AWARE-P: a collaborative, system-based IAM planning software

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Abstract
The AWARE-P project aims to promote the application of integrated and risk-based approaches to the rehabilitation of urban water supply and wastewater drainage systems. Central to the project is the development of a software platform based on a set of computational components, which assist in the analyses and decision support involved in the planning process for sustainable infrastructural asset management. The AWARE-P software system brings together onto a common platform the infrastructural geo- referenced data that describe the physical water supply or sewerage systems, as well as a variety of data originating in the several information systems that exist in the water utility corporate environment, such as maintenance and work orders data, billing and costs databases, or network analysis models. Building on those, it makes available an organized set of user-configurable assessment algorithms related to performance, cost and risk, which are used to evaluate alternative system configurations or planning solutions, against current and projected or hypothetical scenarios.

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

INTRODUCTION
Utilities and municipalities manage the world's largest portfolio of infrastructure assets, and urban water assets are the most valuable part of these infrastructures. Infrastructure inevitably ages and degrades, due to multiple factors, while performance requirements are more and more demanding, and sustainability concerns escalate. Many systems are reaching alarming levels of deferred maintenance and rehabilitation, and the combined replacement value of such infrastructures is staggering.

Today's managers and engineers must cope with a multitude of challenges, from water scarcity, climate change and increased society expectations, to technology developments and health- and risk-related constraints. Resource scarcity imposes the need for increasingly effective and efficient system maintenance practices, to which an integrated and sustainable management is essential. As a strategic sector of great social and economic relevance, it is vital that urban water services are managed in an increasingly rational and efficient way. Without advanced infrastructural asset management (IAM), it will not be feasible to assure adequate levels of service in the future, particularly with regard to reliable high quality drinking water supply, use of natural resources and prevention of pollution and flooding of urban environment.

The AWARE-P project (Alegre *et al.*, 2011; AWARE-P, 2011) aims at providing water and wastewater utilities with the know-how and the tools needed for efficient decision-making in infrastructural asset management of urban water services. All the project's results – from best practice handbooks (Alegre & Covas, 2010; Almeida & Cardoso, 2010) to example business cases (Marques *et al.*, 2011; Beleza *et al.*, 2011; Cardoso *et al.*, 2011), training courses and e-learning materials – are placed on the public domain and will be freely distributedas they become available.

Central to the project is the development of an open-source software system based on a set of tools and models which assist in the analyses and decision support involved in the planning process for sustainable infrastructural asset management. This paper presents 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.

THE AWARE-P IAM PLANNING APPROACH

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 – strategic, tactical, operational – aiming at alignment of objectives, metrics and targets, as well as solid 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**.

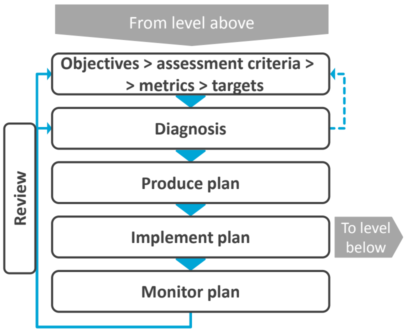

Figure 1–IAM planning at each level

The IAM process is thus fundamentally led by the stated objectives, the criteria and metrics used to assess them, and set quantifiable targets. This is particularly evident at the strategic and tactical levels, the latter being the prime field of application for the type of software described here.

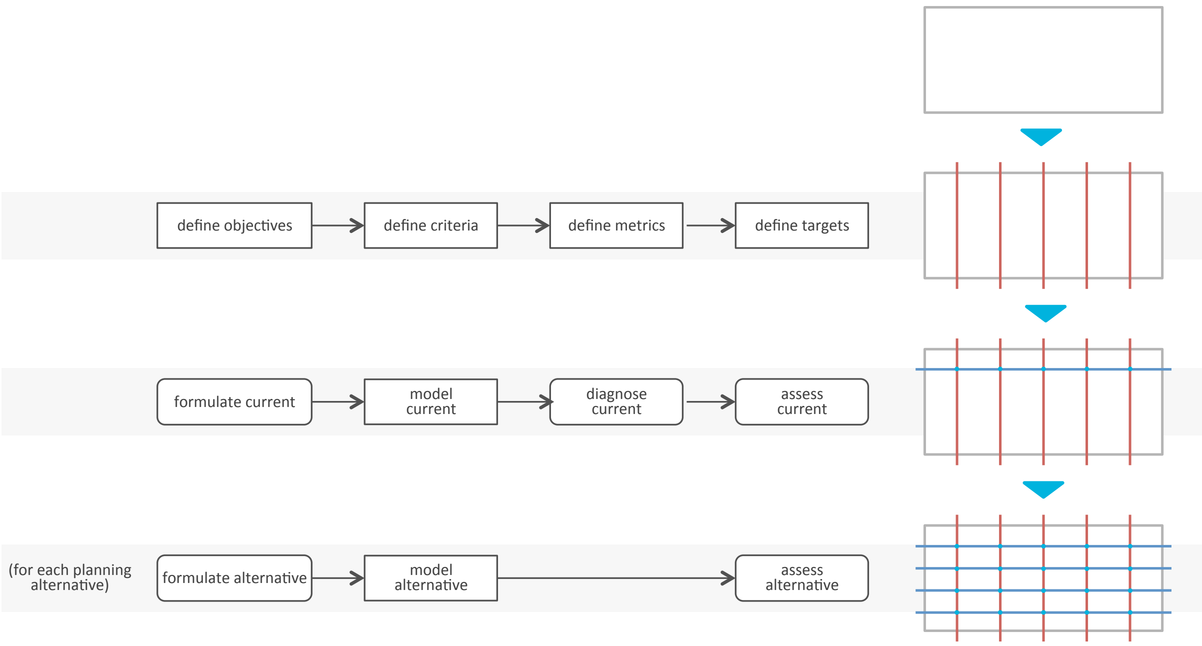

Figure 2– The planning framework process

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), 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.

The planning process is illustrated in **Figure 2**. The drawing board on the right-hand side is initially marked out by the red 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, and the purpose of the process is to fill out the table to the extent possible. Assessments are either compressed in time on a single table, or a separate table is calculated for each relevant time frame of the planning and analysis horizons, effectively giving rise to a *cube* of results.

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

The table(s) present the user with summarized, comparable views of the set of planning alternatives, assessed along the criteria selected, and promote transparency in the decision-making process.

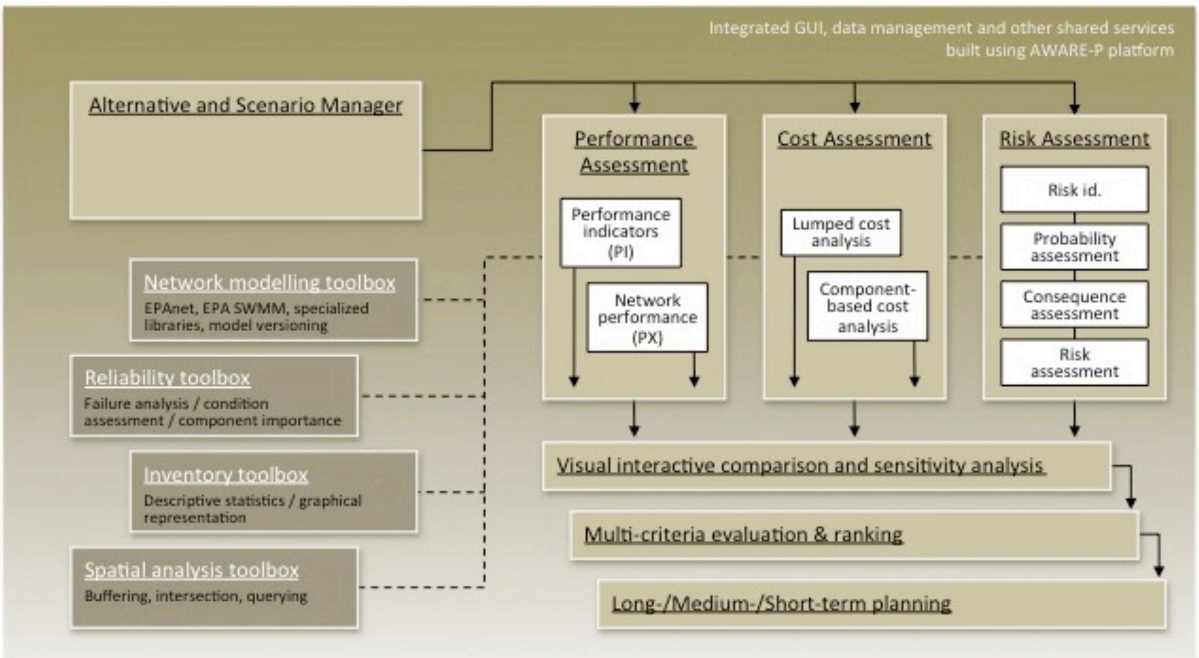

Figure 3– Functional schematic of the AWARE-P software

THE SOFTWARE: GENERAL PRESENTATION

The purpose of the AWARE-P software is to provide the means to visualize, diagnose and evaluate any given water supply, wastewater or stormwater system, through a portfolio of performance, risk and cost models, at both global and detail levels; and, if so desired, to compare a system with any number of alternative solutions or proposed changes using standardized methods that facilitate choice and decision-making – both manually and with the assistance of decision-support tools – tested against current and projected or hypothetical scenarios (**Figure 3**).

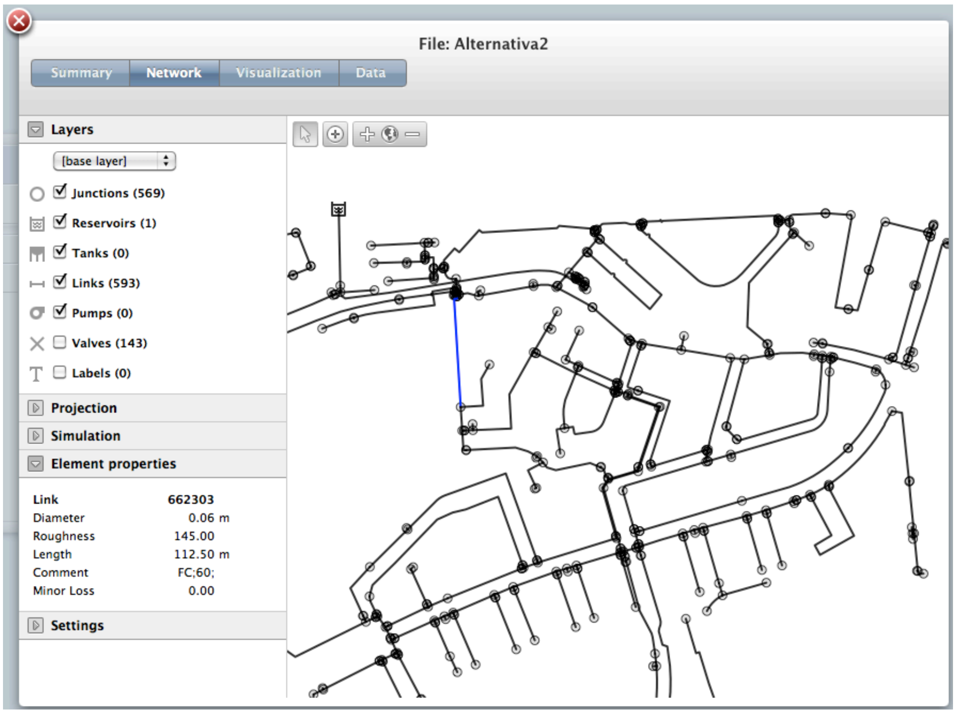

Figure 4– Infrastructure visualization

The overall approach follows the general framework illustrated in **Figure 2**, driven throughout by the stated objectives, criteria, metrics and targets. The assessment tools include performance indicators and indices, network visualization and mapping (**Figure 4**), network modeling – hydraulics, water quality, reliability (component importance, also termed criticality) and other analyses –, system statistics, failure data analysis and modeling, condition assessment, matrix-based risk evaluation, and several costing tools (investment, operating cost, operating revenue).

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

The software brings together onto a common data management (**Figure 5**) the infrastructural geo- referenced data that describe the physical water supply or sewerage systems, as well as a variety of data originating in the several information systems that exist in the water utility corporate environment, such as maintenance and work orders data, billing and costs databases, or network analysis models.

The assessments may be relatively simple calculations, or derive from sophisticated network modeling or statistical analyses. The object of the assessment will be a system, a subsystem, a cluster or a set of individual components, representing the *status quo*[1] or a competing

[1]Often also called the *base case*: the existing system under the current O&M practice (Alegre *et al.*, 2011).

(redesign/ rehab) alternative under evaluation. Based on such assessments, the system provides a basis for comparing different planning alternatives and to make decisions in defining short- and long-term IAM plans.

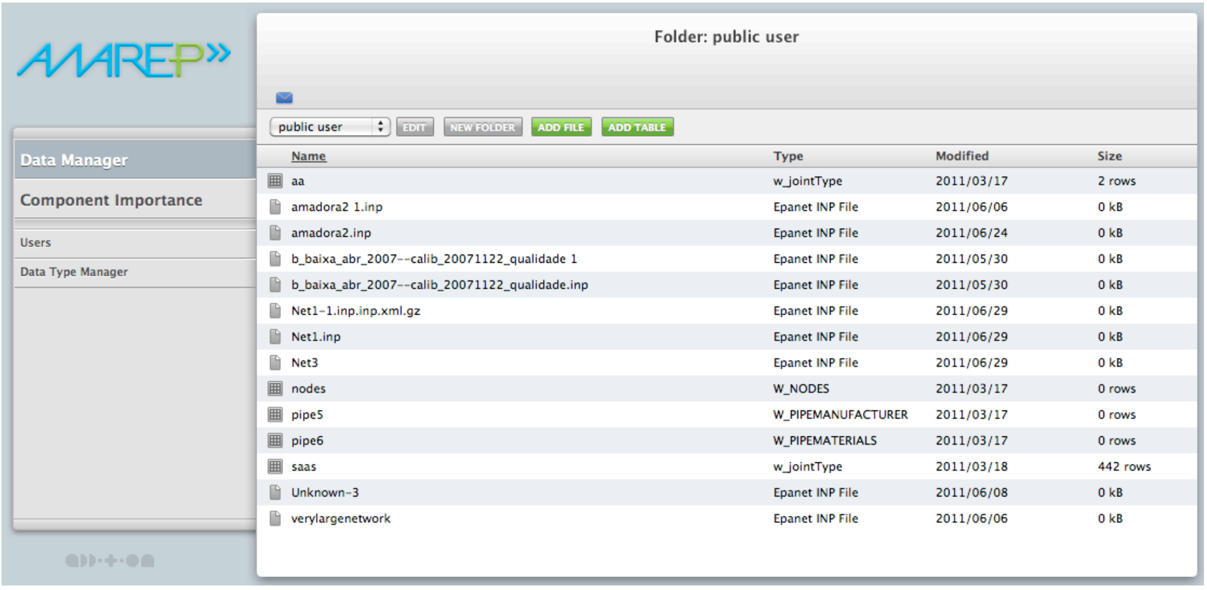

Figure 5– Data management

The assessment of alternatives is often made by comparison with the *status quo*, i.e., by differentiation of a set or sub-set of features where there are measurable changes. The assessment will be made either for the object as a whole (lumped analysis), or for the object as a set of components (component-based analysis). In the first case, an assessment is typically one global value for the object (even if it is computed from its individual components) at each time frame (or a curve over time); in the second case, an assessment produces one value for each component that makes up the object, at each time frame (if an aggregation function is available, there is also a global value calculated from the component values).

One important feature of the software and of the AWARE-P IAM approach is its focus on evaluating the water supply, wastewater or stormwater 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 based on EPA's well known Epanet and SWMM models (Rossman, 2000; Rossman, 2010).

The software is driven by the IAM engineering strategies and know-how contained in the best practice manuals developed for water supply and wastewater systems, during the course of the AWARE-P project (Alegre *et al.*, 2011; Alegre & Covas, 2010; Almeida & Cardoso, 2010). An important guideline during the design of this IAM software system was the emphasis on an analysis path that pays as much attention as possible to system behaviour, as opposed to approaching a networked infrastructure as a collection of its parts.

DEVELOPMENT CONTEXT

The AWARE-P project inherits from a number of previous R&D efforts. The CARE-W and CARE-S 5th FP research projects (Sægrov, 2005 and 2006), developed with significant contributions from AWARE-P partners Sintef (Norway) and LNEC (Portugal), produced methodologies and computer prototype applications for assisting water and wastewater utilities in planning rehabilitation interventions. These two projects were fundamental stepping-stones in the establishment of structured approaches and their implementation into dedicated instruments. Both project produced a vast repertoire of partial models and approaches, 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 that can 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.

Several of the techniques in the AWARE-P portfolio were already present in the CARE-W/S prototypes, having been redesigned as building blocks for the new system. They fit together somewhat differently, since AWARE-P is organized around an evolved approach to IAM planning, as mentioned earlier on in the text. Important differentiation was sought in key areas, as detailed in the next section about design requirements and technology options.

One of the great opportunities afforded by the AWARE-P project was the involvement in the project consortium of four very motivated and technically able industry partners, in close collaboration with the development team. Some of those utilities had taken part in CARE-W/S prototype testing stages, and were in a position to build upon that key experience in the specification of the new software.

Another important aspect was the thorough exploration of the IT landscape and of the most common data systems in use in the water industry in the countries involved in the consortium. Many tools are already in use in the industry, from GIS to network simulation models or to statistical analysis of pipe breaks, and it was important to capture the main usefulness of those tools for IAM applications, while keeping the user in her/his technical comfort zone.

DESIGN REQUIREMENTS AND TECHNOLOGY OPTIONS

As mentioned before, from a usage viewpoint the main design requirement called for uncomplicated, direct usage, a tool that starts simple and provides the shortest path to results, within reason. In particular:

- the user should be able to get assessment results with as little data as feasible;
- the user must be made aware of where she is in the process, and how much has already been achieved – i.e., aided by strong visual and contextual references to the planning procedure, in project mode;
- the user must be able to assess and compare from as early on as possible.

Concurrently, a set of technical requirements was laid out as follows:

- the software should work on a single computer without any network connectivity, as well as on a shared networked client-server model;
- the widest possible hardware and software configuration scenarios should be supported;
- AWARE-P should not imply the purchase or usage of any extra commercial software;

- all code developed for this project will be open-sourced; priority should be given to open-source projects for any libraries or frameworks needed;
- the software platform should be open, and designed to be open from the ground up; future expandability by integrating new modules or refining existing ones is an explicit need and should be safeguarded;
- the user interface should be clear, logical and consistent; users should have common and easy ways to navigate modules and function. future regionalization for various languages and markets should be safe- guarded;
- the platform will be an integration framework for the different data formats and models of each module;
- simple, easy, clear geographical visualization and work is one of the main, universal components of the software;
- another transversal feature is providing a data repository which will be used by all computational modules for input, output and operation;
- the platform should transparently integrate the management of water supply as well as wastewater systems.

As a result of the above considerations, the main technology options adopted for the software were:

- web-based, platform-agnostic – the system will run in any major operating system;
- open-source – developed using widely available open-source software components; should not imply the purchase or usage of any extra commercial software;
- plug-in architecture;
- may be deployed directly on the web or packaged as native platform application (client-server / stand-alone);
- unified data management - storage, backup, versioning, visualization, manipulation and import/export;
- common graphical user interface (GUI);
- permissions and user management included in the platform and accessible via simple programming interfaces (API[2]).

THE SOFTWARE PLATFORM

The AWARE-P software system is based on a modular, generic platform for hosting and integrating engineering software, particularly that which deals with large-scale networked infrastructure, supporting calculation, modelling, geographical visualization and data manipulation.

The platform is the development environment for the functional software proposed. The conceptualization and development of this modular, plug-in enabled platform has been on-going since 2009. It can be seen as a generic platform for hosting and integrating engineering software, particularly that which deals with large-scale networked infrastructure, supporting calculation, modelling, geographical visualization and data manipulation (**Figure 6**).

This platform has been designed from the ground up to be a host of pluggable software modules. Pluggability is therefore the default, documented solution to module development. This enables new modules and features to be added at any time, with full integration with existing modules and features. Storage, manipulation and exchange of system data are shared and consistent, and the visualisation and analysis of results are done using the same user

[2]An application-programming interface (API) is an interface implemented by a software program, enabling it to interact with other software. It is implemented by applications, libraries, and operating systems, and is used to access their services.

interface and a common entry point. The system also fully enables third-party developers – such as other R&D groups – to create new modules or to offer capabilities that extend an existing application. This is explicitly aimed at promoting and facilitating collaborative efforts.

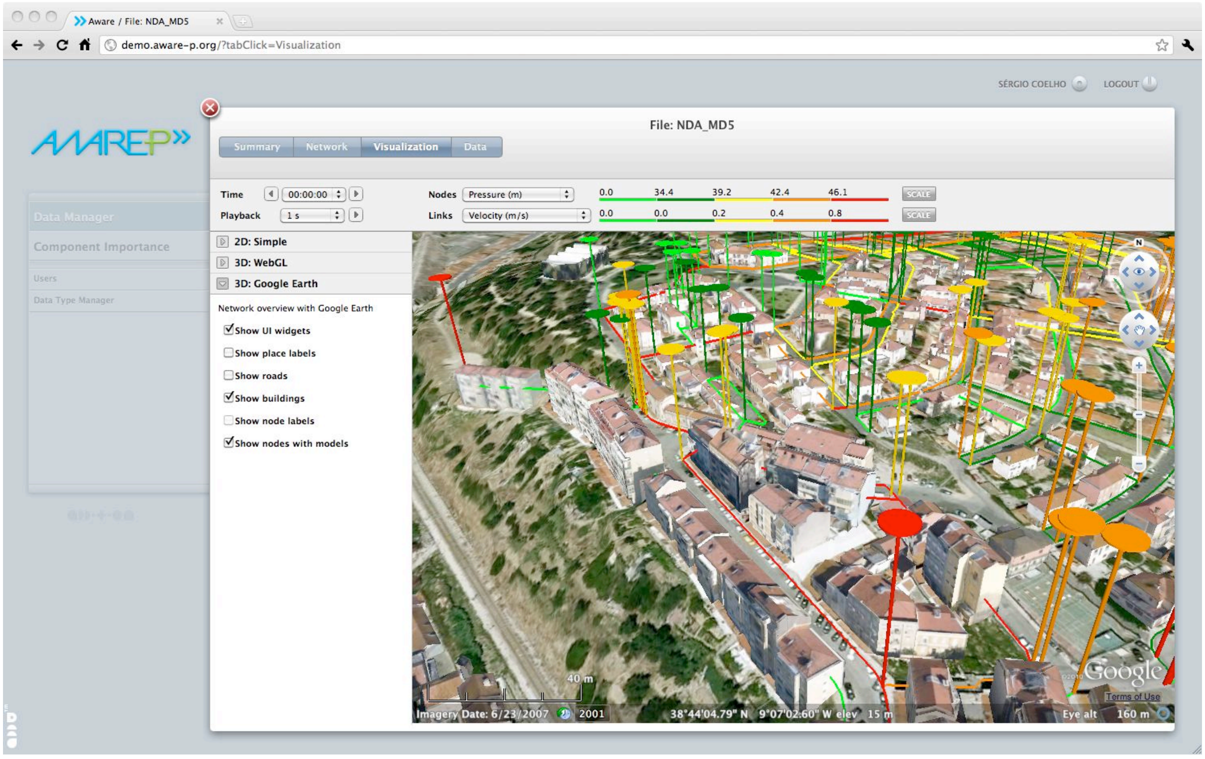

Figure 6– Software platform: Google Earth®-based representation of network performance assessed from simulation model results

Some of the main advantages of the platform are:

- unified data management - data storage, backup, versioning, visualization, manipulation and import/export is one of the major challenges to any engineering related software; in the platform, APIs and user interface features are in place to store any kind of data - tabular, binary, geo-referenced, etc.
- common graphical user interface (GUI) – the modules user interface is contained by AWARE-P: focus on familiar, consistent look-and-feel and functionality.
- permissions and user management is included in the platform and accessible via simple APIs.
- web-oriented user interface - applications can be deployed directly on the web or packaged as native platform applications (stand-alone/ local use).
- Platform-agnostic – the platform and its modules work directly on any modern operating system[3] without any additional software dependencies (except for the ubiquitous and freely available open-source Java). The software should not need specific DLL[4], and should not break when a new service pack is launched.

[3]Such as MS Windows, Unix/Linux or Mac OS.
[4]Dynamic link library (DLL).

- Open-source – the platform itself is developed using widely available open-source software components and should not imply the purchase or usage of any extra commercial software.

The platform is open-source and will be freely available for development. It offers commonality in terms of a web-based interface with a familiar look-&-feel and usage logic, data management, and user management. This greatly facilitates the interaction between software modules and also simplifies future software maintainability.

The platform was planned as an open-source effort from the ground up and will continue to maintain that philosophy throughout, as it seeks to become an attractive and convenient means for efficient development and maintenance of further engineering and planning software, and thus foster a growing community of collaborative applications.

CONCLUDING REMARKS AND OUTLOOK

The AWARE-P software for IAM planning analysis, introduced in this paper, attempts to make available on an advanced technology platform the best tools for visualizing, diagnosing and evaluating any given water supply, wastewater or stormwater 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 is web-based, open-source and will be freely distributed, along with the remaining products of the AWARE-P project. It is expected to be made available to the public on a first release that includes the data management modules and an initial set of analysis modules in the last quarter of 2011.

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. One source of such expansion into new models and algorithms will be the EU 7th F-P funded TRUST[5]project (2011-2014), where a significant effort is planned for the development of further specialized IAM methods, as well as innovative models based on urban metabolism approaches for large-scale and long-term urban water system assessment and planning.

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