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DAIAD: Open Water Monitoring

Spiros Athanasiou[a]*, Thorsten Staake[b], Thomas Stiefmeier[c], Christian Sartorius[d], Jacob Tompkins[e], Efthymios Lytras[f]

[a]*Instiute for the Management of Information Systems/"Athena" Research Center, Artemidos 6 & Epidavrou, Marousi 15125, Greece*
[b]*University of Bamberg, Kapuzinerstrasse 16, Bamberg 96045, Germany*
[c]*Amphiro AG, Weinbergstrasse c/o ETH Zurich56/58, Zurich 8092, Switzerland*
[d]*Fraunhofer Instiute for Systems and Innovations Research, Hansastrasse 27C, Munich 80686, Germany*
[e]*Waterwise, Picadilly 180, London W1J 9HF, United Kingdom*
[f]*Athens Water Supply and Sewerage Company (EYDAP), Oropou-Galatsi 156, Athens 11146, Greece*

Abstract

DAIAD is an FP7 research project addressing the challenge of improving the management of water resources through real-time knowledge of water consumption in order to improve societal awareness, induce sustainable changes in consumer behavior, and explore new water demand management strategies. In this paper we present the motivation of our work, our vision and objectives, along with an early architectural overview of the planned DAIAD system.
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1. Motivation

Efficient water management is a challenging issue with the potential to prevent political conflicts, promote economic growths, and benefit the overall health of citizens. Several EU member states and many areas outside the EU have witnessed firsthand in the past decades the importance of efficient water management as they have been facing droughts, pollution, and water scarcity. The significance of water management is acknowledged in the EU

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* Corresponding author. Tel.: +30-210-687-5402; fax: +30-210-685-6804.
E-mail address: spathan@imis.athena-innovation.gr

through the Water Framework Directive (WFD) and various local/national policies promoting efficient water use. For water stakeholders, sustainable water use and reuse is promoted through Water Demand Management (WDM) strategies, which exploit various facilities and tools, such as pricing models, water restrictions, water efficient devices, education programs, etc. These strategies aim to determine how water demand is formulated, establish the factors that influence it, and forecast future demand. To achieve this goal, water stakeholders require the availability, collation, and analysis of accurate water consumption data, along with demographic, Geographical Information Systems (GIS) and social data sources.

Citizens who consume water in their everyday lives are the central actors in WDM strategies, since the individual reduction of dispensable consumption behavior is an important aspect of sustainability. Techniques to motivate and support individuals to act in an environmentally sustainable manner have received considerable attention from researchers, companies, and policy makers **Error! Reference source not found.**. Several activities target citizen education and awareness towards the importance of water, and attempt to mobilize individuals to reduce water consumption. However, a powerful instrument for promoting behavioral change is to provide feedback on personal water consumption that enables individuals to relate their actions to water use, and consequently motivates them to act responsibly. This has been confirmed by numerous studies, especially with respect to energy consumption **Error! Reference source not found.**. Therefore, accurate water consumption data, delivered to consumers through appropriate feedback mechanisms, is crucial for sustainable water use.

Consequently, efficient water use and reuse is an increasingly *data-driven problem*, a realization established only recently, through comparison with other resource management domains. Further, it is now acknowledged that the available data for water consumption do not provide a satisfying level of spatial and temporal detail. WDM strategies are designed, implemented, and validated on highly aggregated water consumption data, limiting the potential for correlation and analysis with other relevant data sources. To date, information on consumer and apartment level (e.g., on demographics, lifestyles, and attitudes) is at best available as a rough approximation based on small scale questionnaires. Information on weather, irrigation, etc. is also only crudely exploited so far. The same lack of detailed data persists for feedback mechanisms towards consumers. The available information for the vast majority of consumers is limited to an aggregate of their consumption over a few months. They lack of information on *when* and *where* they consumed water, and thus suitable stimuli to understand and modify their behavior is indeed a major hurdle for a more sustainable water consumption. The lack of highly granular water consumption data is caused by the limited capacities of water meters, which are currently the prominent solution for monitoring water consumption. Accordingly, this technical barrier lowers business needs and expectations of water stakeholders, prohibiting innovation. The advent of smart metering can potentially provide better data. However, smart water meters are also hindered by technical constraints and practical considerations regarding the provision of real-time data to consumers. Further, it is increasingly apparent that smart metering infrastructures are deployed only for energy, i.e. decoupled from the water delivery network **Error! Reference source not found.**.

DAIAD addresses two significant problems in water management: the lack of (a) *detailed water consumption data* and (b) the necessary *big data management and analysis services* that can provide a better understanding of the parameters influencing water demand and sustainable consumer behavior. Clearly, there is a significant untapped potential in real-time water monitoring, with the ability to drastically alter consumer behavior and our approach towards water management. At the same time, a critical barrier is apparent due to the lack of ICT innovation in the water domain, which is only reproduced and strengthened by water stakeholders.

2. The DAIAD approach

ICT can provide valuable solutions to drastically improve the management of water resources. Innovations in sensors, data fusion, and big data analytics could potentially enable real-time water consumption, extraction of knowledge at unprecedented levels of detail, and comprehensive data analysis for more efficient resource and demand management strategies.

In DAIAD, we aim to address the challenge of improving the management of water resources through real-time knowledge of water consumption in order to improve societal awareness, induce sustainable changes in consumer behaviour, and explore new water demand management strategies. For this purpose, we will research and develop novel ICT technologies for water monitoring, knowledge extraction, social engagement and resource management.

Our research and technological objectives are organized and influenced from the unifying theme of addressing water monitoring and water management as a *data intensive problem*, providing both the *missing high quality data*, and the techniques to *efficiently analyze* them. Further, the novelty of our approach not only lies on innovations on a technical level, but also on *empowering* and *leveraging* consumers as *catalysts* to accelerate innovation and implementation of efficient water management.

3. Objectives

The integral technical perceptive of DAIAD is the realization that efficient water management is a data intensive area, where sufficiently detailed data and the means to extract added value from them, are severely lacking. Further, we treat openness and social innovation, as the means to support and sustain technical innovation leading to changes in water management at a larger scale. Overall, the DAIAD project aims at realizing the following objectives:

- *Low cost real-time, multi-point water consumption monitoring for residential settings*. The key challenge is to provide new, low cost/maintenance technologies to enable real-time and high granularity water consumption monitoring. Difficulties arise from the inherent complexities of measuring water in residential settings regarding placement, sensing, and installation. These translate to high, prohibitive costs. Further, water metering and water monitoring should be decoupled, as is the case with energy, enabling consumers to voluntarily install water monitoring technologies, create a critical mass, demand for more products, and drive costs down.
- *Consumer-oriented and intuitive knowledge delivery mediums for water consumption.* Consumers have limited knowledge of their water consumption, restricted to periodical aggregated consumption readings and charges. Since they lack the knowledge, they have limited incentives to adopt a sustainable lifestyle. Real time monitoring technologies will provide consumers with the required data, but not with actual knowledge and stimuli. Our goal is to devise novel, self-sufficient, and automated knowledge management/extraction techniques, requiring no effort from the consumers. More importantly, the challenge is to devise simple, intuitive but informative interfaces for consumers in order to efficiently communicate knowledge concerning their water consumption (including patterns, habits), and offer interactive stimuli for inducing changes in consumer behaviour.
- *Big Data management for large scale, real-time water consumption data.* Current ICT systems employed in the water domain cannot scale to efficiently support large scale, real time water measurements, nor can they exploit this additional body of knowledge to extract efficiency and financial gains. Our challenge is to research and develop efficient methods to collect, manage, analyze and visualize real-time water consumption data. We will deliver solutions capable to scale on the city level, supporting millions of consumers and petabytes of real-time and multi-point water measurements. An additional challenge is to democratize these tools, enabling consumers to collectively and voluntarily aggregate, analyze, and communicate water consumption knowledge. In this manner active citizens and citizen associations can create and sustain a critical mass of consumer demand for new water monitoring technologies.
- *Novel resource/demand management strategies, including corresponding pricing and incentive schemes.* Detailed knowledge concerning water consumption has the potential to provide significant benefits in designing, implementing and validating WDM strategies. Our goal is to apply the Big Data management and analysis facilities we will develop, in order to better explore and understand the parameters influencing and determining consumer behavior and thereby water demand. We will combine and analyze detailed water consumption data with readily available data sources influencing water demand (e.g. weather, GIS, demographics) to provide novel insight and discover new correlations. We will thoroughly explore WDM strategies and especially pricing schemes, under these highly detailed data, for the first time in the relevant

literature. Our challenge is to demonstrate the potential gained from real-time water monitoring to water stakeholders and propose novel WDM and pricing strategies in accordance to our findings.

- *Extensive and in depth real life user trials.* DAIAD has a clear focus on applied research, with significant potential impact for efficient water management. A number of complementary innovations on a technical, policy and business level will be delivered which must be verified and evaluated by quantifiable means. This requires extensive testing of results, with emphasis on real-world applications. Our goal is to organize, monitor and evaluate user trials that closely resemble real-life scenarios, with actual consumers and stakeholder participation. We will evaluate both separately and collectively a number of different technologies: water monitoring sensors, knowledge management and extraction of consumption data, interfaces and knowledge visualization services for consumers, knowledge management services for water demand management. Beyond the technical realm, where the focus is on efficiency, scaling, and performance, we will also focus on consumer and business aspects. We will evaluate the impact of these novel technologies in inducing and sustaining changes in consumption behaviour, their level of acceptance, ease of use, engagement, and information delivery capacity.

- *Sustainable adoption of novel water monitoring ICT technologies.* Incurring sustainable changes in water management is a complex problem due to its interleaved technical, societal and business aspects. The challenge is to mobilize stakeholders, provide incentives, and lead society as a whole to sustainable water management practices. We address this challenge through novel and potentially powerful instruments: *openness, social innovation and voluntarily participation*. We will provide the developed software through an open knowledge license, enabling free use and reuse. This means that consumers and water stakeholders will have free access to novel tools for knowledge management. Evolution of software, provision of Software-as-a-Service (SaaS) through cloud computing infrastructures and integration in third systems is also facilitated through open standards. On the hardware level, openness can lead to low cost (re)production of products, integration in existing offerings, lowered costs and higher availability of water monitoring solutions. Combined, we can empower consumers to voluntarily adopt water monitoring products, adapt their consumption habits, and create a critical mass. Increased demand from consumers can further reduce costs, and mobilize water stakeholders. A positive feedback loop can be established, where consumer-driven network effects advance efficient water management at a larger scale.

4. Architecture and Components

   DAIAD will provide a versatile and open architecture with multiple deployment and integration scenarios available, in order to support the needs of consumers, water stakeholders, third party manufacturers and service providers. A high-level architectural overview of DAIAD is depicted in Fig.1. In the following, the project's major technology components are presented:

- *DAIAD@feel*. Our goal is to deliver a low-cost solution for monitoring cold/hot water consumption in residential settings, which will be easy to install from non-experts, battery-less, require limited maintenance, and accurately monitor all types and points of water consumption activity. It will deliver high granularity temporal and spatial measurements of water consumption, well beyond the capabilities of existing systems. *DAIAD@feel will provide the missing real-time water consumption data*.

- *DAIAD@home*. We will research and develop analysis and recommendation services for water measurements established from real-time water consumption data. The services will automatically handle all data collection, management and knowledge extraction duties. They will analyze water consumption data for various residential and consumer dimensions, identify behavioral patterns, and provide personalized recommendations. *DAIAD@home will convert water consumption data to knowledge for consumers and utilities*.

- *DAIAD@know*. Extracting knowledge from water consumption data is inadequate, if not delivered to consumers through appropriate, engaging and easy to comprehend interfaces and stimuli. Our goal is to deliver knowledge in a way that can incur and sustain changes in water consumption. We will focus our efforts in two areas. First, we will research and develop multimodal visualization services for water consumption data, analysis, and recommendations. We will experiment with various representations, capabilities, and user

interfaces, in order to accommodate the cognitive capacity and limited attention span of every day consumers. These interfaces will also be interactive and multimodal, offering simple what-if analysis concerning changes in consumption, and will be available through the Web and mobile devices. The second area concerns the development of non-intrusive, in situ feedback instruments to inform consumers and induce changes in consumption behavior, such as led displays in faucets, sound alerts when exceeding a consumption threshold, and affective displays rewarding sensible consumer behavior. *DAIAD@know will convey knowledge to consumers and induce behavioral changes*.
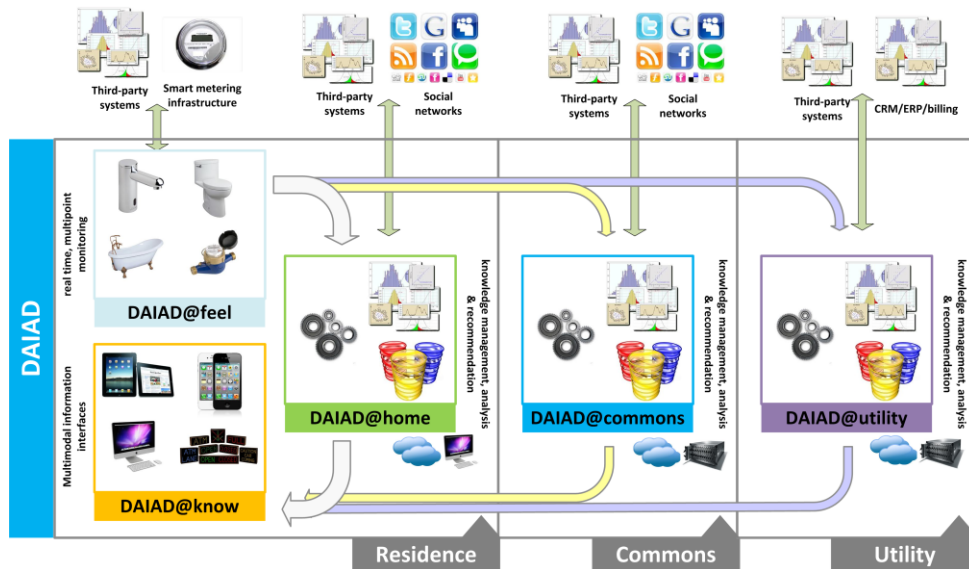

Fig. 1. DAIAD Architecture.

- *DAIAD@commons*. We will research and develop efficient, scalable knowledge management services for big data originating from massive, real-time water consumption measurements. Data management, knowledge extraction and analysis services will be cloud-based, entailing the complete lifecycle of data. The developed software will be a turn-key solution enabling stakeholders to efficiently store and manage water consumption data, perform analysis, identify patterns, estimate projections, and visualize information. The software will be targeted to consumer groups of non-expert users (e.g. neighborhoods, grassroots initiatives, NGOs) that voluntarily wish to participate in efficient water management practices. *DAIAD@commons will empower consumers through social innovation towards sustainability*.
- *DAIAD@utility*. We will specialize and extend the previous software to address the specific needs of water stakeholders regarding the exploration, design and validation of Water Demand Management strategies. We will develop facilities enabling the integration and management of highly granular water consumption data, along with other relevant detailed data sources (e.g. demographics, GIS, weather data). Further, we will research and develop analysis services offering expert users the capability to explore the hidden correlations of the parameters that shape water demand strategies and water pricing. A what-if analysis framework for water management strategies will be developed, supporting novel and non-traditional pricing schemes. The services will extend beyond typical planning and projections, offering targeted testing of various scenarios for specific populations. The operator will be able to design a novel pricing strategy, inform the consumers, roll-out the new policy, and continuously assess its impact. This interactivity, based on two-way communication among consumers and resource providers, is novel in water management. Further, the operator will be able to optimize the usage of the existing infrastructure capacity (i.e. rather use the existing pipe system more efficiently than extending it) and also receive valuable information concerning the location of leakages in the water pipes (i.e.

difference between quantity fed into the pipes and the quantity consumed by specific users). *DAIAD@utility will enable the application of real-time water consumption data towards novel WDM strategies*.

5. Expected Outcome

In DAIAD, we approach water management as a data intensive area, providing novel ICT solutions to overcome the lack of detailed, real-time water consumption data. Moreover, we develop and test technical means to exploit data driven solutions in order to establish efficient water management systems and to promote sustainable consumer behaviour. We expect that the research, development, and experimentation performed during the project will have significant and multi-faceted impact in the water domain. The empowerment of consumers as active stakeholders in efficient water management can create a critical mass demanding better services and products. In this regard, the availability of the project's technology through an open knowledge license enabling free use and reuse will strengthen innovation, introduce immediate pathways for commercialization, and ease the market success of real-world applications.The outcome of the DAIAD project is summarized in the following:

- Low-cost monitoring sensors for residential settings, providing real-time and highly detailed water consumption data.
- Effective feedback interfaces to accurately and timely inform consumers for their water consumption, inducing sustainable behavioural changes.
- Software providing novel analysis and recommendation services for residences based on real-time water consumption data.
- Software providing novel aggregation, analysis and recommendation services for groups of consumers based on real-time water consumption data.
- Software providing novel and scalable management, integration, and analysis services for real-time water consumption data, enabling their correlation with relevant big data sources (demographics, weather, GIS) towards exploring, designing and validating Water Demand Management strategies.
- Extensive real-world user trials to test and validate the project's technologies and to generate data offering novel insight concerning the parameters influencing water demand.
- Improved understanding of the parameters influencing water demand in residential settings.
- Quantified and validated benefits regarding the reduction in water consumption and its sustainability as a result of the project's technologies.
- Novel Water Demand Management and pricing strategies based on the knowledge acquired from monitoring and understanding real-time water consumption.

Acknowledgements

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