegre, 2007)

evolution of IVI over time for a simulation of the case an infrastructure was constructed simultaneously at a given time, which is a rather unfavourable hypothesis for the stabilisation of IVI. Even though, the graph shows IVI clearly converges to a value of the order of 50%.

Values of IVI much higher than 50% correspond to one of the following situations:

- Young infrastructures, not yet stabilized (e.g., systems built recently in areas nor served previously);
- Older infrastructures that face an intensive development stage;
- Over-investment in rehabilitation.

Values of IVI much lower than 50% means that the investment in rehabilitation has been below the needs, and the infrastructures are lacking intervention. Low values of IVI can indicate that the infrastructure is older than it should be, and needs rehabilitation investment.

This index can be particularly relevant in the following situations:

- Establishment of regulatory guidelines and national or regional policies related to investments in infrastructure rehabilitation;
- Establishment and monitoring of AM strategic goals in terms of the global condition of the infrastructure;
- Establishment of regulatory or contractual goals and requirements in managing infrastructures;
- In case of concessions, monitoring of the global condition of the infra-structure at control miles over the concession period;

Conclusions

Looking for simplicity as a key requirement, the model presented in this paper was implemented in the widely spread Microsoft Excel software. In its current form, it is applicable to mains and service connections of water distribution networks. Nevertheless, the approach can be adapted to other type of assets of the water supply systems as well as to wastewater systems.

The development of the model and its application to a small utility demonstrate the feasibility of using coherent information structures to support infrastructure asset manage-ment in small and medium size utili-ties, based on inventory data and other available information.

Ease of data collection is an important aspect to analyse in the case study. In Águas do Marco almost all data required were easily available. The more problematic factors to characterise were 'Asset redundancy' and 'Current Asset Condition'.

'Redundancy' can only be correctly assessed if a network model is available. This was not the case and is not the most common situation in small utilities. Informed guesses had to be adopted, looking network topology, at pipe diameters, and at the consumption spatial distribution.

'Current condition' is also a very important factor because it has a great impact on the model results. However, there is typically limited information available and the default average condition has to be adopted (i.e., the default residual life is considered to be valid). Managers need to be aware of the need to improve the available information with this regard, improving step by step the utility information structure. The use of the model in training activities, testing alternative hypothesis of current condition, may contribute to creating awareness.

The model developed generates three indices: 'Difficulty of Intervention Index', 'Demand for Intervention Index' and 'Importance of the Asset for the Service Index'. These indicators are integrated into a global 'Rehabilitation Priority Index', which also incorporates information on intervention constrains in terms of pipe location and on the need of coordination with other infrastructure interventions. Assets can be sorted according to this index. The resulting listing provides the manager rather valuable information on rehabilitation priorities.

The model also produces a preliminary investment plan is produced based on the assessment of replacement costs and of the expected residual lives of very elementary asset, taking into account their functional condition.

Results are complemented with two global indices: 'average asset age' and 'infrastructure value index'. The latter is particularly relevant because it shows rehabilitation gap of the infra-structure, with regard to a mature and adequately maintained system. ●

Acknowledgments

The authors express their acknowledg-ment to the company AGS, SA and to its subsidiary Águas do Marco, SA, used from scratch as a case study that allowed to shape and frame the model developed. Special thanks are due to José Miguel Maia, João Feliciano, Altino Conceição e Alice Ganhão, for their support, active collaboration and technical contributions.

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Scheduling the renewal of a water supply distribution system – a case study in Portugal

Many water distribution systems are dealing with the problem of aging infrastructure, and maintaining the efficiency levels of their systems has triggered a number of challenges, like the scheduling of the renewal of the water supply infrastructure, along with the definition of the investment priorities. In 2006, a methodology to define the schedule of renewal of the Lisbon water supply distribution system was developed, supported on different approaches: one based on the pipe life cycle analysis, and another based on a multi-criteria analysis. The former took into account mainly pipe failure data analysis in Geographic Information System (GIS), described by the following steps: 1) the pipe failure analysis was made by diameter segments (DN<400 mm and DN>=400 mm); 2) a deterioration model for each diameter segment and pipe material was defined; 3) each unit area (DMA) was classified according to their behaviour age; 4) according to the expected behaviour, an evaluation of the pipe whole life cost is made, for different asset life-time periods; 5) the renewal decision was based on the use of the residual asset-life time that minimizes the total expected costs. An evaluation of the pipe failures externalities in terms of % of the GDP per capita of the clients affected is presented, and the results are compared with the pipe failure rate benchmark used by the Portuguese regulator. In the multi-criteria analysis, different physical criteria were taken into account, as well as economic criteria: expected asset life time; water supply reliability; importance of the pipe for the operational flexibility; performance; and repair vs. renewal costs. An application example of multi-criteria analysis, also using GIS tools, is presented. Finally, the results obtained from the application of each methodology are compared and discussed.

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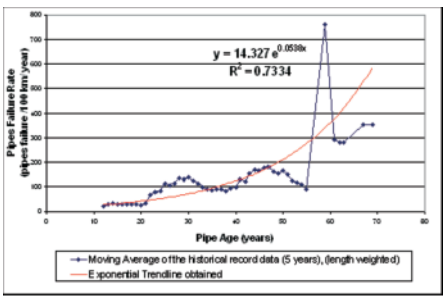
Introduction

EPAL (Empresa Portuguesa de Aguas Livres) is responsible for the human consumption water production and main transport to supply 2.6 million people, corresponding to 26 districts (including Lisbon) covering a total area of 5406 km². Actually, two business areas can be identified: one is responsible for more than 700 km of main trunk pipes that assure the wholesale dealer supply of the 26 districts (Production and Transport Business Area); and the another is responsible for assuring the domestic water supply in the Lisbon district, through the 1400 km of distribution pipes (Distribution Business Area).

Like in any intensive capital businesses, for EPAL, with book value assets of about €650 million ($815 million), the economic sustainability depends significantly on the way asset management is being carried out. Therefore an Asset Management Integrated Model is being currently developed. One of the goals of this Model is the definition of investment priorities so that, on one hand, a global minimization of acquisition, operation and maintenance costs, during the assets whole life cycle, is achieved and, on the other hand, the service levels to the customer are improved (Chopard et al. (2006); USGAO (2004)).

The implementation of the Asset Management Integrated Model is based on methodological approaches that constitute decision support system tools, in order to optimize the asset life cycle and the return in an optic of value creation.



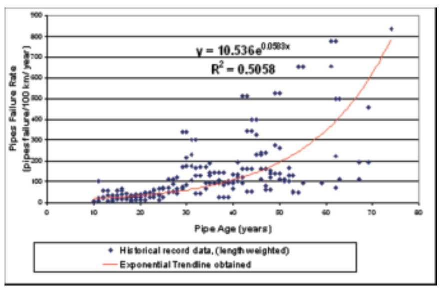


Figure 1
Failure analysis of Asbestos Cement pipes (DN<400)
a) Simple data (left)
b) 5 years moving average (right)

Since many water distribution systems are facing aging infrastructure problems, maintaining the efficiency levels of their systems has triggered a number of challenges. So, one typical decision that has to be made is the setting of a water supply infrastructure's renewal schedule.

The Lisbon district water distribution pipes were the target of the methodologies presented. To define a renewal policy for the distribution system, two approaches were used: one based on the pipe life cycle and another one based on a multi-criteria analysis.

The first approach uses a bottom-up

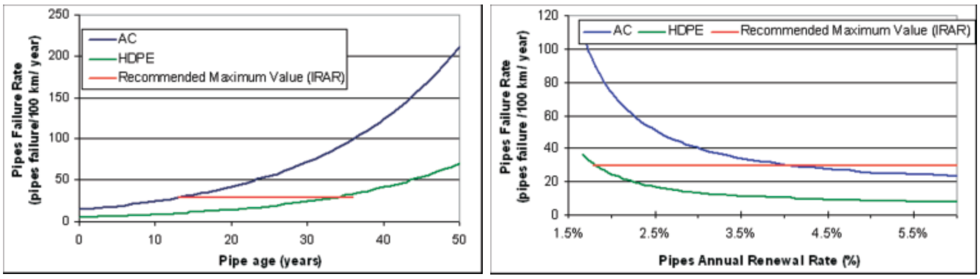


Figure 2
Curves used for the failure rate evolution of asbestos cement and HDPE a) with pipe installation age; (left) b) with the pipe renewal rate adopted (right)

perspective, like the conceptual model proposed by Monteiro *et al.* 2005 and Alegre *et al.* 2006, but in a more pragmatic way – only the most relevant costs factors for the asset management are considered. In this bottom-up approach, renewal decision is based on the use of the residual asset-life time that minimizes the total expected costs. At the end, a comparison is made between two benchmark pipes failure rates: the benchmark pipe failure rate recommended by the Portuguese Regulator (IRAR) for a water distribution system; and the pipe failure rate that minimizes costs in a life cycle analysis. The aim of this comparison was to verify which of the two rates constrained the renewal scheduling. This approach was developed and applied by the consultant team Engidro/ProSistemas/Procesl (2006), during the diagnostic phase of the Lisbon Water Supply Network Master Plan.

In the multi-criteria analysis, different physical and economic criteria were taken into account, and weighted based on the opinion of EPAL technicians and managers that formed an Expert Panel. The factors considered were: expected asset life time; water supply reliability; importance of the pipe for the operational flexibility; performance; and annual repair cost. This methodology was fully developed by EPAL, using GIS tools. As a result of the application of the multi-criteria matrix, a punctuation was assigned to each of the around 35,000 pipes that constitute the 1400 km of the network, indicating its priority for renewal. On a second step, a grid was adjusted so that the quads with higher concentration of high priority pipes were identified. Finally, the rehabilitation areas within these quads were drawn, and the respective preliminary investment costs were calculated.

Summarized descriptions of these two methodological approaches are presented, and the results of their application are compared and discussed.

Life cycle approach Methodology

The life cycle approach methodology was based on the pipe failure analysis data in GIS, described by the following steps: 1) the pipe failure analysis was made by diameter segments (DN<400 mm and DN>=400 mm); 2) a deterioration model for each diameter segment and pipe material was defined; 3) each unit area (DMA) was classified according to their behaviour age; 4) according to the expected behaviour, an evaluation of the pipe whole life cost is made, for different asset life-time periods; 5) renewal decision was based on the use of the residual asset-life time that minimize the total expected costs.

The partition in two diameters' segments was assumed taking into account the different potential damage risk caused by a pipe failure. In the small diameters (DN<400 mm), it was assumed that the risk of flooding damages to other entities was not relevant, while for the upper diameter segment (DN>=400mm), these damages could be significant.

Definition of a deterioration model

Deterioration models were developed for different pipe materials. In Figure 1, the pipe failure rates (pipe failure/100 km) for different installation pipe age observed from 2002 to 2005 are presented. The results clearly show that the pipe failure has a high correlated exponential curve with the pipe installation age, particularly in terms of moving average.

The correlation analysis made for the flexibility factor (FF) of ancient pipe material does not reveal any correlation with the installation age.

For the cash-flow analysis, it was assumed that FF breaks have a constant value, independent from the installation age (90 failure pipes/100 km).

Similar approaches were adopted for the other pipe materials. For high density polyethylene (HDPE) pipe material, the failures data were insufficient to define a deterioration model. But as an assumption was needed to be used in the economic model, it was considered to be a third of the pipe failure rate of asbestos cement (Figure 2 a). In Figure 2 b, also presented is the pipe failure rate for different average renewal investments in a distribution pipe system (i.e. an asset with an average life cycle of 50 years should have a renewal annual investment of 2% = (1/50)%). The red line in Figure 2 is the average recommended maximum value by the Portuguese Regulator (30 pipe failures/100 km).

The right side of Figure 2b shows that the asbestos cement pipe has a global whole life cycle of 25 years (annual renewal rate = 4%) if it is intended not to exceed the Portuguese benchmark fixed by the Portuguese Regulator (IRAR) for the annual failure pipe rate (<30 pipe failures/100 km).

Life cycle analysis

The life cycle analyses were made using discounted cash-flows, considering the following costs:

- Unplanned emergency intervention for pipe failure repair;
- Average water volume leakage from the pipe burst;
- Indirect costs to the client caused by the water supply suspension;
- Risk of direct damages to other entities;
- Renewal investment;
- Fiscal benefits for the investment annual payment (in Portugal 27.5% of the annual amortization value).

Several analyses were made for different observation periods and discount rate. It was assumed that the new renewal pipes are made of HDPE and that the evolution of the pipe failure rate was according to the deterioration models presented before.

Figure 3 presents the Net Present Value (NPV) for a standard rehabilitation Project of 1 km for different Observation Periods and discount rate. In the computation of this Net Present Value, all the direct costs (CAPEX+OPEX-CAPEX Book Residual Value at the end of the Observation Period) were considered. As one can see, for observation periods lower than the fiscal depreciation period assumed (20 years), the NPV grows faster for higher discount rates. The reason for this is the way CAPEX

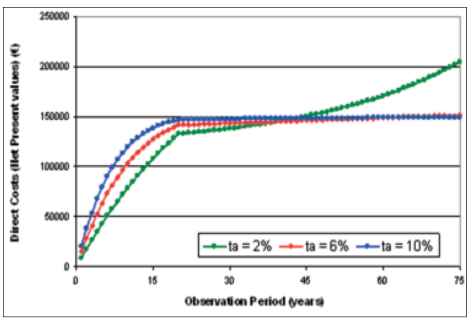


Figure 3
(left) The Net Present Value for different Observation Periods and discount rate (CAPEX+OPEX-CAPEX Book Residual Value)

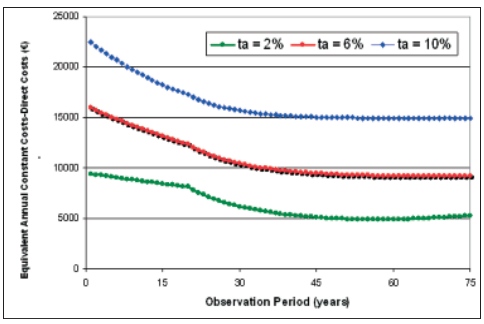


Figure 4
(right) Equivalent Annual Constant Payments for different Observation Period

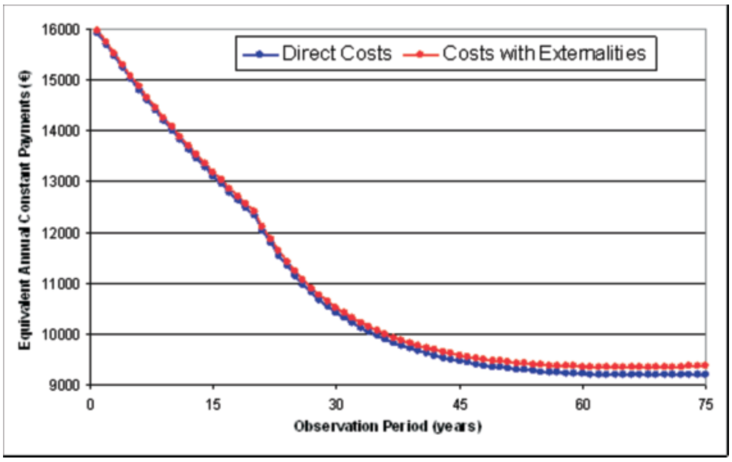


Figure 5
Equivalent Annual Constant Payments with direct costs and with externalities for different Observation Periods (discount rate = 6%).

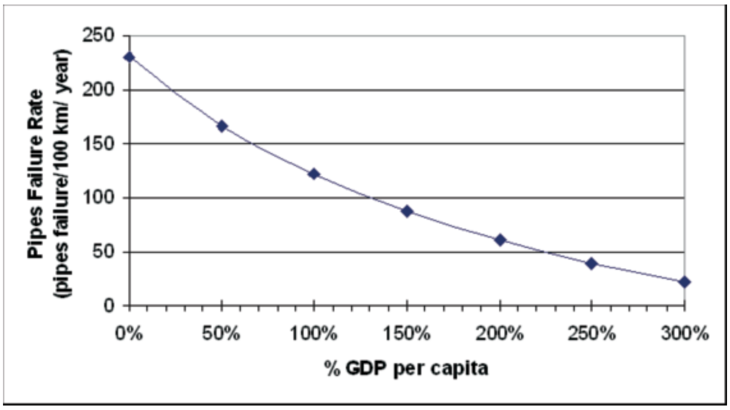


Figure 6
Economic Pipes Failure Rate function Cost of affecting Clients (discount rate = 6.5%).

Table 1
Economic Annual Pipes Renewal Effort (Cost of affecting clients = 50% Portuguese GDP of clients affected)

T=3.5% AC and GI Pipes Renewal Schedule	Length (km)	Investment (€)	Accumulated Difference of the Pipes failure Rate (breaks/100km/year)	Accumulated Difference of Number of Critical Connections	Annual Renewal Length (km/year)	Annual Renewal Length (%/year)
Years 1 to 5	91.6	14,949,259	-2.5	-2825	22.9	1.60%
Years 6 to 10	131.0	21,382,189	-4.5	-7383	26.2	1.84%
Years 11 to 15	165.2	26,967,826	-8.5	-11,821	33.0	2.32%
Total - 15 Years	**387.8**	**63,299,275**	**Annual average value**		**25.9**	**1.81%**

Book Residual Value is being evaluated. After the end of the depreciation period (year 20), the fiscal benefits ends and the NPV has an exponential growth, that is higher when discount rates go down.

In Figure 4 the Equivalent Annual Constant Payments (EACP) is presented, either for different observation periods and equivalent to the NPV. The economic life cycle of an asset is the observation period for which the minimum life EACP is obtained. From Figure 6, it becomes clear that economic life cycle is dependent of the discount rate used.

In Figure 5, two graphics for the EACP with 6% discount rate are presented: one EACP was calculated only considering direct costs; and another one adding the externalities costs caused to the client by the water supply suspension.

The externalities costs caused to the client by the water supply suspension was evaluated considering that they were similar to 50% of the Portuguese Gross Domestic Product (GDP) per capita during the suspension period (six hours in average). It is clear that the life cycle period and the EACP are similar, and the difference is of less than 2%.

Impact of the annual pipes renewal effort in failure pipes rate

In Figure 6, a function of the economic pipes failure rate above which it is economically profitable to proceed to the pipe renewal is presented, in function of the per capita GDP percentage used to evaluate the clients' externalities costs during the suspension period (six hours in average).

As it was mentioned above, the regulator benchmark for annual pipe failures is of 30 pipe failures/100 km. This value is only economically justifiable if, in terms of economic evaluation, it is assumed that the indirect costs evaluation of the clients' externalities during the suspension period is of 250% of the GDP of the Lisbon residents affected by the water suspension.

Based on the analysis developed, different scenarios of renewal priorities were established for the pipe distribution system. In Table 1, the impact benefits of a renewal programme of 25.9 km/year are presented, in terms of pipe failures rate and reduction of critical connections, according to the deterioration model developed. The 1.81% average value for renewal effort was found as the most economic one, when using the 50% GDP per capita as an impact factor in the customer for the water supply suspension and for a discount rate of 3.5%. However, in terms of pipe failures reduction, the results are unsatisfactory to achieve the desired benchmark value from the Portuguese Regulator.

In the Table 2 others scenarios of renewal are presented, more expensive and distant from the economic optimal solution, but assuring the desired reduction of the pipes failure rate.

Table 2
Economic Annual Pipes Renewal Effort Needed

Annual Renewal Extension (%/year)	Annual Renewal Extension (km/year)	Accumulated Difference Global Pipe Failure Rate Indicator 5 years	Accumulated Difference Global Pipe Failure Rate Indicator 10 years
2.0%	28.4	-5.9	-8.4
2.5%	35.5	-8.2	-13.3
3.0%	42.6	-10.5	**-16.8** (regulator target)
3.5%	49.7	-12.6	-19.7

Multi-criteria matrix approach

Starting point

Maximising the efficiency of the operation of the distribution network in Lisbon, with the correspondent reduction of losses and the other environmental, social and economic impacts, has been a concern for EPAL since long. In fact, taking into account the advanced age of the network, in the last five years more than 315 km have been already rehabilitated, totalising an investment of around €57 million ($72 million).

Until 2006, the areas to rehabilitate had been selected based on the network behaviour experienced by some technicians of EPAL, attending to the material, the age and the breaks occurring in the pipes.

However, in 2006, EPAL wanted to assure that, despite the knowledge experienced by those technicians, the selected areas were effectively the ones with highest priority, and, on the other hand, that no area with high priority was left out.

Being this a typical problem of Decision Analysis, a multi-criteria approach was followed, similarly to the one described by Stephens (2005).

The next step was to decide what should be the alternatives in competition: either the 35,000 pipes that constitute the 1400 km of the network, or some kind of aggregation unit, like quads of a grid. EPAL opted for the former one, since the latter would induce the occurrence of a dilution effect of the pipes with worst behaviour in case they were located in a quad with a significant proportion of 'well behaved' pipes.

Being the alternatives geographically spread within Lisbon, it was decided to use EPAL's Geographical Information System (GIS) to perform the analysis.

Multi-criteria matrix structure

To define the parameters of the Multi-criteria Matrix, an Expert Panel was formed, aggregating people from different areas of EPAL. The members of the Panel then decided what the relevant criteria were, as well as the respective weights.

Despite the criteria selection appointed several criteria to be taken into account, some of them had to be excluded (namely the sensitivity of the affected customers, the network pressure, the terrain slope, etc.), since the data was not yet in a format that allowed its incorporation in the GIS tool. The chosen criteria were: Age, Material, Function, Breaks per Year and per 100 km, and Índex R (relation between the cost of maintenance and investment cost).

The punctuation of each pipe according to the different criteria, ranged from 0 (less urgent) to 5 (more urgent), as decided by the Panel. Finally, different weights were assigned to the criteria, as shown in Table 3.

Table 3
Multi-criteria matrix defined by the expert's board

Point of View	Criteria	Weight	Indicator	Punctuation	
	Expected Life	16%	Age	0-20	0
			(years)	20-30	2
				30-50	4
				>50	5
	Supply	36%	No of failures/	0-30	0
	Reliability		year/100km	30-50	1
				50-100	3
				100-150	4
				>150	5
Physical	Operational	11%	Function	Distribution pipes	2
Factors	Flexibility			Water mains	4
				HDPE	0
				Ductil Iron	0
				Europipe Steel	0
				Steel	1
				Reinf. Concrete	3
	Performance	16%	Material	Plastic.PRV	3
				Asbestos	5
				Rocia Concrete	5
				Iron	5
				Unknown FG	5
Economic	Investment	21%	R=	>20	0
Factors	vs		Crn/(Ir,LCu)	10-20	1
	Maintenance		(years)	5-10	3
	Cost			1-5	4
				0-1	5

Note: R=Renewal Cost / [No Failure/year x Maintenance Cost]

Multi-criteria matrix application

Preliminary actions

Prior to the matrix application, some preliminary actions had to take place, as described in the next paragraphs. Having overcome these initial difficulties, the matrix application consisted in the following steps:

- to export the water mains feature (around 2000 records) and the distribution pipes (around 33,000 records) to only one feature (*feature class*);
- to create five new attributes in the feature class, one per each criteria, and another one for the final results of the matrix;
- to classify (from 0 to 5) each of the new attributes accordingly to the pipes' characteristics, executing queries and updating the attributes *(Attribute Queries e Update Attributes functionalities);*
- to visualize the final classification of the pipes, establishing a correspondence between the pipes' punctuation and a colour ramp, ranging from grey (not critical, classification 0) to red (most critical, classification 5), passing through blue (1), green (2), yellow (3) and orange (4).

Figure 7
Pipe function classification: a) Trunk main pipes (orange); b) distribution pipes (green)

Pipe function

The pipes' function was characterized when the mains feature (the big water mains that transport water from one side to other sides of the city) and the distribution feature (the pipes that hang the connections to the customers) were merged into one single feature, being the result shown in Figure 7.

Pipe age

For the pipes' classification according to their age, the estimation of the age of

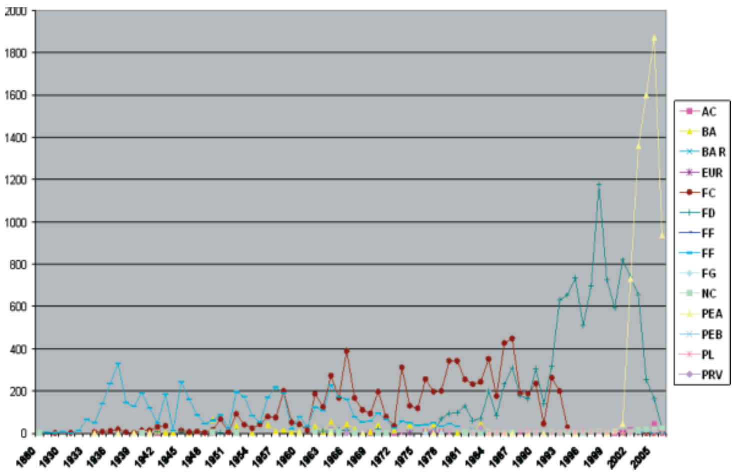


Figure 8
Pipe materials distribution by installation age

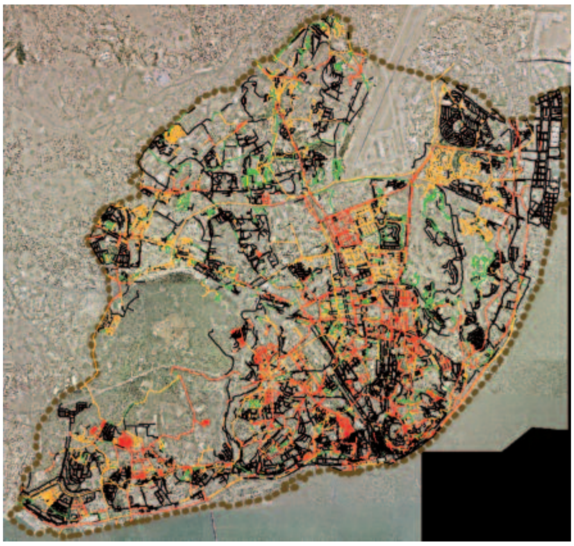


Figure 9
Map with pipe installation age classes

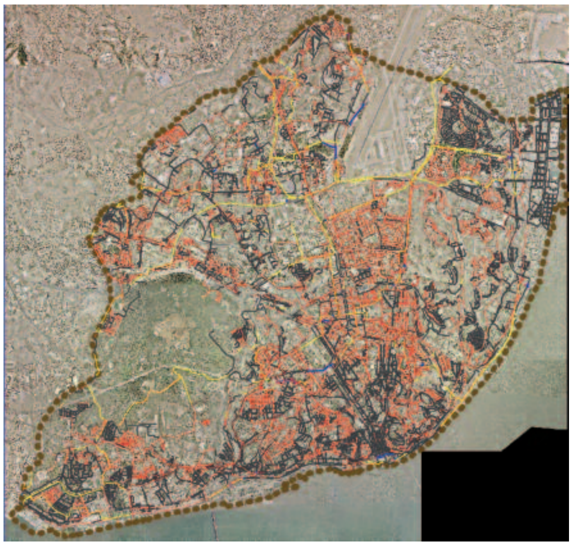
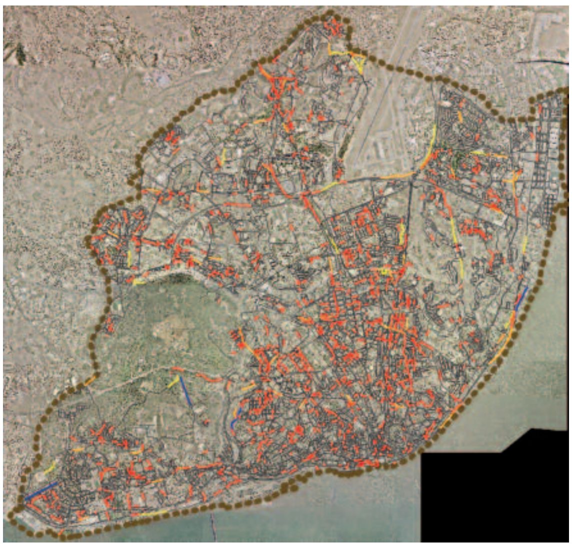


Figure 10
Map with pipe material classes

Figure 11
Classification map of pipe breaks/100 km per year



some of the pipes revealed to be necessary. In fact, in some of the pipes, the 'year of installation' attribute was null.

A different approach was used for the water mains and for the distribution pipes. In the first case, the 112 km (representing around 8% of the total length of mains in Lisbon) whose age needed to be estimated, were assigned the age of the adjacent pipes, as well as the age expressed in the drawings of EPAL's publication 'Elementos Principais da Rede' – Major constituents of the network. In the second case, there were around 77 km (approximately 5% of the distribution network) for which the age was estimated based on the period when the respective material began to be installed, as shown in Figure 8. Finally, for those pipes with both 'year of installation' and material null, the most penalizing punctuation ('5') was assigned.

In Figure 9, the pipes' classification from the Age point of view is presented.

Pipe breaks per length and per year
This criteria is based on the IRAR/IWA performance indicator, and is directly related to the supply reliability. Maintenance work orders' data from 2003 to 2005 were gathered and analysis has been made in order to exclude the ones referring to pipes that had already been replaced.

Pipe material
The punctuation of the attribute 'Material' of the pipes was made directly, according to the matrix definition. In what concerns the records with material 'Unknown', it was decided to assign the most penalizing punctuation instead of making an effort to recover that data, since they represented only 0.6% of the network.

Renovation investment period return (Index R)
Associated to economic concerns, Index R was established, indicating the number of years after which the maintenance costs (considering a rate of breaks identical to the ones verified between 2003 and 2005) would equal the investment cost of replacing the pipes.

The investment and maintenance costs had to be previously loaded into GIS, based on tables with the correspondent values for different classes of diameter and material.

As one can see in Figure 12, if only economic concerns were taken into account, the investments made in the pipes renovation in the last years would be far less significant.

Matrix application results
Having weighted the five criteria, the final classification of each pipe stretch was obtained, as it can be observed in Figure 13.

Identification of priorities areas for rehabilitation
Since the 'red' and 'orange' pipes evinced a significant dispersion within the city, an intermediate step was given in order to identify the most urgent areas for rehabilitation.

The solution consisted in adjusting a grid so that in each quad, the sum of the 'red' and 'orange' pipes' length was calculated, which allowed to focus the attention to the ones with a higher concentration of these pipes.

After a detailed analysis of the network in the red quads, it became easy to draw the priority areas, totalising a number of 13 in the end (Figure 14). Additionally, and because the renovation investment cost had been associated to each pipe stretch, it was possible to determine the total preliminary cost of the renewal

Figure 12
Pipe classification map taking in account the investment period return

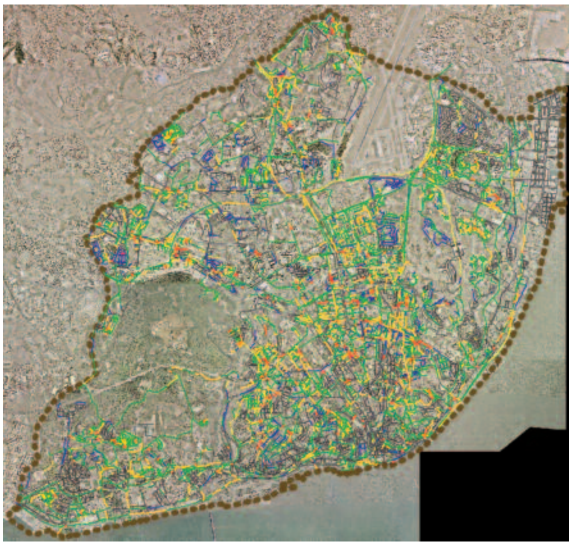


Figure 13
Pipe classification map after multi-criteria matrix application

Figure 14
Identification of priority areas

intervention in each area.

As mentioned before, this analysis was performed using GIS tools and functionalities.

Conclusions

Two different approaches were used in order to determine the priorities of pipe renewal in the Lisbon water distribution system, namely a life cycle analysis and a multi-criteria analysis.

In the life cycle approach, several scenarios of renewal priorities were established for the Lisbon pipe distribution system. The 1.81% average value for renewal effort (almost 26 km/year) was found to be the most economic one, when using the 50% GDP per capita as an impact factor in the customer. However, in terms of pipe failures reduction, this result proved to be unsatisfactory to achieve the desired maximum value recommended by the Portuguese Regulator (30 pipe failures/100 km), which means that a greater annual effort will be necessary.

According to the results of the above mentioned approach, the IRAR recommended maximum value for annual pipe failures is only justifiable if, in terms of economic evaluation, it is assumed that the indirect costs evaluation of the clients' externalities during the suspension period is greater than 250% of the GDP of the Lisbon residents affected by the water suspension. This peculiar result may be perfectly acceptable, in economic terms, for Lisbon city, since most of the jobs in Lisbon district are of non residents and, hence, a water suspension has much more an economical impact, rather than a residential one.

With the multi-criteria analysis, punctuation was assigned to each of the pipes, considering both physical and economic criteria. The zones with a higher concentration of pipes with higher classification (over 4.1 out of 5) were identified, and the areas where the rehabilitation should take place were drawn and prioritized. Additionally, the preliminary investment cost associated to each area was calculated.

As future developments for the multi-criteria analysis, it is foreseen, among others, the accomplishment of a sensitivity analysis to the weights of the criteria, along with the introduction of new criteria, namely criteria related with the risk of causing damage to others, with the number of affected customers by suspensions, and also criteria related with the water quality. It is also expected to perform the comparison of the results with the ones obtained from the application of a multiplicative model (considering the factors 'probability' and 'consequence' of pipe failure) in detriment of the application of an additive model (in which the multi-criteria analysis is based).

The results of both approaches agree in most of the priorities identified, and differences were not significantly relevant. Another interesting conclusion drawn from both approaches, is that it is needed more renewal effort than the economically justifiable by the company accountability, since not only the number of failures recommended by the Portuguese regulator has not yet been accomplished, but also because the city of Lisbon reveals to be of great economic importance, and hence the serviceability must be raised to standards towards which the pipes' renewal must cope with.

With the developed work, EPAL obtained tools that will allow a periodical re-evaluation of the needs of pipe renewal to be done in the Lisbon water distribution system, within a structured and methodical framework. ●

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Application of monitoring and information technologies to optimise asset management

Water and wastewater operators are requested to optimise the operation of their assets whilst ensuring quality of services to customers and due respect to the environment. Aged infrastructure, deferred maintenance and investment constraints make asset management an arduous task, aggravated by the fact that most assets are hidden underground. The advances in monitoring and information technologies are however simplifying life for water managers as they help to assess system performance and target capital and operational investments in the most effective manner. A. Pretner, A. Bettin and L. Sainz in this paper illustrate the experience gained in two European projects focused on the application of asset data and monitoring tools to enhance the efficiency of water and sanitation services. The first is TILDE (Tool for Integrated Leak Detection), a research project funded by the European Commission aimed at facilitating the adoption of best practice for leakage control in water distribution networks. This project has developed and demonstrated a set of data management tools for leakage control in two pilot areas in Italy, one in Cyprus and one in Norway. TILDE was completed in 2006 and since then the project technologies have been widely disseminated. Their application has been particularly welcome in those countries facing severe water scarcity where the management of leakage can yield greater economic and environmental benefits. The other project is ADRICOSM (Adriatic sea integrated coastal areas and river basin management system pilot project), started in 2001 and still on-going. The project focuses on implementing integrated wastewater management to minimise the pollution of the Adriatic Sea. Simulation models of the sewer networks and receiving waters have been developed in order to assess the impact of waste and storm water pollution on the rivers and coastal areas. Both projects tackle major technical problems in asset management which, if appropriately solved, can draw substantial operational, financial and environmental benefits. Our projects have demonstrated how mathematical modelling, monitoring and data management are crucial to optimising data collection and analysis, and enhancing knowledge for decision making.

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Introduction

Much of the water and wastewater infrastructure in our cities dates back to the first half of the last century or even longer, and was constructed to serve a smaller population. Maintenance of infrastructure has been often neglected due to its high costs and because problems are hidden underground, not visible to the public unless severe damage occurs. As a result, today's assets are ageing and overburdened.

In many parts of the world a decline in asset performance has been observed, with increasing leakage rates in water distribution networks, and more frequent sewer flooding and pollution. These problems have become more apparent in the last years, as extreme rainfall and drought events have occurred and some customers have suffered the consequences of service disruption and infrastructure collapse.

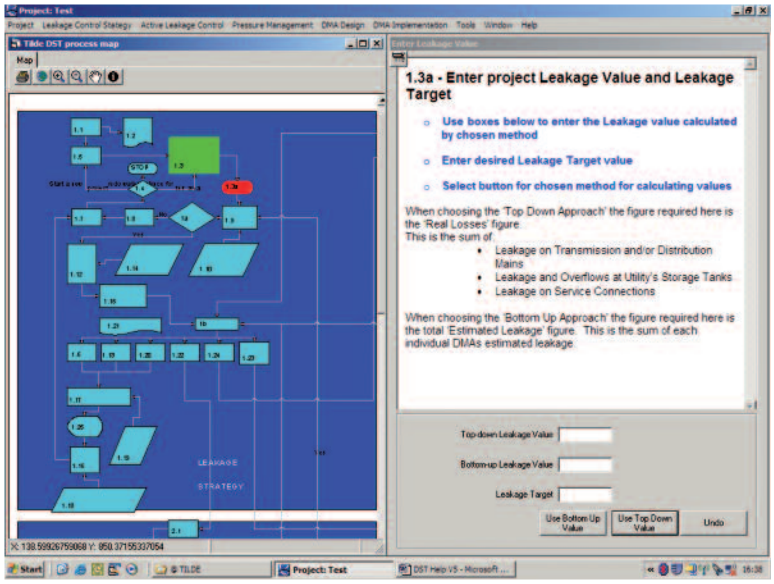


Figure 1
Zoomed in view of DST, with the process map on the left and the description of the processes on the right

Operators of water and sanitation assets face a tremendous challenge as they endeavour to achieve service standards, optimise the operational and financial performance of their old systems and comply with increasingly stringent environmental legislation. These duties are often conflicting and require a clear understanding of asset operation and of the impacts that future interventions may bring to the overall system performance.

In the last 15 years, our company SGI Studio Galli Ingegneria has been actively involved in the implementation of projects funded by the European Commission and other international funding institutions focused on the application of information and monitoring technologies to optimise asset management. In this paper we illustrate the experience gained in two of our most recent projects, TILDE (Tool for Integrated Leak Detection) and ADRICOSM (Adriatic sea integrated coastal areas and river basin management system pilot project). Both projects have been implemented by a consortium including water operators, research institutes and consultants across Europe, reflecting the issues affecting today's water industry. In particular the projects highlight the major role that information and monitoring technologies play in the work of water and wastewater operators. They provide the means to investigate the operational and structural conditions of assets, therefore helping to prioritise interventions in a rational and cost-effective manner. The methodology and results achieved by the two projects are reported in the following chapters.

The TILDE Project

Droughts experienced in many parts of the world have highlighted the problem of water shortage. The World Water Forums held over the last decade have recognised freshwater as an economic good whose limited availability is increasingly becoming a severe problem for a large share of the population on Earth.

Leakage in networks can be over 50% of the water produced, which entails substantial economic, social and environmental costs. Leakage management in distribution networks is drawing a greater attention at water utilities as it is evident it needs a unified and integrated approach.

Management of water losses has been implemented so far in a fragmented manner, without a long term strategy or performance measurements. However international experience has demonstrated that an integrated approach based on the adoption of advanced monitoring and information technologies can prove extremely cost-effective.

The objective of TILDE was to enable the adoption of best practice for leakage management amongst water operators. TILDE stands for Tool for Integrated Leakage Detection. The project was co-financed by the European Commission and the Italian Ministry of Environment, and finalised in 2006 after three years of work. TILDE was coordinated by our company SGI and grouped water operators from Italy (Acquedotto Pugliese and Abbanoa), Cyprus (Nicosia Water Board) and Norway (Bergen municipality), the Greek consultant Z&A Associates, the British Water Research Centre and the Norwegian SINTEF.

The project developed three software technologies for promoting the application of best practice among water operators and facilitating the management of information related to leakage control. These are the TILDE DST, the TILDE DMS and the Leakage Check Up. Additionally the project published a web portal of the project which includes information on the project and its results (www.waterportal.com).

Results of the TILDE project

The TILDE DST is a Decision Support Tool that guides the water practitioner in the selection of the most appropriate methodology to reduce and control water losses following a systematic approach. The DST is structured software with help menus and detailed explanations that lead the user through the 'process maps' involved in leakage control;

The TILDE DMS or Data Management System is software that

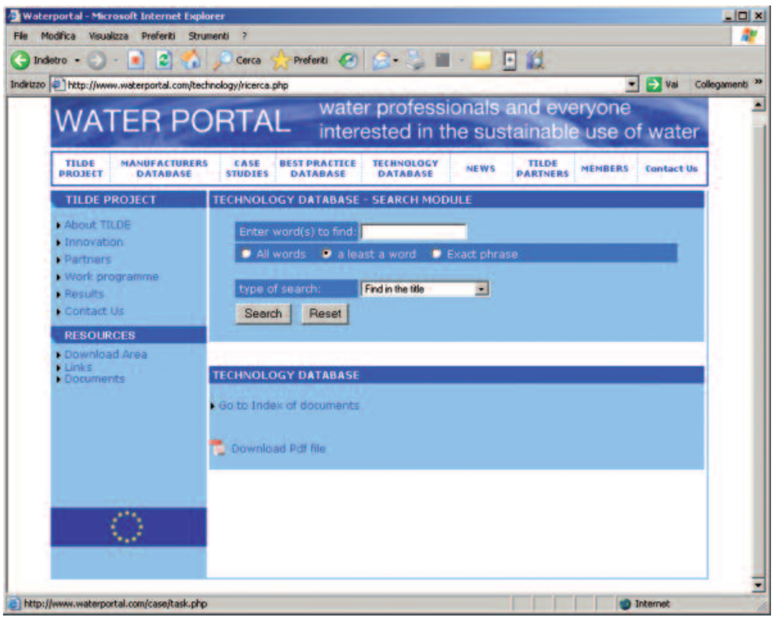


Figure 2
Technology database developed in the TILDE project

consents the integrated management of all data coming from the leakage control activity in the field (flow and pressure monitoring, location of bursts and leakages, repairs made, district metering area data). Based on the analysis of data, the DMS identifies priority areas, where the repair of leakage can yield the greater benefits. The functionalities of the DMS include:

- Statistic analysis and reporting of leakages;
- Storage and issuing of field work forms including data about leaks found and repaired
- Link with a Geographical Information System (GIS) and production of leakage maps
- Centralised management of data and prioritisation of critical areas

The Leakage Check Up is a basic tool that determines the level of leakage of the network based on the International Water Association's (IWA's) water balance, and calculates leakage performance indicators.

These tools have been validated in the four pilot sites participating in the project (Sassari (Italy), Bari (Italy), Nicosia (Cyprus) and Bergen (Norway)). The application of the TILDE products to such diverse contexts from the technological, operational and socio-economic perspective has endorsed the software with a wide applicability.

TILDE was finalised in September 2006 and since then TILDE products have been promoted by the project partners in countries such as Egypt, Jordan and Iraq. All three countries are particularly concerned with water scarcity and place leakage control as a priority in the asset operational programmes. SGI is actively engaged in the training of staff at these utilities to ensure the assimilation of best practice and technologies. This is in fact the ultimate aim of the European Commission, to foster the dissemination and replication of project results on an international scale.

The TILDE Decision Support Tool – TILDE DST

The TILDE DST is a decision support system that guides the water manager along the methodological path to apply the best practice for leakage control in their distribution network. The DST can be imagined as an electronic book that interfaces with the water practitioner along the decision making process for implementing a leakage control policy.

The DST may be used at different levels of detail, since it can support managers in taking decisions at strategic level, as well as helping water engineers in the detailed implementation of leakage schemes.

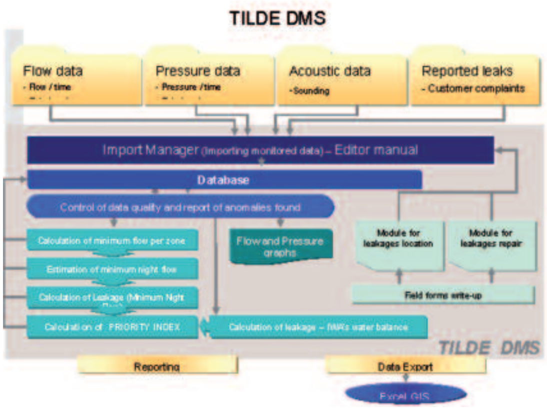


Figure 3
Functions of the TILDE Data Management System

The core of the TILDE DST software is the set of process maps that include all the steps required from the moment the water operator decides to undertake a leakage control strategy up to the moment field technicians are locating leakage in the network. The DST is a comprehensive information source containing detailed information about the processes and technologies involved in water loss management.

The DST user will learn about the current best practice for tackling water losses in his network improving his knowledge on topics such as the calculation of the water balance, the components of Non-Revenue Water, flow and pressure monitoring technologies, leakage detection instrumentation and Active Leakage Control methodologies.

The process maps of the DST are connected to the other two major components of the DST which are the best practice database (compendium of leakage control methodologies) and the technology database. The following sections provide an overview of the DST components.

The process maps

Process maps are the central part of the DST structure since they provide the primary reasoning for the procedures behind leakage control best practice. The development of the process maps was undertaken by WRc (group of UK businesses providing research and consultancy on water supply, waste treatment and the public) specialists through a review of best practice literature related to leakage strategy, management and best practice.

The processes built into the DST are five, namely Leakage Control Strategy; Active Leakage control (ALC), Pressure Management, Zonal Disaggregation and District Metering Area (DMA) implementation.

A process flow chart has been made for each of these five subjects, and the DST takes the user along each of the above processes to enhance his knowledge about the system's operation and providing him with insight about ALC and pressure management techniques. ALC is based on the sectorisation of the network into areas placed under flow and pressure monitoring in order to detect sudden variations likely to be caused by increase of leakage.

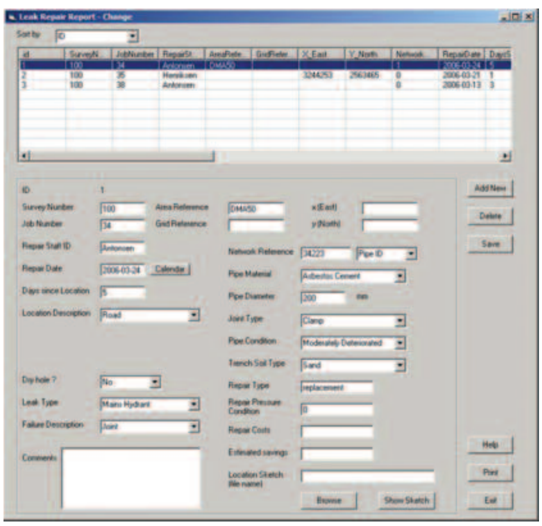
The process maps are logical flow-paths that interface with the user asking him about the system's features and operational targets. On the screen the DST appears as a window where the graphical process map is shown indicating where the user is and what decision he has taken so far. Clicking on each element of the process map the user will view descriptive text for each task and decision. The DST has been based on the standard approach proposed by the IWA and World Health Organization (WHO). Figure 1 shows how the DST appears on the computer screen.

The technology database

The DST is linked to the technology database developed through TILDE which provides a comprehensive overview on available technology for leakage management. The database contains information about the features of technologies, their applicability and main manufacturers. The instrumentation for leakage detection and control has been categorised under three main headings:

- *Leak detection and location* instrumentation including acoustic technologies, gas tracers, ground probing radar, in-pipe methods, remote sensing system, flow monitoring.
- *District Metering Area (DMA) network monitoring* including loggers, flow monitors, telemetry, water quality tools, network mapping and

Figure 4
TILDE DMS – Leakage repair report



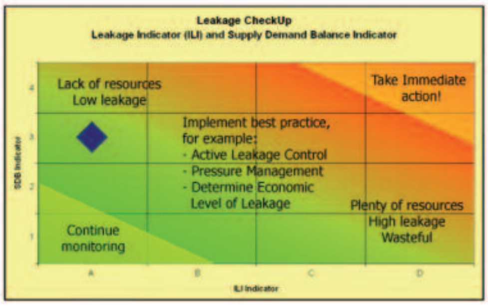


Figure 5
Leakage Check Up: Supply-Demand against Leakage indicators

modelling, pressure sensors.

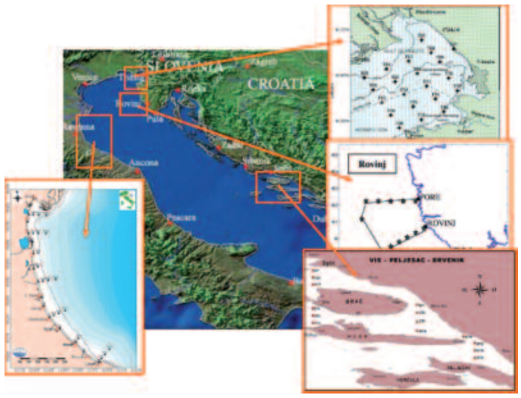
- *Leakage control* including the description of flow and pressure regulation devices.

The technology database produced in the TILDE project has been published in the web at www.waterportal.com, where registered users can download it as a document or make on-line searches using keywords. Figure 2 shows the technology database as shown in the portal.

The best practice database

Similarly to the technology database described in the previous chapter, a database describing the methodologies

Figure 6
ADRICOSM - Location of some project sites



involved in the leakage control processes was also implemented through the project. The best practice database runs with the DST and it provides the descriptive text for the actions of the process maps.

Figure 7
The MIKE 11 model representation of the river Cetina in Croatia

The TILDE Data Management System

- TILDE DMS

The main goal of the TILDE project is to provide water operators with a more systematic approach for leakage management. Leakage engineers have to handle numerous data coming from measuring devices like flow and pressure meters and various acoustic instruments indicating leakage. The instruments that are applied for this purpose have varying data output facilities and formats. Acoustic raw data has to be translated into an understandable output by product specific software. Some of these systems have no data export facility or at least not in an easily readable format. This makes data processing a hard job.

The main idea behind the development of the TILDE DMS was consequently to offer the user a central data management system for all leakage related system. The user can then access all relevant data from one database, make further analysis, produce reports and field work forms. This enables a better system overview and eases management decisions.

The functionalities of the TILDE DMS are represented in Figure 3.

The basic data going into the DMS concern flow, pressure and noise, all of them monitored by the instruments installed along the network. For each monitor, the DMS creates a specific report including the physical data about the monitor and its location as well as the monitored data that can be viewed as a graph.

Additionally the data on reported leaks or service problems (e.g. low pressures) provided by clients can be inserted into the DMS. Each leakage or problem reported is kept in a record including the data about the client who reported the issue as well as the characteristics of the problem. The DMS allows inserting and viewing a picture of the reported leakage or the figure with the location.

Other data that can be imported in the DMS includes information about leakage location and leakage repairs. As can be seen in the previous figure the DMS contains two modules for this information. These data include details about leakage location, pipe material, cost of repair, estimation of the leakage, etc.

The DMS creates a specific record for each leakage and it is possible to map the leakages by combining the DMS output with a GIS. This is useful too represent the pipes with the highest number of leaks (no. of leaks/km) and the leak frequency (no. leaks/km/year). An example of the record kept in the DMS is shown in Figure 4 that includes data about the leakage repairs.

Analysis of priority intervention

One of the key features of the DMS is its capability to prioritise leakage interventions hence allowing the operator to target leakage in a cost-effective manner. The DMS calculates the leakage in each district by subtracting the minimum night flow to the monitored flow data in each district. Combining leakage data with information related to repair costs, the DMS determines the order of priority for intervening, or the so-called 'zone ranking factor'.

If flow records are insufficient to determine leakage based on the minimum night flow method, the DMS can also establish the level of losses using the IWA water balance, also termed the Top-down approach. This is the approach used by the other TILDE product, the Leakage Check Up described in the next section.

The Leakage Check Up

The Leakage Check-Up performs a simplified evaluation of the IWA's water balance and of the performance of individual water systems. Through an easy three-step procedure, the Leakage Check-Up allows the user to calculate the components of Non Revenue Water and IWA's leakage performance indicators. It also helps to benchmark the system efficiency both in terms of leakage and its capacity to meet demand, i.e. supply-demand balance.

A dedicated section of the water portal allows registered members to use for free the Leakage Check-Up tool and evaluate how their networks are performing as regards leakage. Registered users must fill the Leakage Check-Up form on-line with some basic data about their utility and networks in order to evaluate the volume of real annual losses in their networks. The value of the unavoidable annual losses depends on the length of mains, number of connections, average pressure, and average length of service pipe. The calculation of leakage performance indicators is then carried out. Specifically the Infrastructure Leakage Index (ILI) is calculated as the ratio between current annual real losses and unavoidable annual real losses. Moreover other IWA performance indicators are calculated such as volume of leakage per connection per day.

The Leakage Check-Up establishes how critical leakage is for a system considering the system's capacity to meet demand. This analysis is produced on a graph that plots the supply demand indicator against the leakage indicator (ILI) (see Figure 5). Depending on the place that the system occupies in the graph (blue square), the tool gives recommendations on the actions needed to improve performance.

The ADRICOSM Project

The ADRICOSM project was launched in 2001, supported by the Italian Ministry of Environment under the *Adriatic-Ionian Initiative* that focused on promoting scientific collaboration among the seven Adriatic Sea bordering countries Albania, Bosnia-Herzegovina, Croatia, Greece, Italy, Slovenia and Serbia-Montenegro. ADRICOSM aims at improving pollution control into the Adriatic Sea which is under great pressure by the population and economic activities of the basin draining to it.

Almost 50 million people discharge wastewater into the rivers flowing into the Adriatic sea, and intensive fishing farming and industrial activities generate loads of nutrients and pollutants. The problem is manifested with events of extensive algae blooms and sea water anoxia.

ADRICOSM has developed an integrated river basin management strategy to mitigate land-based pollution on the rivers and coastal areas of the Adriatic based on the mathematical modelling and monitoring of all the elements within the wastewater cycle, i.e. sanitary assets and receiving waters.

ADRICOSM started with one pilot project in the Cetina river basin (Croatia) and the analysis of urban pollution in the city of Split. The benefits demonstrated by this study and the scientific interest it rose, led to its replication in other basins of Croatia (Bojana River including Pula Bay and Nerteva river, this last shared with Bosnia Herzegovina), one in Albania (Ishem river that crosses the capital Tirana) and one in Montenegro (Bokakotorka Bay).

Figure 6 shows some locations where the ADRICOSM project is implemented.

The achievements of ADRICOSM were recognised at the World Summit on Sustainable Development (Johannesburg, September 2002) where the project was considered a model for sustainable development of river basins and coastal areas.

The project has been of particular interest to wastewater utilities aiming at improving the operation of their assets to prevent pollution and flooding. The operators involved in ADRICOSM have enhanced the knowledge about their systems through the application of technologies that measure and analyse the quantity and quality of wastewater in their networks and spills into receiving waters. These technologies have proved useful in their daily operation of the systems and for strategic planning of their future capital investments.

The following paragraphs describe the methodology and results achieved with the project in its first application site, i.e. the Cetina river basin and the city of Split. Analogous methodology and results have been developed in the other project sites.

Results of the ADRICOSM project

The focus of the ADRICOSM project is to demonstrate the benefit of using mathematical models and water monitoring technologies to improve pollution management of the rivers and coasts along the Adriatic Sea.

The project has resulted in the development of simulation models of the sewer networks and receiving waters (rivers and coastal areas) using existing data and measurements of flows and water quality collected through a monitoring campaign. The models have been calibrated to represent the hydraulics and water quality processes in the sewers and water bodies, and subsequently used to analyse the system performance, and to identify the solutions against wastewater pollution and flooding.

Mathematical models

All the project sites in the ADRISCOSM project include the analysis of three elements, namely the river basin, the sewer networks of the main city in the basin and, in most cases, the coastal area where the river discharges. Mathematical models were developed for each of these elements using existing data from past surveys and previous studies.

The *sewer system model*: The MOUSE sewer modelling system was used to represent the sewer network of the main city in the river basin. MOUSE is a professional engineering tool developed by the Danish Hydraulic Institute for the simulation of the hydrology, hydraulics, water quality and sediment transport in urban drainage and sewer systems.

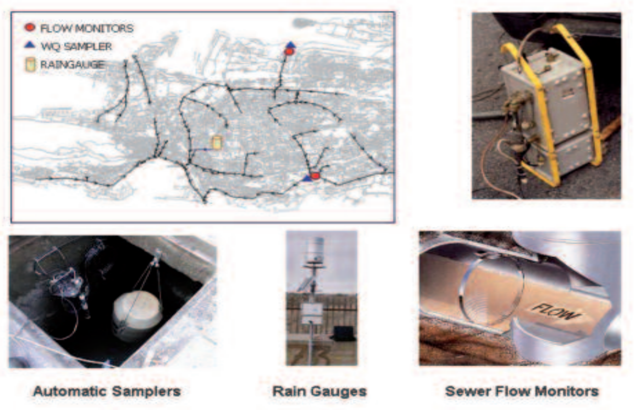
The following computation modules were used:

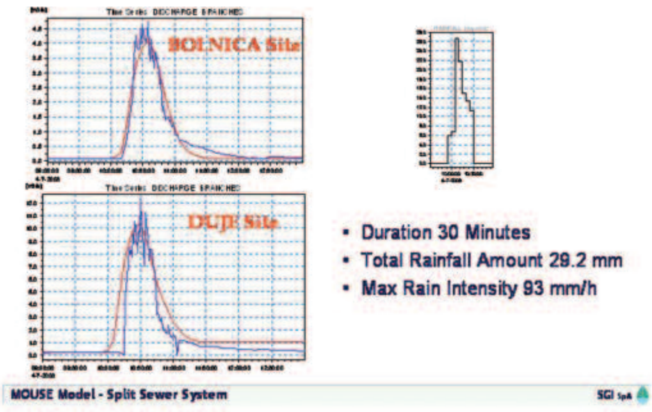
- RUNOFF: surface runoff models for urban catchment applications;
- HD: hydrodynamic network model;
- TRAP: pollutants process on catchments surfaces and in drainage networks.

The *river basin model:* The software selected for the set-up of the water quality model was MIKE 11, developed by the Danish Hydraulic Institute and known and applied all over the world. MIKE 11 is a model for simulating the hydrodynamics and water quality of receiving waters. It represents the impact of spills from wastewater facilities, the advection and dispersion processes of pollutants in rivers and pollution loads on coastal areas. Figure 7 shows the extent of the river model in the Cetina river site study.

The *coastal area model:* The US Army Corps of Engineering's RMA-2 (2-dimensional hydrodynamic computation) and RMA-4 (Advection dispersion computation) were used to simulate the coastal area in Croatia bordered by Split and the Cetina mouth, the island of Hvar and Drvenik Veli, including the Brac Island. The model area has been schematized with a square and triangular finite element mesh, in order to represent accurately all the geometric discontinuities of the coastline and the bathymetry (under-

Figure 8
Split Sewer system – Monitoring campaign and calibration of the mathematical model





water depth). The mesh element size varies between 20 and 1200 metres with the smallest elements lying near the wastewater outlet and the other pollution sources.

Flow and water quality monitoring surveys

The models have been calibrated against flow and water quality data collected in specific monitoring surveys, in order to ensure they represent the real conditions in the sewers and water bodies.

Water quality data have been collected using automatic samplers placed at suitable locations in the sewer network, river and coastal area. Laboratory analysis has provided the values of suspended solids, total nitrogen and COD (chemical oxygen demand). One of the fundamental objectives of water quality monitoring is to provide data for the calibration of the Advection Dispersion (AD) modules. When these modules are integrated with the hydrodynamic models they are capable of simulating advection-dispersion of pollutants both in dry weather conditions and during storm events. In addition to samplers, the installation of rain gauges and flow meters was also carried out. These instruments are shown in Figure 8, which also contains the plan of the modelled sewer of the city of Split.

Models calibration was the next task and it involved the adjustment of internal model parameters so that model prediction is in good agreement with observed data. The model of the Split sewer system was calibrated using the data collected in the monitoring survey initiated in June 2003.

Measurements were conducted in two significant pilot catchments suitably chosen to represent Split sewer system: Duje catchment, where foul water is directly discharged into the Kastela Bay, and Bolnica catchments which delivers water to one of the main combined sewer overflows operating only during rain events. Figure 8 also shows the good flow hydrograph fit achieved in the calibration exercise. The red curve is the modelled flow hydrograph whereas the blue curve represents the monitored flow data.

Performance Analysis

The performance analysis of the wastewater facilities was carried out using the calibrated models in order to assess the impacts of wastewater pollution on the coastal areas. The parameters considered for evaluating sewers performance were length of surcharged pipes, duration of pressurised flow in surcharged pipes, number of nodes where maximum water level exceeds ground level (indication of possible flooded areas), total volume discharged into the sea from combined sewer overflows (CSOs) and outlets.

The model results using a design rainfall with five years return period indicated that five CSOs out of 12 in Split, discharge over 80% of the total discharged volume (168,000 m^3) containing 90% of the pollution load.

The models were used to verify the impacts of proposed solutions which included development of wastewater treatment plants in the municipalities of the Cetina river basin and the construction of storage tanks to collect the volume of surface runoff generated by the first flush phenomenon. Simulations results highlighted that a reduction of COD and suspended solid load of around 75% could be achieved by collecting 20% of the total discharged volume into storage tanks. Five storage tanks (total volume of 35,000 m^3) have been simulated upstream the main CSOs that discharge more that 80% of all spills.

Conclusions

Water utilities are nowadays facing many challenges as they strive to optimise the operation of their aged and poorly maintained assets. The costs for rehabilitation are huge, demand for water and wastewater services increases, and the need for environmental sustainability is imposing strict limitations to preserve water quality and prevent overexploitation.

In such context the application of the information and monitoring technologies described in this paper can be extremely helpful and cost effective. These technologies help to collect, organise and analyse data in order to establish the performance of water and wastewater assets, identify critical areas, and help to define strategies and interventions to improve efficiency cost-effectively.

TILDE technologies are concerned with the reduction of water losses in municipal distribution networks, an issue of increasing importance for water operators, particularly in places suffering water shortage. The TILDE technologies offer a great opportunity to water utilities aiming at increasing their knowledge about water loss management best practice and technologies. The TILDE Decision Support Tool, Data Management System and Leakage Check Up can help water managers and engineers in developing strategies for managing their water losses according to internationally recognised best practice.

The ADRICOSM project has promoted the use of mathematical models and monitoring technologies to help operators to improve the operation of wastewater facilities and prevent pollution of receiving waters. Through the development of mathematical models, water operators have reviewed and updated their data on the systems, increase the knowledge about the asset operation and advance their technological know-how. They have identified strategic solutions to minimise pollution and enhance the management of their assets.

Decisions on asset management and planning must be backed by extensive data analysis, and the support that technologies offer today for monitoring and analysis what is happening in our hidden underground assets is of crucial importance to facilitate and optimise the work of water and sanitation operators. ●

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Concerns over water loss and source water protection

Two new research reports, released by Miya and the American Water Works Association, have revealed that the main concerns of water industry experts are water loss and source supply protection. Lis Stedman reviews the reports' findings.

It is perhaps not surprising that leakage (a supply-related issue) and source water protection (also a key element in ensuring supplies) should be found to be top concerns among water industry professionals around the world.

The Miya report found that the key issue when considering urban water losses was reported to be the provision of safe, clean water for the world's urban population (53% of respondents) followed by saving money (20% of respondents). Economic issues also featured in the American Water Works Association (AWWA) findings.

Respondents stated that lack of funding and a reluctance to invest based on concern over revenue returns are the greatest barriers to resolving water losses. Just over half of respondents cited a general lack of awareness of the issue as a problem, and just under half believed the water industry itself is unaware of the extent of the problem.

Estimates suggest that if current demographic and economic trends continue the world will require 40% more water by 2025. The survey respondents identified reducing water loss as the best and the most cost-effective solution to increasing the water supply. The ability to provide turnkey solutions, including funding was also felt to be key to successfully implementing water loss projects.

Booky Oren, President and CEO of Miya, said: 'That the industry believes that the extent of water loss is unacceptable is no real surprise to us. That financing and lack of comprehensive coordination are perceived as major barriers to implementing effective water loss solutions is no real surprise to us. Miya was conceived to meet a very real and growing need. We believe that by offering municipalities best know-how and expertise as well as an unparalleled range of services, including effective financial solutions, we will enable many cities to address the growing problems with their water systems.

'What was surprising to us was the industry's concern over lack of awareness. We as an industry have a collective responsibility to sound the alarm and to address the fundamental threat water loss poses to safe, clean, affordable drinking water in cities.'

The AWWA report, now in its fifth year, has input from over 1800 leaders assessing the overall health of the industry and identifying key challenges. Among survey respondents, 68% were water utility professionals, 24% represented industry manufacturers or service providers, and the remaining respondents came from academia, science, and regulatory bodies.

AWWA Executive Director Gary Zimmerman noted of his association's contribution to the issues debate: 'The State of the industry report provides direct insights into how water professionals feel about issues today and in the future. Our analysis of this data guides the association's programming decisions to help address the greatest concerns of our membership.'

Some of the responses clearly parallel areas of concern identified in the Miya report – AWWA found worries about ensuring adequate future water resources, particularly in arid or semi-arid regions experiencing population growth, for instance, and many respondents stressed the need for effective water efficiency and conservation programmes. Others indicated a growing interest in 'water efficient' technologies such as water reuse and desalination.

The significant concern about the continent's ageing infrastructure, and the fact that deferring investment will only lead to bigger bills in the future, neatly ties together concerns about leakage and finance.

Many of the respondents also expressed concern about complying with new and complex regulations, and the effects of the retiring 'Baby Boomer' generation and the consequent fierce competition for the shrinking pool of new workers.

Business factors of concern included financing infrastructure repair and improvements, source water development, regulatory requirements, security, and a range of other factors.

The report, which has separate US and Canada break-outs, also provides an assessment of the industry's overall soundness. Interestingly, this year respondents rated the current soundness of the industry slightly higher than in 2007, but for the first time US respondents rated the future soundness of the industry as lower than its current state of health, which indicates significant concerns about the years ahead. Future soundness ratings for the Canadian water industry also dropped significantly, mirroring the US's optimism deficit.

AWWA President Mike Leonard said: 'The report confirms a lot of things we know to be true, but also illuminates some blind spots. As an organisation, we will continue to provide water professionals with the resources they need to continue to supply their customers with safe drinking water.'

AM DIARY

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

International Conference - Water Efficiency in Urban Areas: Concepts, Technologies, Socio Economics
29-30 January 2009, Wuerzburg, Germany
Contact: Gabriele Struthoff-Mueller
Email: gabriele.struthoff-mueller@otti.de
Web: www.otti.de/pdf/wea3091.pdf

3rd Specialised Conference on Decentralised Water & Wastewater International Network
9-11 February 2009, Kathmandu, Nepal
Web: www.iwa.nepaliko.com

Water Loss 2009
26-29 April 2009, Cape Town, South Africa
Email: waterloss2009@randwater.co.za
Web: www.waterloss2009.com

Water Malaysia 2009
19-21 May 2009, Putra Word Trade Centre, Kuala Lumpur
Contact: Ms Kelly Liau
Tel: 603 6140 6666
Email: kelly@protempgroup.com
Web: www.watermalaysia.com

Singapore International Water Week
22-25 June 2009, Singapore
Web: www.siww.com.sg

Asset Management of Medium and Small Wastewater Utilities
3-4 July 2009, Alexandroupolis, Greece
Contact: Konstantinos Tsagarakis
Tel: +30 28310 77433
Email: iwa@econ.soc.uoc.gr
Web: http://iwasam.env.duth.gr

2nd International Conference on Water Economics, Statistics & Finance
3-5 July 2009, Alexandroupolis, Greece
Contact: Konstantinos Tsagarakis
Tel: +30 28310 77433
Email: iwa@econ.soc.uoc.gr
Web: www.soc.uoc.gr/iwa

5th IWA Specialist Conference on Efficient Use and Management of Urban Water Supply
19-21 October 2009, Sydney, Australia