An integrated approach for infrastructure asset management of urban water systems

A paradigm shift is required towards managing urban water services in a more integrated and efficient way, which includes the use of advanced asset management in order to ensure high quality and adequate water supplies in the future. Here, Helena Alegre, Dídia Covas, Sérgio T Coelho, Maria do Céu Almeida and Maria Adriana Cardoso present the AWARE-P R&D project, which aims to produce adequate and effective support tools for assisting urban water utilities in decision making and rehabilitation planning.

Helena Alegre
Sérgio T Coelho
Maria do Céu Almeida
Maria Adriana Cardoso
LNEC – National Civil Engineering Laboratory, Lisbon, Portugal.

Dídia Covas
Instituto Superior Técnico (IST), Lisbon, Portugal.

Infrastructure asset management (IAM) is increasingly becoming a key topic in the move towards compliance with performance requirements in water supply and wastewater systems.

Sustainable management of these systems should respond to the need for:

- Promoting adequate levels of service and strengthening long-term service reliability
- Improving the sustainable use of water and energy
- Managing service risk, taking into account users' needs and risk acceptance
- Extending service life of existing assets instead of building new, when feasible
- Upholding and phasing-in climate change adaptations
- Improving investment and operational efficiency of the organisation
- Justifying in a clear and straightforward manner the investment priorities

Effective decision making requires a comprehensive approach that ensures the desired performance at an acceptable risk level, taking into consideration the costs of building, operating, maintaining and disposing capital assets over their life cycles. Brown and Humphrey (2005) summarize these concepts by defining IAM as 'the art of balancing performance, cost and risk in the long-term'. IAM is most often approached based on partial views: e.g., for business managers and accountants, IAM means financial planning and the control of business risk exposure (Harlow and Young, 2001); for water engineers, IAM is focused on network analysis and design, master planning, construction, optimal operation and hydraulic reliability (Alegre and Almeida, 2009); for asset maintenance managers, the infrastructure is mostly an inventory of individual assets and IAM tends to be the sum of asset-by-asset plans, established based on condition and criticality assessment; and for many elected officials, since water infrastructures are mostly buried, low visibility assets, IAM tends to be driven by service coverage, quality and affordability in the short run. Common misconceptions include reducing IAM to a one-size-fits-all set of principles and solutions, mistaking it for a piece of software, substituting it for engineering technology, or believing that it can be altogether outsourced. In practical terms, many existing implementations tend to be biased by one or several of these perspectives.

The integrated IAM approach described in this paper aims to avoid the shortcomings inherent to those partial views. It is driven by the need to provide adequate levels of service and a sustainable service in the long-term. This approach is the result of work developed during AWARE-P – Advanced Water Asset Rehabilitation, an R&TD project aimed at producing adequate and effective support tools for assisting urban water utilities in decision making and rehabilitation planning (www.aware-p.org).

The AWARE-P methodology and associated tools incorporate the principles generally recommended and adopted in IAM by leading-edge research, consultant and utility organizations (Hughes, 2002; INGENIUM and IPWEA, 2006; Saegrov, 2005; Saegrov, 2006; Sneesby, 2010). It approaches IAM as a management process, based on PDCA (plan-do-check-act) principles and requiring full alignment between the strategic objectives and targets, and the actual priorities and actions implemented. It expressly takes into account that a networked infrastructure cannot be dealt with in the same way as other collections of physical assets – it has a dominant system behaviour (i.e., individual assets are not independent from one another), and as a whole it does not have a finite life – it cannot be replaced in its entirety, only piecemeal (Burns et al., 1999). The methodology allows for the assessment and comparison of intervention alternatives from the performance, cost and risk perspectives over the analysis horizon(s), taking into account the objectives and targets defined (Alegre and Covas, 2010; Almeida and Cardoso, 2010). In summary, the objective of the AWARE-P IAM approach is to assist water utilities in answering the following questions:

- Who are we at present, and what service do we deliver?
- What do we own in terms of infrastructures?
- Where do we want to be in the long-term?
- How do we get there?

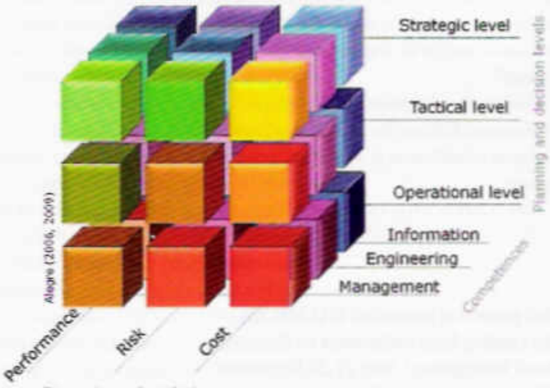

Figure 1
The AWARE-P approach

Infrastructure asset management

The problem

Let us put ourselves in the position of a utility manager in charge of infrastructure planning and rehabilitation. The utility's executive board has defined 'Improving the sustainable use of water and energy while minimizing the carbon footprint' as one of the key corporate strategic objectives. This utility's networks display undesirable failure rates (pipe breaks and sewer collapses) and the energy bill for pumping is rather high; the water supply network has unflattering losses,

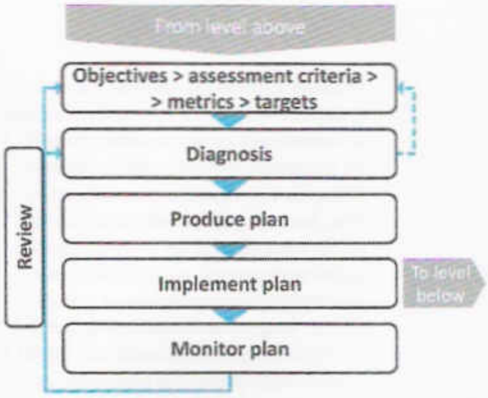

Figure 2
The planning process (at each planning level)

and localized pressure problems at peak consumption hours remain; there are floods or overflows from the wastewater network even under moderate rainfalls. The following questions are due:

- How would we act?
- How would we prove that our decisions are effectively addressing the strategic objective?
- How would we quantify the impact of our decisions and of subsequent actions?

Traditional AM practice

The traditional approach would probably be to start with an updated and reliable inventory of the existing assets by compiling as many reliable records as possible of their condition and failure history. Locations could try to be identified where there are pressure problems, flooding and overflows, and pump efficiency and energy consumption could also be looked at. The relative importance of each asset could also be assessed.

Combining these types of information, we would prioritize interventions within our budget constraints. This would contribute to the first question. What could be done about the other two? Fixing pumps and replacing some pipes or sewers will undoubtedly help save water and energy, but would that maximize the utility of the investment made? A discerning board might be less than satisfied, and the third question would still remain unanswered. They might ask some additional questions:

- How did we deal with the hydraulic problems? Were we able to allocate levels of service to each individual asset when dealing with pressures, water losses and floods?
- How did we select the sizes and materials of the new pipes and sewers?
- Did we assume that the existing networks configurations (e.g., layout and diameters of networks, location and characteristics of storage tanks and pumping stations) are adequate from the energy point of view?

These are the types of issues that the proposed approach is designed to tackle in a structured, aligned and transparent way. The following sections explain how.

The AWARE-P approach

The cube shown in Figure 1 symbolizes the AWARE-P approach. It advocates that IAM must be addressed at different planning decisional levels: a strategic level, driven by corporate and long-term views and aimed at establishing and communicating strategic priorities to staff and citizens; a tactical level, where the intermediate managers in charge of the infrastructures need to select what the best medium-term intervention solutions are; and an operational level, where the short-term actions are planned and implemented. It also draws attention to the need for standardised procedures to assess intervention alternatives in terms of performance, risk, and cost, over the analysis period. The other relevant message is that IAM requires three main pillars of competence: business management, engineering and information.

At each level of management and planning – strategic, tactical and operational – a structured loop (Figure 2) is proposed that comprises the following stages: definition of objectives and targets; diagnosis; plan production, including the identification, comparison and selection of alternative solutions; plan implementation; and monitoring and review. Most utilities already have several elements of this process in place. What is often missing is a review mechanism – a way to measure compliance with set goals – as well as an effective alignment between the different management levels.

Setting up objectives, assessment criteria, metrics and targets is a crucial stage in order to set up clear directions of action, as well as accountability of results through timely review. Clarifying the four distinct but sequential concepts:

- Objectives are the goals that the organization aims to achieve. The AWARE-P approach, in accordance with the ISO 24510:2007, 24511:2007, 24512:2007 and EN 752:2008 standards, demands that objectives are clear and concise, as well as ambitious, feasible and compatible, and take into account the ultimate goal for the utility of providing a sustainable service to society. For each objective it is recommended that key assessment criteria be specified.
- Criteria are points of view that allow for the assessment of the objectives. For each criterion, performance, risk and cost metrics must be selected in order for clear targets to be set, and for further monitoring of the results.
- Metrics are the specific parameters or functions used to quantitatively or qualitatively assess criteria; metrics can be indicators, indices or levels.
- Targets are the actual proposed values to be achieved for each metric within a given time frame (short-, medium- or long-term).

For instance: for an objective of environmental sustainability, one possible criterion could be water usage efficiency, measured through areal losses per service connection (l/conn./day) metric, for which a target of 100 l/conn./day might be chosen.

Assessment metrics are a key element of the whole process: they are used to establish targets, to set up a diagnosis, to compare and select alternative courses of action, and to monitor and review the process. They should be relevant, reliable, simple, and effectively measure success. The AWARE-P software offers a wide variety of metrics that the users can choose from, or define their own (Coelho and Vitorino, 2011). Objectives and targets are also a powerful means of communication within the organisation and with other stakeholders. For our utility example, Table 1 illustrates possible assessment criteria, metrics and targets that might be used for the strategic objective of improving the sustainable use of water and energy while minimizing the carbon footprint. Only performance indicators are shown, but risk and cost metrics might also be considered.

As illustrated in Figure 3, the process cascades through the decisional levels within the organisation's management structure. The global approach is based on PDCA principles, aiming at the continuous improvement of the IAM process. The key notions in this process are alignment, feedback, involvement and empowerment:

- Alignment among strategic, tactical and operational objectives and targets is paramount in ensuring that efforts and resources are not wasted in the long run. In other words, making the best out of limited resources cannot be achieved without smart alignment across the utility.
- Feedback is crucial because alignment cannot be assured through a top-down process alone. It is fundamental to have feedback mechanisms within each level, as well as between levels.
- People are the key element in this process. First of all, top management must be engaged in the shift of paradigm to an integrated IAM approach. It is equally important

Table 1 - Example of assessment criteria, metrics and targets

Strategic objective 1: 'Improving the sustainable use of water and energy while minimizing the carbon foot print'

Assessment metrics	Current situation	Targets	
		In 5 years	In 20 years
Criteria 1: Sustainable use of water			
Real losses per connection (l/connection/day)	250 (poor performance)	150	100
Wastewater reused (%)	0 (poor performance)	5	20
Criteria 2: Sustainable use of energy and minimization of carbon footprint			
Standardized energy consumption (kWh/m³/100 m)	0.6 (fair performance)	0.40	0.40
Excessive energy per revenue water[1] (kWh/m³ revenue water)	0.15 (poor performance)	0.10	0.05

[1] This represents the maximum theoretical potential of energy reduction per m³ of revenue water (Duarte et al., 2009).

to ensure the involvement of the entire organization, from the CEO to the asset operators, and the empowerment of the staff, in order to promote leadership, co-ordination, collaboration, corporate culture acceptance, motivation, commitment and corporate know-how.

Quoting Plant (2008), the commitment to continuous improvement is not just needed during the production of the plan documents, but it is an on-going commitment of the organization to ensure strategic success.

Going back to above-mentioned example, the implementation of the AWARE-P approach would have required the board to be more specific, identifying how to assess success by means of metrics and targets over time (see example in Table 1) and providing some directions for action. These guidelines would have been useful in assisting the utility to establish its own tactical objectives and targets, carrying out diagnoses, devising and assessing alternative solutions and monitoring their impact, once implemented.

From problems to solutions

The previous section made the case for effective IAM and for the AWARE-P approach as an organizational and management process. However, it is equally a problem-driven process, guiding and assisting the utility decision makers in addressing the key infrastructure-related issues by carrying out diagnoses, assessing and comparing alternative solution paths, and selecting the best performance, risk and cost trade-offs in view of the stated objectives.

In order to decide where and how to act in an infrastructure, it is essential to carry out a sound diagnosis, in particular at the strategic and tactical levels of planning. This diagnosis should be grounded on the objectives, criteria, metrics and targets, as introduced in the previous section. These are established not only based on input from the level of planning above (or from the mission and vision, if at the strategic level), but also based on a preliminary assessment of the existing situation and on contributions resulting from the existing feedback mechanisms.

Diagnosis begins with the assessment of the existing system. This must be done not only for the present time but over the planning horizon (usually one year, 3-5 years or 15-20 years, for operational, tactical or strategic planning, respectively) and the analysis horizon (e.g., 20-40 years). The analysis horizon should be significantly longer than the planning horizon, to make sure that the implemented solutions adequately respond to expected changes. For instance, if the planning horizon at the tactical level is typically 3-5 years, the analysis horizon should not be less than 20 years.

In the AWARE-P approach, diagnosis should be carried out from the whole infrastructure to each individual asset. At the strategic level, the infrastructure is assessed as a whole, aiming at the identification of global, core problems. At the tactical level, and at a first stage, the infrastructure should be partitioned into smaller subsystems (e.g., trunk system, pressure zones or district metering areas in water systems; catchments or sub-catchments in wastewater or stormwater systems). At this stage, diagnosis aims at prioritizing such subsystems for intervention, by looking for areas with poor performance, areas containing black spots or areas with fair performance but higher priority due to external factors (e.g., coordination with road works or municipal rehabilitation). At a second stage of tactical planning, a more detailed analysis is carried out for each of the selected priority subsystems, by looking at components (e.g., condition, construction and maintenance costs, criticality) and their system behaviour (e.g., hydraulics, water quality, energy, operational conditions and costs).

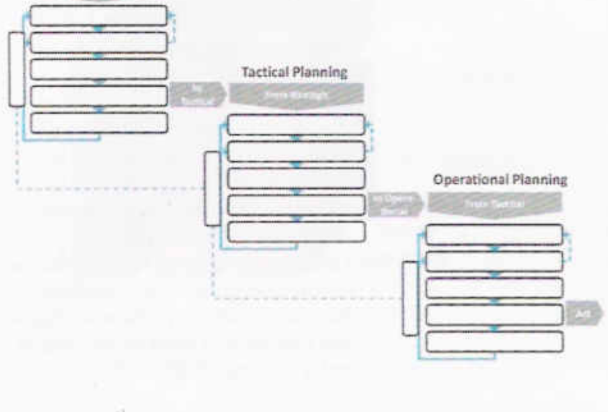

Figure 3
Alignment and feedback between planning (decision making) levels

The assessment of the existing system should be carried out using the established metrics for the above-mentioned three dimensions– performance (MP), cost (MC) and risk (MR) – and for different scenarios. Scenarios are defined as conditions not controlled by the utility, but which may influence the analysis and should therefore be considered (e.g., demographic or economic trends, regulatory changes). In this context, the existing system is assessed over time. From the comparison of assessment values with the set targets, it is possible to identify problems and to explore potential causes.

Once the diagnosis is carried out, alternative solutions (i.e., strategies, tactics or actions, according to the level of planning) can be identified. For instance, if the tactical objective was to reduce wastewater overflows, possible types of alternatives might be: (A0) keep the existing system, assuming the current O&M practices – this is termed the status quo alternative, often also called the base case; (A1) reduce infiltration and cross-connections; (A2) increase the internal storage capacity of the system; or (A3) change operational procedures.

The AWARE-P software provides tools for developing and analysing the alternatives (Coelho and Vitorino, 2011). Engineering solutions associated to each alternative must be specified (e.g., sewers to replace, CCTV inspections to carry out, O&M procedures).

One of the main innovations inherent to the AWARE-P approach is the realisation that the alternative solutions cannot be exclusively established based on the probability of failure of individual assets and that like-for-like replacement is not the only available option. System behaviour cannot be ignored:

- The cause of a problem and its associated symptoms often occur at different locations; therefore, levels

of service cannot be directly associated to individual pipes or sewers.
- Most existing networks gradually expanded over the decades, in response to urban growth and needs. These rarely match the systems' long-term design assumptions, so consequently the vast majority of existing systems are some distance (often far) from their optimal configurations, both at present and for future needs and expectations.

For these reasons, the development of planning solutions should be firmly anchored on a system's view, looking at cost-efficient alternatives that globally make the best trade-offs between the required performance and the acceptable risk levels. This will often lead to evolving the system to a more rational or more ideal configuration – in view of the stated objectives – over the medium- and long-term, and / or changing O&M procedures to improve efficiency. Marques et al. (2011) show the application of these concepts to a real case, analysing system-driven solutions as well as like-for-like replacement solutions.

Alternative solutions should be assessed based on the same metrics, targets and scenarios previously used for the status quo case (Figure 4). Alternatives should be compared among each other and with the status quo, and the solution will be found among those that ensure the best trade-offs between performance, cost and risk. The AWARE-P software (Coelho and Vitorino, 2011) provides performance, risk and cost assessment tools (Almeida et al., 2011). It also offers features for simplified multi-criteria comparison and ranking of alternatives, as well as for more sophisticated multi-criteria analysis for sorting and ranking (Carriço et al., 2011).

The previous section already provided an insight on the topic of performance assessment. As regards cost assessment, the AWARE-P software will contain a feature (under development) to assess the net present value of each alternative, including investment, operating cost and operating revenue occurring in the period of analysis of the plan. The current version considers neither intangible costs nor external costs, assuming that these are taken into consideration under either the risk or the performance perspective. With regard to risk, the current AWARE-P materials are based on a qualitative approach (Almeida et al., 2011). The software contains features to assess both the probability of failure for the cases of pipe breaks and sewer collapses, and the corresponding consequence.

When the alternatives are selected (i.e., strategies, tactics or actions), the plans can be produced. A plan should be a short and clear document, avoiding repetition of other references. The geographical, temporal and thematic scope of the plan should be specified, as well as objectives and targets for short, medium and long-term. The plan should contain a summary of the diagnosis and of selected alternative solutions. It should specify the procedures (tasks and responsibilities), the scheduling of the intervention, the financial plan, and the monitoring and revision frequency.

Tactical plans are the most complex documents among the three levels of planning, often needing support from external consultants. The diagnosis and the formulation and analysis of alternatives require the use of engineering expertise, greatly corresponding to an evolution of the most traditional master plans. However, it is important to note that not only infrastructural alternatives should be considered, but also operations and maintenance or other non-infrastructural measures (e.g., demand management, geographic information system improvement) should also be considered, if relevant.

Back to the problem – what would have been done differently using the AWARE-P approach? Firstly, the utility would have clarified its understanding of corporate vision, objectives, targets and strategies, and kept them as its long-term direction. Based on those, and on its knowledge of the infrastructure and its performance, it would have defined its own tactical objectives and targets. The data it would have gathered in the traditional AM approach would be just as relevant here. However, the specific information really needed to support the decisions would probably have been clearer.

Since the utility would start with a global, bird's eye view of its systems, followed by a subsystem-level evaluation, before an asset-by-asset analysis, it would have a clearer diagnosis and would have been driven to alternative designs that are globally more effective. It might have also found out that the present layout and diameters are far from optimal, and may have concluded that some structural changes would have a higher priority than using up the entire budget on replacing poor condition assets on a like-for-like logic. Indeed, some well-judged adjustments to the system configuration and operation modes might have much more impact on energy consumption than just improving the individual efficiency of the pumps. it would have dealt with the hydraulic issues (pressures, floods, overflows) at the system or subsystem level, not at an asset-by-asset basis. Asset condition and relative importance would still inform the alternatives under consideration, and those components in most need of replacement would still be replaced, but with the broader view of a path to a better system, rather than to a collection of better parts.

By carrying out a systematic alternative assessment and comparison for the relevant scenarios, based on the pre-selected metrics and targets, communication and negotiation among internal and external stakeholders would have become clearer and easier. Decisions would hopefully be less subjective and more easily accountable to the board or to the elected politicians, and their impact on corporate objectives better assessed. The utility would be able to improve monitoring of results and to learn from them and act accordingly. Practical applications and business cases illustrating this methodology can be found in Marques et al. (2011), Cardoso et al. (2011) and Carriço et al. (2011).

A word on data

A key issue for IAM is the need to have available information to support diagnosis and assessment. Information is the set of data necessary for decision making, and which allows for the

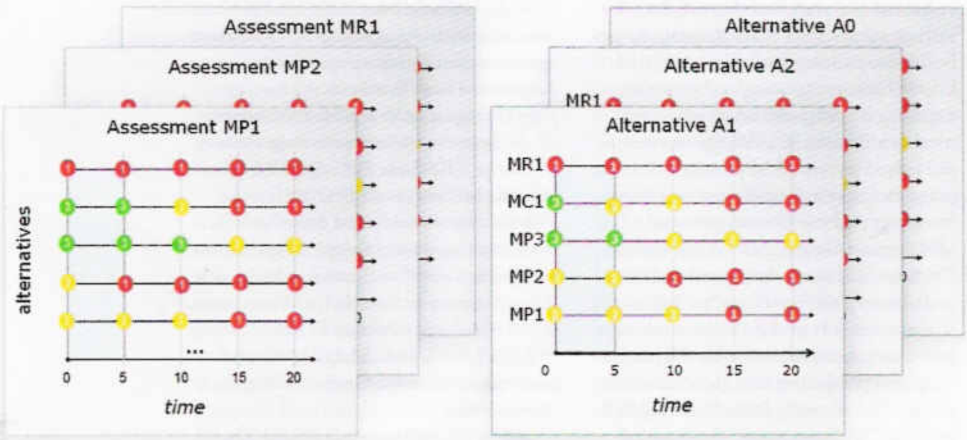

Figure 4
Assessments per scenario, comparing all alternatives for each assessment (on the left) or all assessments for each alternative (on the right)

establishment of actions. Important decisions are grounded in reliable data, inaccurate or missing data can lead to poor decisions. Thus, step one of IAM is to have updated and reliable asset inventories. But other types of information are also needed. Alegre and Covas (2010) and Almeida and Cardoso (2010) identify the most relevant information to be taken into consideration in each level of the IAM planning. Beleza et al. (2011) address the issue of information management, including data availability, accuracy, integrity, usability relevance and transformation into information.

Given the importance of data, the diagnosis should necessarily include the assessment of available data and produce recommendations regarding the improvement of data quality (in terms of reliability and uncertainty), the coherence and fluxes between different data sources, data use, integration of different information systems and data bases and procedures for data update.

Final remarks

In the current world context it is essential to ensure that urban water services are managed in a more dynamic, rational and efficient way than up to the present. This is a strategic sector of great social and economic relevance, supported on expensive and long-lasting physical infrastructures, with a reputation for high inertia and low efficiency. A change of paradigm is urgent and requires advanced asset management, assuring adequate levels of the service in present and in the future, particularly with regard to reliable and high quality drinking water supply, efficient use of natural resources and prevention of pollution and flooding.

The AWARE-P project aims at creating awareness to this need, changing current practices, improving technical know-how in the industry and providing guidance tools and software. The objective of the proposed approach is to encourage and assist urban water utilities in implementing a coherent and structured procedure for infrastructure asset management. It builds on existing leading-edge IAM know-how, integrating and complementing it with new knowledge and methods. This methodology has been published in two IAM manuals of best practice for urban water systems – one for water and one for wastewater (Alegre and Covas, 2010; Almeida and Cardoso, 2010) – complemented by web-based software (Coelho and Vitorino, 2011) and by other training and dissemination materials. All project output is public domain (www.aware-p.org). The recently launched TRUST project (7th Framework Program of the European Union) will allow for the further development of the IAM techniques and software launched with AWARE-P. ●

Acknowledgements

The authors are grateful to the entire AWARE-P project team for their contributions and commitment, as well as to the Financial Mechanism Office of EEA Grants for their support to the project. Special thanks are due to the participating water utilities – AdP Serviços, S.A., AGS, S.A., Veolia Águas de Mafra and SMAS Oeiras and Amadora – and to the National Authority for the Regulation of Water and Waste Services, ERSAR.

References

Alegre, H and Almeida, MC (2009). Strategic asset management of water and wastewater infrastructures. IWA Publishing, ISBN 97843391869.

Alegre, H and Covas, D (2010). Infrastructure asset management of water services. An approach based on rehabilitation (in Portuguese). Technical Guide n. 16. ERSAR, LNEC, IST, Lisboa. ISBN: 978-989-8360-04-5.

Almeida, MC and Cardoso, MA (2010). Infrastructure asset management of wastewater and stormwater services. An approach based on rehabilitation (in Portuguese). Technical Guide n. 17. ERSAR, LNEC, IST, Lisboa. ISBN: 978-989-8360-05-2.

Almeida, MC, Leitão, JP, Martins, A (2011). Incorporating risk in infrastructure asset management of urban water systems. Urban Water (submitted).

Beleza, P, Feliciano, J, Maia, J, Ganhão, A, Almeida, R, Santos, A and Coelho, J (2011). Integrated information tools for strategic asset management. International Water Association 4th Leading Edge Conference on Strategic Asset Management, 27-30 September, Mülheim an der Ruhr, Germany.

Brown, RE and Humphrey, BG (2005). Asset management for transmission and distribution. Power and Energy Magazine, IEEE, 3 (3,39).

Burns, P, Hope, D and Roorda, J (1999). Managing infrastructure for the next generation. Automation in Construction, 8(6), 689.

Cardoso, MA, Santos Silva, M, Coelho, ST, Almeida, MC and Covas, D (2011). Urban water infrastructure asset management - structured approach in four Portuguese water utilities. International Water Association 4th Leading Edge Conference on Strategic Asset Management, 27-30 September, Mülheim an der Ruhr, Germany.

Carriço, NG, Covas, DIC, Alegre, H, Almeida, MC and Leitão, JP (2011). Prioritization of rehabilitation interventions for urban water assets using multiple criteria decision-aid. International Water Association 4th Leading Edge Conference on Strategic Asset Management, 27-30 September, Mülheim an der Ruhr, Germany.

CEN (2008). EN 752:2008 Drain and sewers outside buildings. Committee European de Normalization.

Coelho, ST and Vitorino, D (2011). AWARE-P: a collaborative, system-based IAM planning software. International Water Association 4th Leading Edge Conference on Strategic Asset Management, 27-30 September, Mülheim an der Ruhr, Germany.

Duarte, P, Alegre, A and Covas, DIC (2009). PI for assessing effectiveness of energy management processes in water supply systems. Proceedings of the PI09 Conference - Benchmarking water services - the way forward, Amsterdam, The Netherlands, 11-13 March.

Harlow, VK and Young, K (2001). Asset management war stories or doing it by the numbers! Asset Management Series: Number 5. Brown and Caldwell (California), Hunter Water (Australia).

Hughes, DM (2002). Assessing the future: Water utility infrastructure management. AWWA, USA.

INGENIUM, IPWEA (2006). International infrastructure management manual, version 3.0. Association of Local Government Engineering NZ Inc (INGENIUM) and the Institute of Public Works Engineering of Australia (IPWEA), ISBN: 047310685X.

ISO 24510: 2007. Activities relating to drinking water and wastewater services – Guidelines for the assessment and for the improvement of the service to users.

ISO 24511: 2007. Activities relating to drinking water and wastewater services – Guidelines for the management of wastewater utilities and for the assessment of drinking water services.

ISO 24512: 2007. Service activities relating to drinking water and wastewater – Guidelines for the management of drinking water utilities and for the assessment of drinking water services.' Intern. Org. for Standardization, Geneva.

Marques, MJ, Saramago, AP, Silva, MH, Paiva, C, Coelho, S, Pina, A, Oliveira, SC, Teixeira, JP, Cmacho, PA, Leitão, JP and Coelho, ST (2011). Rehabilitation in Oeiras & Amadora: A Practical Approach. International Water Association 4th Leading Edge Conference on Strategic Asset Management, 27-30 September, Mülheim an der Ruhr, Germany.

Plant, TE (2008). Strategic planning for municipalities. A users' guide. Municipal Knowledge Series. Municipal Word Incorporation (Pub). ISBN: 9780919779846.

Sægrov, S ed. (2005). CARE-W – Computer Aided Rehabilitation for Water Networks. EU project: EVK1-CT-2000-00053, IWA Publishing, ISBN: 1843390914.

Sægrov, S ed. (2006). CARE-S – Computer Aided Rehabilitation for Sewer and Stormwater Networks. IWA Publishing, ISBN: 1843391155.

Sneesby, A (2010). Sustainable infrastructure management program learning environment (SIMPLE). Sustainable Infrastructure and Asset Management Conference. Australian Water Association. 23-24 November 2010, Sydney, Australia (CD).

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