AWARE-P: A SOFTWARE FOR URBAN WATER INFRASTRUCTURE PLANNING[1]

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ABSTRACT

High levels of deferred maintenance and rehabilitation and overwhelming investment needs in urban water services infrastructure demand wise spending and innovative, efficient planning. Rather than component-centric AM approaches, such as like-for-like prioritization and replacement, the complexity of the problem must be addressed by system-centric methods that ensure the best possible compromise between performance (level-of-service), risk and financial effort.

An open-source software system based on a set of tools and models that assist in the analyses and decision support involved in the planning process has been developed in order to host the methods mentioned above. This paper presents the methodology and the software's objectives and features, describes the context and vision that led to its inception and details the main design requirements and technology options.

KEYWORDS: infrastructure asset management, urban water system, planning, software, open-source

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INTRODUCTION

Urban water assets are the most valuable part of the public lifeline infrastructure worldwide, and utilities and municipalities are vested with the responsibility of keeping and expanding them for current and future generations. Infrastructure inevitably ages and erodes, but society places increasing demands for performance, risk management and sustainability.

As many systems reach high levels of deferred maintenance and rehabilitation, the combined replacement value of such infrastructures is overwhelming, demanding judicious spending and efficient planning. However, the best possible use of manpower and financial resources in the long run is hardly ever ensured by traditional risk-based, component-centric AM approaches, such as like-for-like prioritization and replacement.

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 of 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*.

The AWARE-P project (www.aware-p.org; Alegre *et al.*, 2011) aims at providing water and wastewater utilities with the know-how and the tools needed for efficient decision-making in infrastructural asset management (IAM) of urban water services. All project results – from best practice handbooks to business cases, training courses and e-learning materials – have been placed in the public domain and are freely distributed as they become available.

The infrastructure asset management approach developed in the project is a broad management process that addresses the need for a fundamental plan-do-check-act cycle at the utility's various decisional levels – strategic, tactical, operational – aiming at alignment of objectives, metrics and targets, as well as effective feedback across levels. It incorporates 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 and 2006; Sneesby, 2010).

Diagnosing and assessing a water supply or wastewater/ stormwater system, over given time horizons (at least the planning horizon and a longer, impact-analysis horizon), draw from a large range of methods and models for evaluating performance, risk and cost (Marques *et al. 2011;* Almeida *et al.*, 2011). For this purpose, a portfolio of techniques was selected that range from system statistics to network simulation models, to hydraulic and water quality performance, to component failure analysis and forecasting, to component importance and criticality, and to methods for estimating tangible capital and running costs.

An open-source software system, based on a set of tools and models that assist in the analyses and decision support involved in the planning process, has been developed in order to host the methods mentioned above. This paper presents the methodology and the software's objectives and features, with mention to the context and vision that led to its inception, and insights into the main design requirements and technology options.

The AWARE-P project inherits from a number of previous R&D efforts, such as the CARE-W and CARE-S 5th FP research projects (Sægrov, 2005 and 2006). These two projects were crucial stepping-stones in the establishment of structured approaches and their implementation into dedicated instruments, producing a range of partial models and approaches that were grouped together into two groundbreaking software prototypes that attempted to integrate important tracks of the planning process. The prototypes, while functional and very valid first efforts – having been deployed in several seminal "real life" case studies – understandably lacked an integrated computational design and were several stages away from being ready for industry use, requiring difficult, time-consuming data preparation, while not all of the results proposed were of easy usage or interpretation.

AWARE-P is a direct follow-up, trying from the outset to reach the water industry with useable, effective, professional-grade software, able to make a difference in capacity-building and support to the planning process. It was extremely important that the lessons learned from the Care-W/S experiences would be built upon, particularly as regards usability, compatibility with utility data systems, and clarity of the results produced.

PLANNING APPROACH: THE AWARE-P IAM METHODOLOGY

AWARE-P has defined both a language and a complete IAM methodology. The infrastructure asset management approach developed in the AWARE-P project is a broad management process that addresses the need for a plan-do-check-act (PDCA) philosophy at the various decisional levels in a utility – strategic, tactical, operational – aiming at alignment of objectives, metrics and targets, as well as effective feedback across levels (Alegre *et al*., 2011). This concept permeates the planning processes at each of the levels, through the PDCA- inspired loop illustrated in Figure 1.

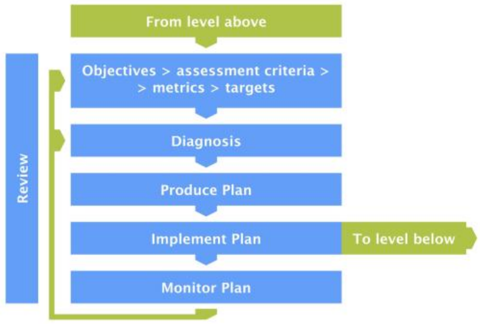


Figure 1. The AWARE-P management process

The IAM process is fundamentally led the stated objectives, and by an educated choice of assessment criteria, metrics and quantifiable targets – the process's underlying *language*. This is particularly evident at the strategic and tactical levels, the latter being the prime field of application for the software described here.

Producing the plan is a problem-driven process, with a strong emphasis on thorough diagnosis in order to identify and assess the system's main issues and shortcomings, in view of the set targets, and to help decide where and how to act. Diagnosing and assessing a water supply or wastewater/ stormwater system, over given time horizons (at least the planning horizon and a longer, impact-analysis horizon), effectively must draw from a large range of methods and models for evaluating performance, risk and cost (Alegre & Covas, 2010; Almeida *et al*., 2011).

For this purpose, a portfolio of techniques was selected that range from system statistics to network simulation models, to hydraulic and water quality performance, to component failure analysis and forecasting, to component importance and criticality, and to methods for estimating tangible capital and running costs.

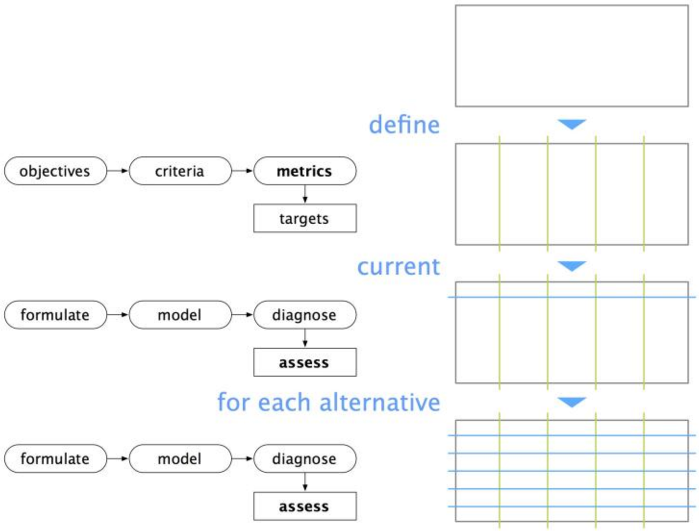


Figure 2. The IAM planning process

The planning process is illustrated on Figure 2 in very simple terms. The drawing board on the right-hand side is initially marked out by the green vertical lines, representing the metrics for the criteria chosen to drive the analysis. A thorough diagnosis and assessment of the current system according to those metrics is carried out (represented by the first blue horizontal at the top).

The planning board is then successively populated with planning alternatives (represented by the subsequent blue lines). The intersections represent the assessment of each planning alternative for each metric. The purpose of the process is to fill out the table to the extent possible.

A separate table is calculated for each relevant time frame of the planning and analysis horizons, effectively giving rise to a *cube* of results, such as made available by the software's planning tool (Figure 3). This is a powerful means of visualizing, assessing and comparing competing projects or alternative solutions to a planning problem or an expansion need. The software implementation described in this paper effectively turns it into a useable, standardized and straightforward tool.

The criteria draw from the available analysis methods in the performance, risk or cost dimensions. For example: hydraulic performance related to minimum available pressure (as given by a hydraulic model); the risk of supply interruption or reduced service due to pipe failure (e.g., evaluated by combining forecast failure rates with component importance derived from network analysis); the net present value of a given alternative over a certain planning horizon. The metrics used to evaluate these criteria tend to lead to standardized quantities, which are more easily compared together and thus facilitate decision-making. Applications of this methodology can be found, for example, in Marques *et al*. (2011) or Alegre *et al*. (2011).

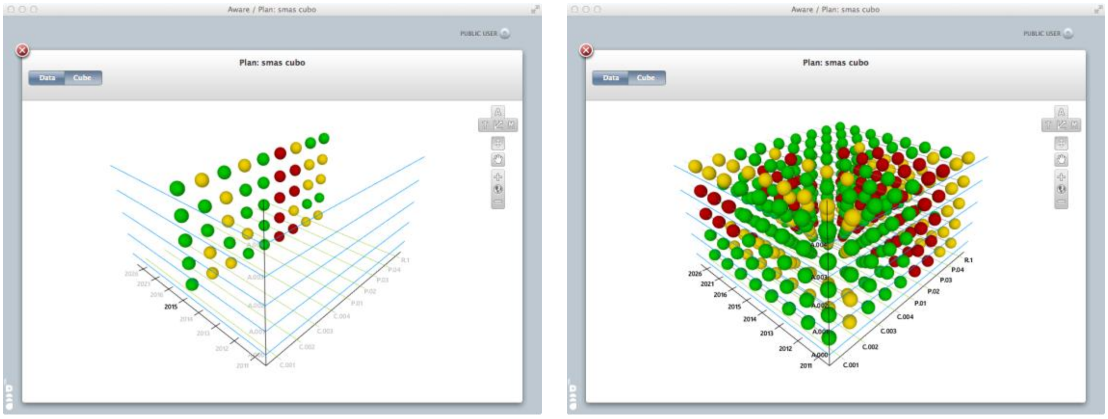


Figure 3. Planning tool: a single time frame (left) and a *cube* of results (right)

THE AWARE-P PLANNING SOFTWARE

The AWARE-P infrastructure asset management (IAM) planning software is an organized assessment environment where planning alternatives or competing solutions are measured up and compared through selected performance, risk and cost metrics. It comprises a portfolio of system metrics and network analysis tools that may be used individually for diagnosis and sensitivity gain purposes, or as part of the integrated AWARE-P IAM planning process.

The software is a web-based application that may be run on public or private server, or as a local, stand-alone deployment. It is implemented using the open-source baseform™ (baseform, 2012) development platform and materializes as an integrated and expandable suite of plug-in tools made available on that platform, taking advantage of its user management, common data integration services and next-generation 2D/3D visualization capabilities (Figure 4). It is Java-based and platform-agnostic, running wherever Java is supported, such as Windows, Mac OS or Linux.

As seen before, the IAM process is fundamentally led the stated objectives, and by an educated choice of assessment criteria, metrics and quantifiable targets. Building on those, the software makes available a coherent set of user-configurable assessment algorithms or models related to performance, cost and risk, which are used to evaluate user-defined alternative system configurations or planning solutions, following the AWARE-P methodology. Based on given planning objectives and measuring criteria, the user selects a set of metrics from the software’s available metrics portfolio and proceeds to evaluate each planning alternative at the selected time frames within the planning and analysis horizons, feeding a cubic space of planning results.

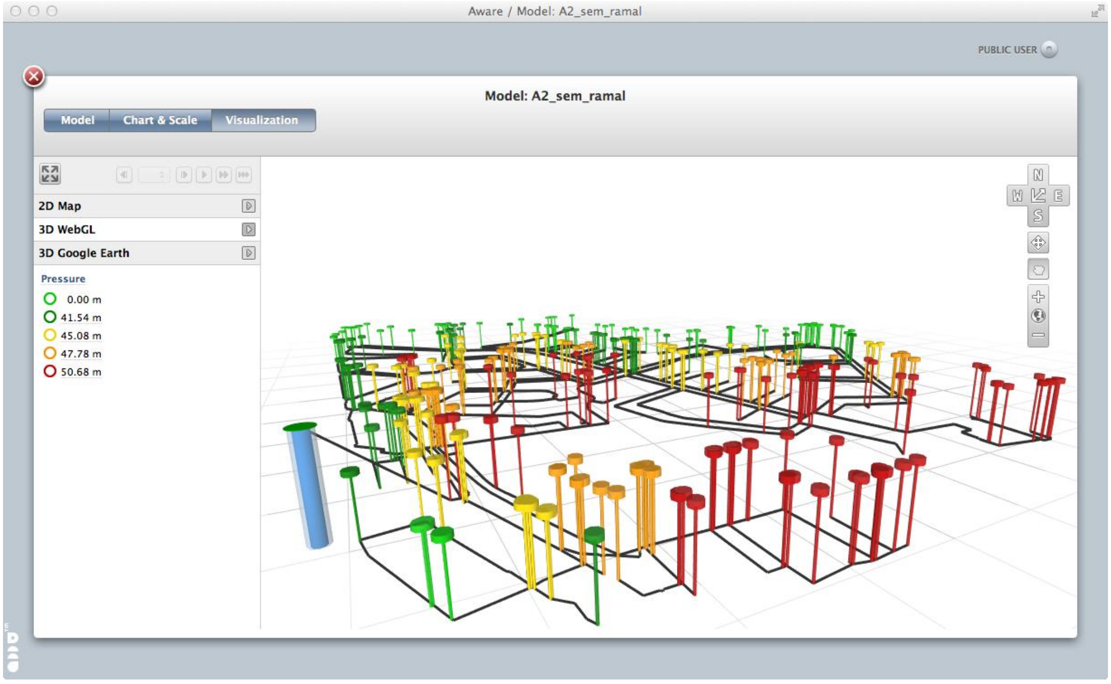
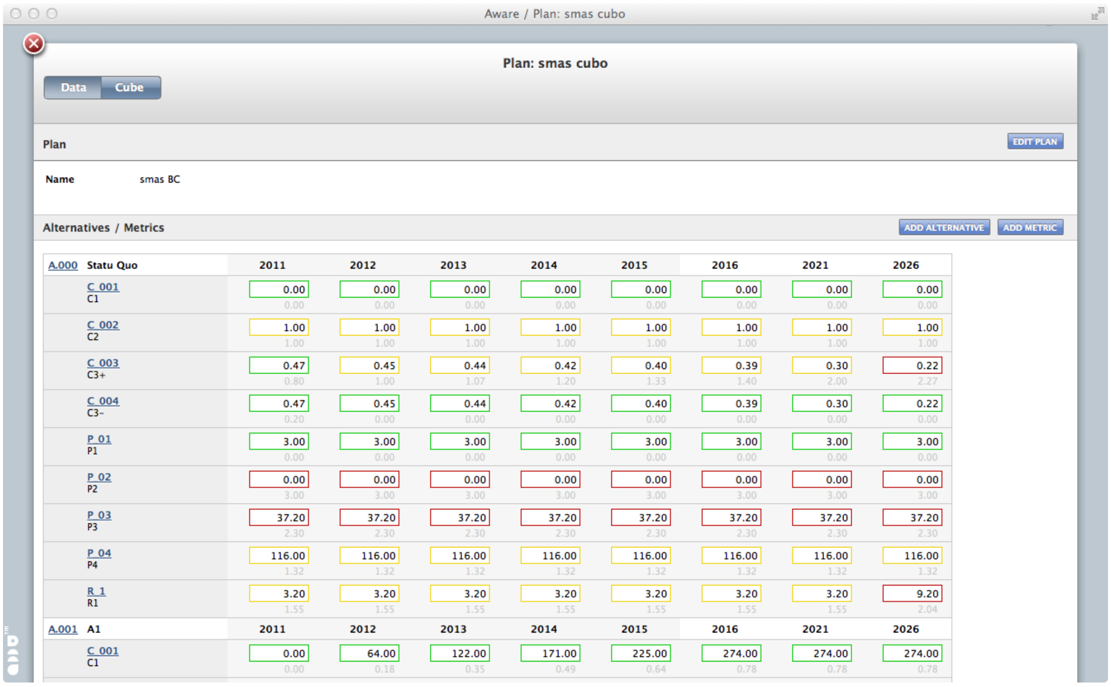


Figure 4. The AWARE-P software's 3D network visualization



A.000	Statu Quo	2011	2012	2013	2014	2015	2016	2021	2026
	C 001 C1	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
	C 002 C2	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00
	C 003 C3+	0.47 0.80	0.45 1.00	0.44 1.07	0.42 1.20	0.40 1.33	0.39 1.40	0.30 2.00	0.22 2.27
	C 004 C3-	0.47 0.20	0.45 0.00	0.44 0.00	0.42 0.00	0.40 0.00	0.39 0.00	0.30 0.00	0.22 0.00
	P 01 P1	3.00 0.00	3.00 0.00	3.00 0.00	3.00 0.00	3.00 0.00	3.00 0.00	3.00 0.00	3.00 0.00
	P 02 P2	0.00 3.00	0.00 3.00	0.00 3.00	0.00 3.00	0.00 3.00	0.00 3.00	0.00 3.00	0.00 3.00
	P 03 P3	37.20 2.30	37.20 2.30	37.20 2.30	37.20 2.30	37.20 2.30	37.20 2.30	37.20 2.30	37.20 2.30
	P 04 P4	116.00 1.32	116.00 1.32	116.00 1.32	116.00 1.32	116.00 1.32	116.00 1.32	116.00 1.32	116.00 1.32
	R 1 R1	3.20 1.55	3.20 1.55	3.20 1.55	3.20 1.55	3.20 1.55	3.20 1.55	3.20 1.55	9.20 2.04
A.001	A1	2011	2012	2013	2014	2015	2016	2021	2026
	C 001 C1	0.00 0.00	64.00 0.18	122.00 0.35	171.00 0.49	225.00 0.64	274.00 0.78	274.00 0.78	274.00 0.78

Figure 5. The numerical, standardized planning table for the cube in Figure 3

The software's tools are also ready to be used in stand-alone, direct assessment mode for the fastest possible path to results (or in the context of general-purpose sensitivity gain and system diagnosis). Examples of such uses may be a PI calculation (AWARE-P includes a full-fledged performance indicators tool with the most up-to-date PI libraries), an analysis of failures rates (Poisson and LEYP models are available), a water quality simulation (Epanet is available), or a fully hydraulic-enabled investigation of network component importance (often termed *criticality*). The tools have been specifically developed to make the best available methods and analysis algorithms accessible for effective industry usage, striving to retain a maximum of simplicity in delivering meaningful and useable results.

AWARE-P has essentially two main usage modes:

(i) as a portfolio of assessment-oriented models and analysis tools that may be used individually or in combination in order to diagnose and gain sensitivity to a system; or

(ii) following the Aware-P IAM planning procedure, oriented to the definition of a planning framework (time horizon, metrics, alternatives) and to feeding the planning tool (Figure 3 and Figure 5) with metric values produced using the tools available.

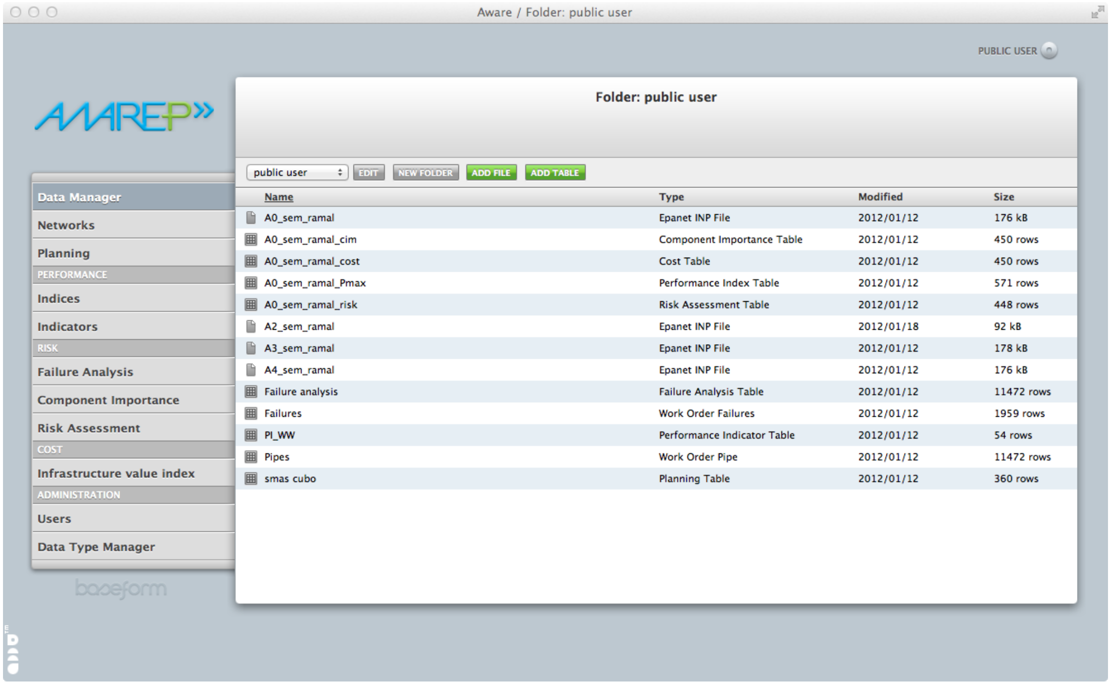


Figure 6. The software's main menu and data manager

AWARE-P (Figure 6) hosts a growing number of plug-in tools that are as effective for stand-alone usage, as fully-fledged analysis algorithms and models, as for producing metrics that feed the central planning tool. The range of tools that are currently present include, among others:

- EPANETJAVA – an efficient, Java-implemented Epanet simulation engine and natively integrated MSX library, for full-range hydraulic and water quality network simulation (Figure 4), taking advantage of baseform's 2D / 3D network and results visualization.
- PLAN – the central planning framework of the AWARE-P infrastructure asset

management methodology, where planning alternatives or competing solutions are measured up and compared through selected performance, risk and cost metrics, through interactive numerical 2D/3D graphical information display.

- PI - Performance Indicators, quantitative assessment of the efficiency or effectiveness of a system through the calculation of performance indicators based on state-of-the-art, standardised PI libraries as well as user-developed or customised ones.
- PX – Performance Indices, technical performance metrics based on the values of certain features or state variables of water supply and waste/stormwater networks. The indices measure performance concepts related to level-of-service, network effectiveness and efficiency.
- FAIL – using models such as Poisson and LEYP, prediction of future pipe or sewer failures for a given network, e.g. in the context of estimating risk or cost metrics, based on an organized failure history in the form of work orders and pipe data.
- CIMP – calculates a component importance metric for each individual pipe in a network, based on the impact of its failure on nodal consumption. The measure is computed based on the network's hydraulic model, using full simulation capabilities.
- UNMET – calculates a service interruption risk metric expressed as the expected volume of unmet demand in a system over one year, given the expected number of outages for each pipe, the average downtime per pipe outage, and the component importance of each pipe, expressed in terms of unmet demand.
- FIN – Financial Project, which enables the user to create and include any type of investment, expenditure and revenue along a given time frame, thus projecting the main elements of the financial balance of a project, taking due account of any chosen discount rate, and calculating the NPV and IRR.
- IVI - Infrastructure Value Index, representing the ageing degree of an infrastructure, calculated through the ratio between the current value and the replacement value of the infrastructure.

One important feature of the software and of the AWARE-P IAM approach is its focus on evaluating the water networks as systems rather than as collections of independent assets. For this reason, the range of assessment models and methods available draws heavily on the capability to simulate system behavior, as much as possible with support from network simulators, such as EPA's well known Epanet. This leads to the capability to produce both component-based metrics and system-wide metrics.

The entire set of visualization and analysis tools is available for exploratory use without having to follow a predefined project-driven script. From this viewpoint, the software is akin to a wide-ranging, system-based modeling software, suited to what-if and sensitivity analyses and to general system modeling.

CONCLUDING 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.

The software introduced in this paper is an innovative proposal in the field of IAM planning analysis, as it makes available on an advanced technology platform the best tools for visualizing, diagnosing and evaluating any given urban water system, through a portfolio of performance, risk and cost models, at both global and detail levels, enabling the user to compare a system with any number of alternative solutions or proposed changes using standardized methods that facilitate choice and decision-making.

The software development is a continuing effort that takes advantage of the modular, plug-in architecture of the software platform deployed in order to add new modules as they become available. A significant effort is on-going for the development of further specialized IAM methods.

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