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Optimized Water Demand Management Through Intelligent Sensing And Analytics: The WISDOM Approach

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OPTIMISED WATER DEMAND MANAGEMENT THROUGH INTELLIGENT SENSING AND ANALYTICS: THE WISDOM APPROACH

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New business and technology platforms are required to sustainably manage urban water resources. However, any proposed solutions must be aware of security, privacy and other factors that may inhibit adoption and hence impact. The FP7 WISDOM project aims to achieve a step change in water and energy savings via the integration of innovative Information and Communication Technologies (ICT) frameworks to optimize water distribution networks and to enable change in consumer behaviour through innovative demand management and adaptive pricing schemes. The requirements of users and stakeholders at domestic, corporate and city levels are core to the WISDOM concept which centres on the integration of water distribution, sensor monitoring and communication systems. This is coupled with semantic modelling (using ontologies, to serve as intelligent linkages throughout the entire framework) and control capabilities to provide for near real-time management of urban water resources. The WISDOM framework will be modelled and simulated with initial testing at an experimental facility in France and in water facilities in Cardiff (UK) and La Spezia (Italy). These demonstrators will evaluate the integrated concept providing insight for wider adoption.

MOTIVATION

As water is an essential natural resource for both life and economy, community interest in more sustainable approaches to water management is increasing [4,5,6]. Industry, agriculture and the whole water sector are exploring innovative ways to conserve, capture, treat and reuse water. In fact, water scarcity and droughts (WS&D) increasingly affect many regions of Europe [1], exacerbated by climate change and population growth.

The demand on water resources in the urban environment requires more efficient water management to deal with urbanization and population growth, more complex water facilities in new buildings, and the deterioration of existing water infrastructure. There is an urgent need to (a) reduce the water abstracted for use in buildings, (b) promote water savings, (c) stop wastage, and (d) facilitate comparability of the building's performance. The ability to provide appropriate means to intelligently monitor the water network and analyze real time information (smart technologies) will provide optimized alternatives to take better actions to balance the conflict between water demand and provision [4].

In order to reduce water use in buildings, and by extension in urban areas, several options are available [2,3,4,5], including: raising awareness to improve behaviours; changing the pricing policies; metering water to both detect leaks and raise awareness from consumers; limiting water use by regulatory requirements; installing more efficient water-using products; planning buildings so they are more water efficient; and using “alternative” water sources such as rainwater or greywater.

Further, the nexus between energy and water is gaining interest as the two are inextricably linked. Various industries, including the steel industry, have open abstraction licenses for water. Evidence suggests that the more water they abstract, the more energy they consume. At building scale, a great potential exists for energy recovery from domestic water uses, such as hot water production by solar panels or energy recovery from bathroom greywater. However, there is a need to monitor this equipment in order to underline and optimize all the benefits of such practices.

This paper begins by discussing current approaches to the holistic problem space. The paper then introduces the WISDOM framework in terms of the approaches taken to its design and implementation. The evaluation plan is then presented and finally the paper concludes with conclusions next steps.

CURRENT APPROACHES

Current water management practices have a large margin for improvement, and ICT technologies provide a unique opportunity for implementing Integrated Water Resources Management (IWRM) [5] effectively. IWRM has been developed over several decades; it is a philosophy of varying definitions and interpretations. ICT will and has to play a key role in holistic water resource management in the urban environment [6,7,8]. Various new ICT technologies have been applied in different ways at different stages in water management cycle - sensor systems have been widely utilized in water distribution network monitoring [9, 10]; various analysis models / algorithms have been developed to help to achieve better decision making [11, 12, 13]; and ontology [11, 14, 15], virtual reality [12, 16], GIS [8], collaboration platform [7] and cloud computing [17] etc. can all find their applications in the water management domain. However, in implementing ICT components into an integrated urban water resources management system, some major issues still remain Table 1:

Table 1 Example issues in terms of IWRM

Lack of data and knowledge integration	Information sharing across the water supply chain is still not fluent enough to allow two-way and multi-way data communication amongst hardware and software systems. There is an urgent need to develop the common information sharing standard that will enable real-time data and knowledge harvesting at domestic, corporate and city level.
Lack of innovative demand and management schemes	Current water development and planning (i.e., between water supply, sanitation, reuse, …) is still uncoordinated and sector based; the water supply and sanitation is not sustainable enough, and requires stronger management

	interventions and measures; current urban water resource management addresses problems mostly from the supply side with few efforts focusing on demand management (end user related). Economic tools, price signaling mechanisms, water-saving devices, and awareness or enforcement for building codes and byelaws are lacking.
Lack of end-user awareness and behavioural change strategies	Linked to the previous point, there is a need for adapted user-oriented interfaces to improve household and business societal awareness about water consumption to induce changes in consumer behaviour and to enable the introduction of innovative resource and demand management schemes.
Lack of holistic knowledge driven approach	In terms of the decision making process, the various existing models and components developed describe parts of the required water system. Some models may produce output needed as input by other model(s), and some may run interactively. This means that all models will have to be linked in an integrated computational framework to achieve better efficiency. For real time water network monitoring, large amounts of data will be collected; a smart way to manage this data in reaching the appropriate decisions is required.
Deficiency in the Building & Urban metabolisms	In terms of overall management and assessment at building and urban scale, a better integration of water management performance is necessary, by creating synergy between the different components of buildings and cities (building/urban metabolism). This means closer links, especially with the energy management - water/energy nexus. The smart technologies and ICT systems could highly contribute in meeting this requirement, in order to achieve better overall efficiency at building and urban scale
Lack of authoritative water-related environmental performance certification	Unlike the highly regulated energy sector, a concept of water performance certification is lacking for existing and new developments. There is a need for stringent water regulations and policies at the European and National levels, ideally enforced through adapted ICT.

These issues indicate that further integration and interaction between different hardware / software systems is required. The tight integration of sector systems/devices/technologies should be embedded into an ICT framework that will support a smart water management strategy, as illustrated Figure 1. To this end the WISDOM project aims to pilot and demonstrate innovative ICT systems and services for efficient water use and reuse, in order to improve household, business and societal awareness, to induce changes in consumer behaviour and to enable the introduction of innovative resource and demand management schemes and adaptive pricing incentives.

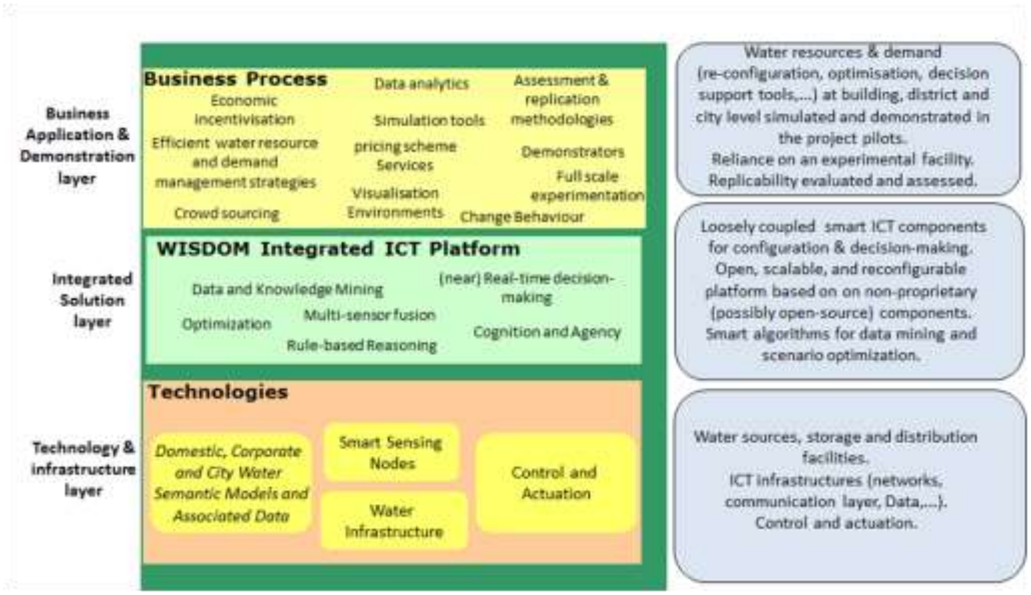

Figure 1 Smart water management strategy

THE WISDOM FRAMEWORK

The needs and operational requirements of users and stakeholders at domestic, corporate and city levels are core to the WISDOM project and central to the framework. User requirement driven architecture design is to be implemented that not only establishes the degree to which the project can integrate legacy systems and current numerical modelling techniques but also to better understand the shortcomings of such current technical solutions. To this end, a multidisciplinary team (human sciences experts, designers, scientists, final users) is being brought together in creativity sessions, brainstorming, with focused interviews, to sketch the functional features of the framework and derive the Socio-technical specification of the framework. The technical design and implementation of WISDOM

Figure 2 will essentially adopt a system-of-systems approach that essentially operates at three levels or scopes of abstraction with the first two constituting the platform:

1. Acquisition / Aggregation/ Actuation
2. Persistence, semantics and analytics
3. Services and decision support.

Acquisition, Aggregation and Actuation Scope: This project assumes a distributed solution to support of end-to-end water network monitoring and control. To this end, processing is controlled in a lightweight and scalable way across the ICT continuum of sensor nodes, gateways, co-processing nodes and up to the cloud as appropriate. This infrastructure assumes a two-way flow of information. Lower components of the system are given parameters regarding how to self-manage and optimise or initiate an actuation. While two types of data flow up-wards; sensor data and systems data; the former is to understand the water network's performance, the latter informs the system about the ICT systems' performance and reliability.

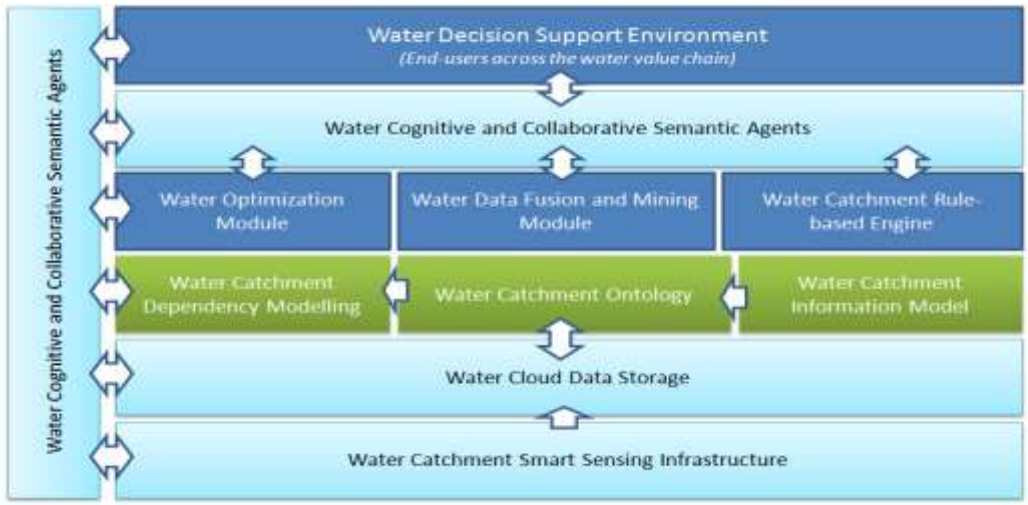

Figure 2 WISDOM abstract architecture

Persistence, Semantics and Analytics scope: The collected data, including water pipe monitoring, water consumption patterns identification, water network and building infrastructure modelling, etc., could easily reach terabyte storage level. Hence there is a need to use scalable storage for large scale data management purposes. We will deliver a facility that maps to and supports non-vendor specific cloud storage solutions. This will also take data protection and reliability into account. All components rely on a common data framework, or an information modelling approach useful for utility operators which will focus on the future real-time monitoring of water networks, and water management in domestic, corporate and city settings.

This includes the tools to enable data fusion at varying levels of precision and then specify and deliver the data analytics to inform the Water network optimization modules and higher and subsequently end-user services. This includes predictive modelling and data analytics capabilities, real-time visualization of water resources in terms of availability and demand; and a real-time context-based pricing schemes implementation. Specifically this provides:

- A semantic layer that will comprise a water catchment ontology and associated water dependency models.
- Water systems optimization modules exploiting relevant algorithms (e.g. evolutionary algorithm, artificial neural network, fuzzy theory, etc.) to assist with implementing efficient resource and demand management strategies and pricing schemes.
- Data mining and fusion schemes: Given that monitored and collated data will have multiple sources, we will use data mining and fusion rules based on formalisms which can deal with environments characterised by uncertainties with nonlinear and varying dynamics, incomplete (sparse) information, and where real-time reasoning is necessary. This will be delivered through our Data Mining and Fusion Module. Data quality will be of utmost importance and will be managed through long monitoring periods exceeding one year duration.
- A Rule-based Engine: Our water experts will advise on a number of rules that will be triggered when conditions are met to alert key decision makers on predictive or reactive actions. This will be provided by our proposed Water Catchment Rule-based Engine.

Services & decision support scope: At the highest level domain focused or end-user services are made available. Such services utilise the loosely coupled WISDOM platform to consume data services of the platform (Persistence, Semantics and Analytics scope) in order to provide tailored perhaps even third party developed services.

EVALUATION *'IN THE WILD'*

A two pronged approach to evaluating the WISDOM solution will be facilitated using an experimental full-scale facility and two pilot demonstrators. In this context, AQUASIM will be used as a demonstration facility to conduct experiments on any proposed WISDOM solution and fine-tune various configuration parameters prior to *en situ* deployments. The AQUASIM facility is designed to enable realistic and accelerated simulations of physical and chemical events occurring in the water chain in a controlled way.

A WISDOM compliant deployment will be implemented in Wales (UK) and Italy, with the objective being to link all the base tools that will enable water and business experts to perform various simulations in order to optimize the design of the pilots, to foresee district-level water markets, and to assess applicability of the solution. Knowledge engineering will be widely applied in this task, different domain ontologies will be developed to convert relevant knowledge (e.g. water management, water supply, end user consumption patterns, etc.) into computer understandable ontology services, by which the various tools can then be smartly integrated together. Here the WISDOM framework integrates three physical networks together; (a) the water distribution network; (b) the real time sensor monitoring network that provides the low-level protocols; and (c) the high performance computing network that will carry out services such as analytics and model predictive control. This will also include the adaptation of legacy and existing Sensor systems (SCADA). Those low data rate / ultralow power communication nodes will transport the information reliably and seamlessly to the data fusion infrastructure.

CONCLUSION / NEXT STEPS

Aiming to increase the sustainability of vital water systems, the WISDOM project takes a pan-European approach to developing a holistic framework that has been designed taking into account the needs and operational requirements of users and stakeholders at domestic, corporate and city levels. To achieve this, the interoperability of a number of demand and operational models, fed with data from diverse sources such as sensor networks and crowdsourced information is required. This has implications regarding the provenance and trustworthiness of such data and how it can be used in not only the understanding of system and user behaviours, but more importantly in the real-time control of water systems. Adaptive and intelligent analytics will be used to produce decision support systems that will drive the ability to increase the variability of both supply and consumption. This in turn paves the way for adaptive pricing incentives and a greater understanding of the water-energy nexus. This integration is complex and uncertain yet being typical of what is now termed a cyber-physical system, therefore the relevance of the technologies, solutions and techniques that are being developed in WISDOM can transcend the domains of water resource management to alternative utility management and large distributed control systems.

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