Where Water and Data Flow!

AMR Chronicle

Nicosia, Cyprus

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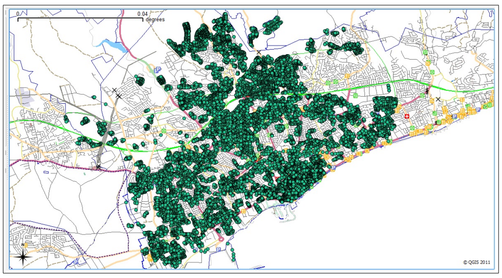

The UCyAMR project in action. Geocoded AMR devices and simulated data collection from the City of Lemesos, Cyprus (Aug. 2011).

The UCyAMR Project

18.nov 12:34 h — Real-time monitoring and intelligent decision support systems are paramount to the sustainable management of water distribution networks. Automatic Meter Reading (AMR), coupled with GIS, artificial agents and neurofuzzy decision support systems, has the potential of being the next big thing in waterloss detection and sustainable management of UWDN. The UCyAMR project investigates this potential through the development and implementation of a cutting-edge AMR platform.
(more on p.2)

SECTION A

Sustainable Management of Urban Water Distribution Networks (UWDN)

Past Research on UWDN at the University of Cyprus - A prelude to the UCyAMR project.

19.11 10:23 h — How can UWDN operators reliably and continously evaluate the performance of their piped networks and reach intelligent 'repair-or-replace' decisions in real time? How can we learn from nature and how can technology help? The article describes some of the studies on UWDN performed at the University of Cyprus, including risk analysis, neurofuzzy systems, sensing technologies, artificial agents and GIS.
(more on p.3)

SECTION B

Does Intermittent Water Supply Help Save Water?

A Study On The Effects of Intermittent Water Supply (IWS) On The Vulnerability Of Urban Water Distribution Networks.

19.11 10:02 h — Even though one of the primary reasons for enacting an IWS policy is to reduce water consumption as forced upon us by extreme drought conditions, the post-policy analysis indicates that the side-effects of such policy are significant. Such side effects are the increase in pipe-burst incidents, the increased water loss due to IWS-induced leaks in the network and the increased cost for maintaining the networks under such abnormal operating conditions. **(more on p.10)**

SPONSORS/AFFILIATIONS

REPUBLIC OF CYPRUS · STRUCTURAL FUNDS · EUROPEAN UNION · Research Promotion Foundation · ΔΕΣΜΗ 2008 · ΔΕΣΜΗ 2009-2010 · University of Cyprus

MAIN INDEX

UCy AMR

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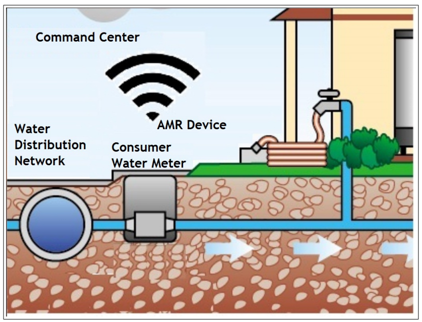
http://sites.google.com/site/UCyAMR

SECTION A - OVERVIEW

The UCyAMR Project

The project's scope, its progress to-date and future directions.

Dr. Symeon Christodoulou, **Nicosia**



Basic AMR concept.

20.11 08:25 h — The problem of aging infrastructure and of associated water losses in urban water distribution networks has been one of the biggest infrastructure problems facing city and municipal authorities and a major task in their efforts to achieve efficient and sustainable management of water resources. Interestingly enough and as a measure of the magnitude of the problem, the unaccounted-for water is in the range of 20% to 30% even in developed countries, whereas in developing countries this percentage is even higher (as reported by the International Water Association, IWA).

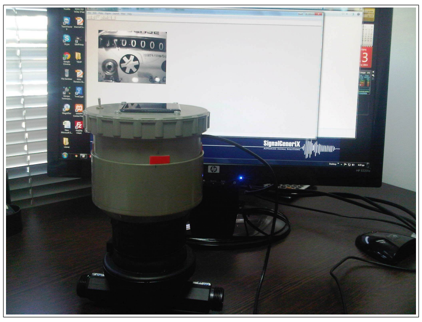
Real-time monitoring and intelligent decision support systems are paramount to the sustainable management of water distribution networks

According to studies found in literature for example, water losses in Frances water distribution network have been estimated at an average 26%, in UK at 19%, in Italy 29% and in Cyprus 25-30%. Yet, local communities have poor prediction tools to prioritize how essential infrastructure investment is conducted and to dynamically account for the water consumption at households and in the network in general.

One of the main issues in mitigating the effects of pipeline failures is the identification of the pipes vulnerabilities in advance and the implementation of suitable rehabilitation and prevention procedures. Furthermore, the online measuring of water consumption will allow Water Boards to dynamically monitor the water balance in the networks, to detect water losses as they occur, implement virtual water and water-pricing policies based on consumption, and enforce water saving measures devised on volumetric consumption, water quota, and online monitoring. The UCyAMR project aims at:

- Expanding current research on water-loss reduction (projects EDRISYS, WATERSENSE & MSAD funded by the Cyprus Research Promotion Foundation),
- Performing vulnerability assessment of lifeline systems, with a focus on urban water distribution networks,
- Developing prediction and evaluation methods for evaluating the social and economic vulnerability with a view to integrating these methods with engineering-based vulnerability or fragility evaluation methods,
- Developing a comprehensive hardware and software solution for the monitoring of piping systems with ad-hoc wireless sensors,
- Developing a comprehensive hardware and software solution for the automatic meter reading of water meters,
- Implementing the developed system at a pilot location,

A more detailed description of the Work Packages involved, relevant deliverables and reports, as well as information on related research projects undertaken by the research partners and their findings can be found in the UCyAMR webpage (http://sites.google.com/site/UCyAMR) or by contacting the project coordinator, Dr. Symeon Christodoulou (`schristo@ucy.ac.cy`).



The UCyAMR device currently in development.

The **UCyAMR** and **MSAD** research projects are co-financed by the **European Regional Development Fund** and the **Republic of Cyprus**, through the **Cyprus Research Promotion Foundation**.

UCyAMR's research partners are:

- The University of Cyprus (Department of Civil and Environmental Engineering)
- SignalGenerix Ltd.
- FWS Ltd.

Special thanks are extended to the Water Boards of Lemesos, Nicosia and Larnaca for providing the UCyAMR and MSAD research teams with knowledge and operational data on their water distribution networks.

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University of Cyprus SignalGeneriX Advanced Signal Solutions fontinalia water solutions ltd.

SECTION A

Past Research On Urban Water Distribution Networks At The University Of Cyprus

The prelude to the UCyAMR project.

Dr. Symeon Christodoulou, **Nicosia**

20.11 09:05 h — How can UWDN owners/operators reliably and continously evaluate the performance of their piped networks and reach intelligent 'repair-or-replace' decisions in real time? How can we learn from nature and how can technology help? A lot of research has already been carried out and documented in literature on a variety of technicques. The article describes some of the studies on UWDN performed at the University of Cyprus, with an emphasis on survival analysis, neurofuzzy systems, sensing technologies, risk analysis, artificial agents and geographical information systems, and how these technologies lead to Automatic Meter Reading (AMR).

Each year, across Europe hundreds of kilometers of pipes are upgraded or replaced in an attempt to maintain the transport and delivery of millions of liters of water, sewage, and natural gas. In Dublin, Ireland, alone around 280km (174 miles) of old cast-iron water mains will be renewed in a 118m capital improvement program to span the next decade. The accidental or deterioration-based breakage of each of these systems represents a range of health and safety problems, which may unintentionally place the health of thousands of EU citizens at risk during even a single break. Yet, local communities have poor prediction tools to prioritize how essential infrastructure investment is conducted. Even more troublesome is the fact that many public agencies lack the expertise, corporate knowledge and human resources' skills to manage tools and processes delivered to them through technological innovation.

Sustainable development of urban water distribution networks is one of the most notable cases of the need to integrate technological change in a low-tech business environment and use the technology to address strategic asset management dilemmas (such as the question of whether to 'repair or replace' pipeline assets and when to do so). Ensuring protection of existing systems and wise investment during the next century requires the incorporation of a wide set of parameters as existing utility systems are increasingly at risk due to a myriad of factors (aging, surface transport loading, corrosion, etc.). Given UN predictions that 75% of all people (around 6 billion people) will live in urban areas by 2025, continued, safe and uninterrupted transport of clean water becomes an increasing challenge.

What is needed is the means to develop and manage technological change across a corporate structure in an effective and sustainable manner that takes into consideration not only the advancement of science but also the status of the organization's existing personnel and modus-operandi.

Metropolitan Water Boards in Cyprus (the cities of Lemesos, Nicosia and Larnaca) recognized at a very early stage the importance and significance of establishing a proper water audit system and have over the years developed their infrastructure in such a way so as to be able to account efficiently and accurately for all water generated or 'lost' (non-revenue water) in their networks. Reduction and control of water loss was achieved through the application of a holistic strategy based on the approach developed by the Water Loss Task Force of the International Water Association. Integral part of this approach is the establishment of a strategy for pipe break incidents. The policy further envisions the prioritization of the repair/replacement actions on the basis of risk of failure, life-cycle costing, social and financial impacts.

Following the DMA strategy for minimizing water losses through uniform pressure zones, the Water Boards recognized the need to develop mechanisms for evaluating historical incident data (when and how water pipes break) for identifying possible data patterns in the behavior of the network, and for using these patterns for forecasting new breaks.

RISK-OF-FAILURE ANALYSIS and NEUROFUZZY DECISION SUPPORT SYSTEMS

The analysis of historical data was based on a number of analytical and numerical tools (such as statistical analysis, artificial neural networks, and neurofuzzy systems) and investigated the possible contribution of a number of presumed risk factors to a 'break or not?' outcome, ranking these factors according to their relative importance and their contribution to the 'Break or Not' forecasted output.

Analysis by Christodoulou et al. (1; 2) on a dataset from New York City identified as most important risk factors being the number of previously observed breaks (NOPB), the material type (MAT), the length (L) and the diameter (D) of each pipe. The presence of high traffic volume (TRAF), subway (SUB), block intersection (INTER BLOC) and highway (HWAY) seem to be of less risk-contributing importance than the former four factors (Fig. 1). Similar results were later obtained from extensive datasets pertaining to the cities of Lemesos and Larnaca (Cyprus), which were extensively reported on by Christodoulou et al. (3; 5–8).

The analysis on whether to repair or replace a burst, and thus a Water Board's asset management strategy, should be based on a combination of the previously mentioned tools (statistical analysis, survival analysis, neurofuzzy systems), with the end-results tabulated in a database management system and then mapped on

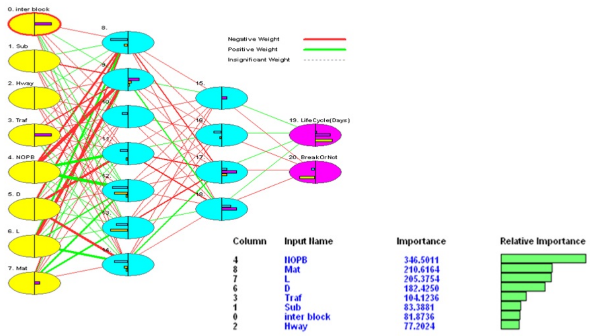

Figure 1. Neurofuzzy pattern recognition of risk-of-failure metrics.

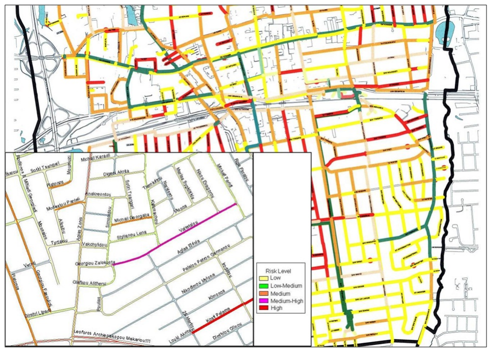

Figure 2. GIS mapping of risk-of-failure metrics.

a spatial database (GIS) that enables users to query both the raw data and the computed risk-of-failure values.

An example of the GIS-based decision support system is shown in Fig. 2. At first historical data on previously observed breaks (NOPB) are lumped at a street level and then mapped to a GIS map of the pipe network, color-coded to indicate the variable degrees of their inherent risk of failure (Fig. 2). The Water Boards can therefore easily and holistically review the status of their network in terms of where and how often pipes break, as well as the computed risk-of-failure for each segment of the pipe network. Even though the eventual goal is to calculate risk-of-failure metrics at the pipe level and not the street level (in other words an individual forecast for each pipe segment) it was deemed redundant and overcomplicating at this early stage of the research and thus overlooked in favor of metrics for each street segment.

This type of visually-represented analysis furnishes the managing agency with an insight into the frequency, the severity, the categorization and the reasons behind pipe breaks over time for all segments of the pipe network. However, such analyses are mostly post-event analysis tools. Since they rely on historical data to identify patterns in the behavior of a water distribution (either through statistical or neurofuzzy analysis, coupled with decisions support systems), they are often used posteriori and not apriori or in real-time. Other methods need to be employed for real-time monitoring; namely remote sensing.

Relevant Project & Funding Agency:
EDRISYS, Cyprus RPF;
EDRISENSE, Cyprus RPF;
PRWDS, USA NSF.

In order to be able to monitor an urban water distribution network for localization and quantification of leaks, parameters such as water flow, pressure, soil moisture and acoustic noise should be collected directly from sensors embedded in strategic places within the network.

AD-HOC WIRELESS SENSOR NETWORKS FOR INTEGRATED MANAGEMENT OF WATER DISTRIBUTION INFRASTRUCTURE

In order to be able to monitor an urban water distribution network for localization and quantification of leaks, parameters such as water flow, pressure, soil moisture and acoustic noise should be collected directly from sensors embedded in strategic places within the network. The wide area of an urban water pipe system and the cost related to the deployment of a wired sensor data acquisition system prohibited the investigation of multi sensor systems for years. Recent advances, though, in Wireless Sensor Networks (WSN) provide researchers with an easily deployable, scalable, flexible and relatively inexpensive approach for real time distributed data acquisition and monitoring. Adhoc WSN are self-organized networks composed of a large number of sensor nodes that interact with their environment and communicate in a wireless fashion, with the goal of transferring their processed data to a remote base station.

The University of Cyprus, in collaboration with industry partners, has investigated the use of WSN applications in UWDN through the development of in-house technologies (6; 15–18). The WATERSENSE and MSAD projects, for example sought the development of WSN hardware and software for improving the efficiency and manageability of UWDN, lab development, in-situ testing (Fig. 3), monitoring and decision-support systems (Fig. 4). WATERSENSE consists of tens of wireless nodes placed at various locations in the water distribution system, to collect and reliably transmit sensor data to a remote base-station as shown in Fig. 5. A multi-parameter decision system based on artificial neural networks and fuzzy logic is responsible for detecting and localizing leaks and other anomalies in water pipes and for producing early notifications and suggestions, which are then distributed to field engineers and maintenance technicians. Deterioration modeling and detection of leaks in water-pipe infrastructure is certainly a very complex task due to the non-linear behavior of the system. In order to overcome this, WATERSENSE is based on the processing of multi-parameter da-

Figure 3. WSN-based leak detection -

The WISENSE in-situ field trial.

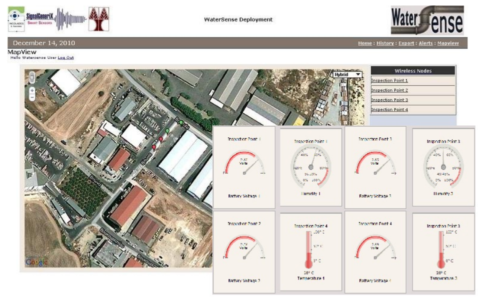

Figure 4. WSN-based leak detection -

The WISENSE website and measured parameters.

ta such as water pressure and flow, acoustic/vibration signals, soil moisture and rainfall readings. Processing of acoustic/vibration signals in combination with soil moisture readings are used for detecting leaks while the analysis of pressure transients and flow enables early detection and localization of larger leaks.

The MSAD project focused on the development and field-validation of a small-scale prototype deployment (Fig. 3) which resembles the operation of a town's water system. The purpose of the prototype deployment was to investigate the communication challenges imposed by the environment and to evaluate the system in terms of durability of sensors and sensor nodes under real operational conditions.

The WSN system developed is based on the Mica2 433 MHz motes, enclosed in waterproof package for outdoor monitoring. Soil volumetric water content is measured by the Decagon Ech2o dielectric sensors attached to sensor nodes using an MDA300 data acquisition board. Soil Moisture is measured from various locations at 0.5m and 1.0m below the level of the water pipe network. Water flow is measured using the widely deployed KENT V100 (PSM) meters while pressure transducers from Honeywell and acoustic sensors from PCB Piezotronics were modified so as to be integrated to the MDA300 data acquisition boards. The TinyOS operating system installed at each mote was used as the software platform for data acquisition, processing and efficient low-power communication. The communication of the motes to the base station provides the functionality equivalent to a data logger where the data acquired from all sensors are stored in a specifically designed database. The motes communicate with the Stargate gateway which is responsible for sending the acquired data to the remote base-station via a GPRS link. The Stargate gateway is also used to update the configuration of each individual sensor mote giving the ability to modify the configuration of the whole WSN if needed. Parameters that can be adjusted include data-acquisition sampling rate, sampling duration, period of sampling and sleep time.

Wireless Sensor Networks and Sensor Placement Optimization are simply opposite faces of the same coin.

The majority of the parameters measured in the aforementioned projects, such as pressure, flow and moisture entail low data acquisition and transmission rates while acoustic noise/vibration data acquisition need significantly higher data rates. For this reason, the WSN is designed in such a way so as to be easily adapted to the needs of the monitoring and management system. Originally the WSN will operate in a low rate function acquiring data from all sensors except the acoustic sensors. When the system indicates a probability of a leak then it triggers the acoustic sensors which are used for the localization of the leak. Standard correlation algorithms are used for locating the leaks within the infrastructure water network.

The WISENSE wireless sensor platform is battery-operated, so special interest is given towards the design of an optimal power management and energy conservation system. Research is currently concentrated on two directions; (a) the use of solar power to drive the Stargate gateway so as to be also deployable in remote locations and b) the incorporation of techniques to reduce the power consumption of the motes. For the latter, programmable sleep-time operation is used in which the motes wake-up at specific time slots, collect the required data from the sensors, transmit the data to the gateway and then go back to sleep. In addition data compression techniques will be studied so as to increase performance and decrease power consumption. The final system is expected to be able to integrate battery and solar-operated motes and gateways according to the physical location of the sensors in the urban water distribution network.

Related to the issue of WSN and the parameters monitored in real-time, is the problem of sensor placement optimization. Since the parameters monitored and the sensors uses have a degree of accuracy and sensitivity to a radius of measurement, and since the number of sensors used in an UWDN is limited by cost and accessibility to physical locations, it is critical that the minimum possible number of sensors (but with a reasonable degree of redundancy) be deployed. The problem turns into a sensor placement optimization problem and a possible solution can be obtained through GIS (Fig. 6).

Relevant Project & Funding Agency:
WATERSENSE, Cyprus RPF;
MSAD, Cyprus RPF;
SPO, University of Cyprus.

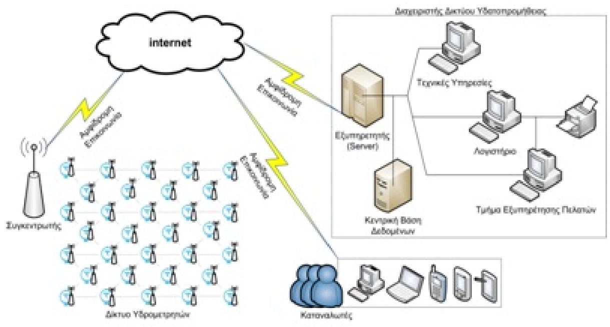

Figure 5. WSN node-to-node architecture

Figure 6. Sensor placement optimization.

PIPE ROUTING THROUGH ANT COLONY OPTIMIZATION (ACO)

As the need to better manage scarce water resources and water distribution systems increases, the problem of efficient routing of piping networks is gaining importance within the framework of an overall strategy for improving the networks efficiency and resilience to undesired emphoperational changes. Within this scope, a methodology was developed for optimizing flow routing in pipe networks by imitating the natural selection processes used by real-life ants in search of the shortest path to a food source. The method, known as ant colony optimization (ACO), is a population-based, artificial multiagent, general-search technique for the solution of combinatorial problems with its analogical roots based on the behavior of real-ant colonies. ACO is utilized for identifying 'shortest paths' in water pipe networks. Such shortest paths could be not only the minimum pipe lengths between nodes of interest, but also the minimum number of valve operations required to keep a flow path active, the minimum number of customers affected during a flow reroute either because of planned (maintenance) or unplanned (water leak) conditions, and the minimum pressure drop along a path during adverse conditions.

Central to the balancing act of minimizing operating costs and maximizing reliability are two very important questions facing water distribution agencies: (1) what is the best way to map a network so as to minimize installation, operational and maintenance costs and at the same time increase its reliability and (2) how can one evaluate the risk of failure for a piping network and what is the proper course of action in terms of repairing or replacing failure-prone or unreliable pipe segments?

The ACO work by the University of Cyprus (9; 13) addresses the former of the two problems to the extent of providing the means for quickly assessing node-to-node shortest or longest routes in a water piping network. The term 'route' is used in its broader sense and not necessarily confined to 'distance length'. Such capability provides the means for assessing several parameters of a network, such as the operational cost, network reliability, network efficiency, fault tolerance, and network management under both normal and abnormal conditions. Examples of such computational needs are the calculation of node-to-node risk of failure, the minimization of the number of impacted customers during normal (maintenance) or abnormal conditions (network failure or intermittent supply), the length and size of pipe segments, and the optimization of the number and location of pipe segments and valves.

In terms of node-to-node or overall network reliability, this metric is related to both the probability of failure for each individual pipe segment and the topology of the network (for example the number and nature of paths through the segments of interest).

The need to identify the longest and shortest paths to a desired location in the pipe network is important given, for example, that at the time of an evaluation the water distribution system may be experiencing a failure at another location in the network. By solving the shortest-path problem the network manager can find answers to questions such as: (1) which sequence of pipe segments and valves need to be opened or closed to redirect the flow of water to the specific location (network node) at minimum cost and time? (2) What is the number of customers affected by each possible rerouting scenario and how can one optimize the choice of rerouting paths? (3) How can the network's combined risk of failure be evaluated and minimized given the possible network topologies resulting from the possible pipe routes?

Why ant colony optimization, and how can it be applied to pipe routing? The answer to this question lays in the similarities that ACO and traditional path analysis methods exhibit in their approach to network mapping and to longest-path or shortest-path calculations. It has been observed that real ant colonies exhibit a behavior that is suitable to optimal network traversing and thus, by induction, to pipe routing. This behavior is characterized by an ant colonys ability to map a network and the possible paths within it, and to find the shortest path between a food source and an ant nest through the use of chemical aids (much similar to corporate learning and memorization). Thus, since the underlying topology and path-traversing mechanism in ACO exhibits many similarities to urban water distribution systems (UWDS), the concepts and methodology employed by the ACO metaheuristic can find a direct application in pipe routing optimization.

Examples of UWDN-related scenarios that can be investigated and

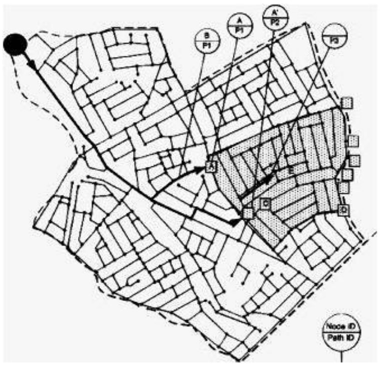

Figure 7. ACO-based waterflow routing.

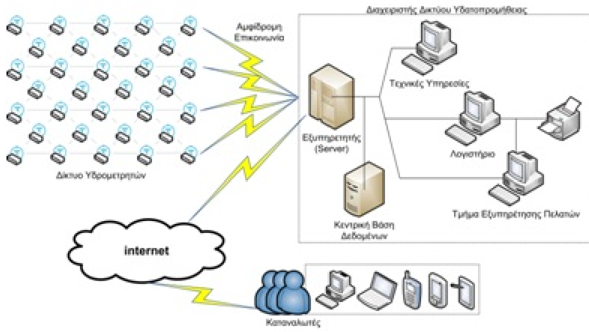

Figure 8. AMR node-to-server architecture.

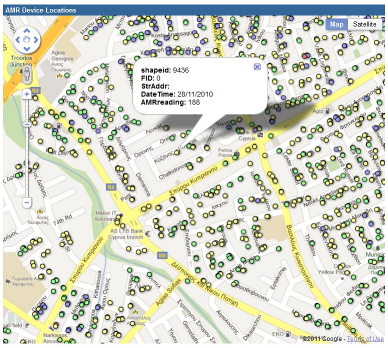

Figure 9. GIS-based AMR visualization.

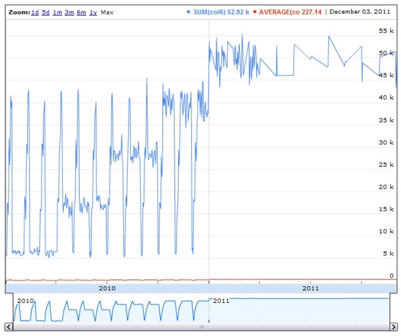

Figure 10. GIS-based AMR network performance anaysis.

solved by ACO are the following:

- Intermittent water supply: What is the most efficient way (time and cost) to provide service from source S to node A under abnormal operating conditions, in terms of the number of valves to open/close every time?

- Pipe failure on critical supply path: if a pipe breaks at a location B on the active pipe path, what is the best way to reroute service to a subDMA shown shaded in Fig. 7, based on the number of valves to open/close?

- Water feed to adjacent DMA: what is the best way to reach the external boundary of the shaded subDMA and deliver water to the adjacent DMA, based on the number of valves affected?

Relevant Project & Funding Agency:
ACOuwdn, University of Cyprus.

AUTOMATIC METER READING (AMR)

Real-time monitoring and intelligent decision support systems are paramount to the sustainable management of water distribution networks. Automatic Meter Reading goes beyond analysis of historical network performance data, into real-time data acquisition from water meters and selected nodes in an UWDN.

Automatic Meter Reading (AMR), coupled with GIS, artificial agents and neurofuzzy decision support systems, has the potential of being the 'holy grail' in sustainable UWDN management and waterloss detection.

AMR work at the University of Cyprus (6; 15; 17; 19) focuses on both hardware and software development for an integrated AMR platform, including but not limited to: AMR hardware add-ons, computer vision, wireless sensors, node-to-server architecture, client-server applications (Fig. 8), artificial intelligence (Fig. 2), decision suport systems (Fig. 2), and geographic information systems (Fig. 9, 10). It should be noted that the AMR platform in development moves away from node-to-node and towards a node-to-server architecture (Fig. 8), where AMR devices communicate directly with a commnand center and transmit information for analysis in real time.

Relevant Project & Funding Agency:
MSAD, Cyprus RPF;
AMR, Cyprus RPF;
NIREAS IWRC, Cyprus RPF.

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SECTION A

FURTHER READING

A listing of recent publications on UWDN by UCyAMR research associates.

Conspectus librorum

[1] Christodoulou, S., and Aslani, P. (2002). A Risk Analysis Framework for Evaluating Structural Degradation of Water Mains in Urban Settings, Using Neurofuzzy Systems and Statistical Modeling Techniques. Proceedings of the 2003 ASCE EWRI 2003 World Water & Environmental Resources Congress. (Pennsylvania, USA, Jun.23-26, 2003).

[2] Christodoulou, S., Aslani, P. and Deligianni, A. (2006). Integrated GIS-Based Management of Water Distribution Networks. Proceedings, 2006 ASCE joint International Conference on Computing and Decision-Making in Civil and Building Engineering. (Montreal, Canada, June 14-16, 2006).

[3] Christodoulou, S., Charalambous, B., and Adamou, A. (2007). Managing the Repair or Replace Dilemma on Water Leakages. Proceedings, International Water Associations (IWA) Third Specialty Conference on Water Loss Reduction (Water Loss 2007). (Bucharest, Romania, Sep. 23-26, 2007).

[4] Christodoulou, S., Charalambous, B., and Adamou, A. (2008). Rehabilitation and Maintenance of Water Distribution Network Assets. Journal of Water Science and Technology: Water Supply, IWA, 8 (2), 231-237.

[5] Christodoulou, S., Charalambous, B., and Adamou, A. (2008). Rehabilitation and Maintenance of Water Distribution Network Assets. Proceedings, International Water Associations (IWA) World Water Congress. (Vienna, Austria, Sep. 7-12, 2008).

[6] Christodoulou, S., Kounoudes, A., Agathokleous, A., Milis, M. and Charalambous, C. (2008). Ad-Hoc Wireless Sensor Networks for Integrated Management of Water Distribution Infrastructure. Proceedings, IEEEs WoSPA 2008 Conference on Signal Processing and its Applications. (Sharjah, U.A.E, Mar. 18-20, 2008).

[7] Christodoulou, S. and Deligianni, A. (2009). A Neurofuzzy Decision Framework for the Sustainable Management of Water Distribution Networks. Journal of Water Resources Management, Springer, 24 (1), 139-156.

[8] Christodoulou, S., Deligianni, A., Aslani, P. and Agathokleous, A. (2009). Risk-Based Asset Management of Water Piping Networks Using Neurofuzzy Systems. Journal of Computers, Environment and Urban Systems, Elsevier, 33 (2), 138-149.

[9] Christodoulou, S. and Ellinas, G. (2010). Pipe Network Routing Through Ant Colony Optimization. Journal of Infrastructure Systems, ASCE, 16 (2), 149-159,.

[10] Christodoulou, S., Agathokleous, A., Kounoudes, A. and Milis, M. (2010). Wireless Sensor Networks for Water Loss Detection. European Water, Springer, 30, 41-48.

[11] Christodoulou, S. (2011). Water Network Assessment and Reliability Improvements by use of Survival Analysis. Journal of Water Resources Management: Special Issue on EWRA2009, Springer, 25(4), 1229-1238.

[12] Christodoulou, S., Agathokleous, A., Charalambous, C. and Adamou, A. (2010). Proactive Risk-Based Integrity Management of Deteriorating Water Distribution Networks. Journal of Water Resources Management, Springer, 24(13), 3715-3730.

[13] Christodoulou, S. and Ellinas, G. (2011). Ant Colony Optimization Agents and Path Routing: The Cases for Construction Scheduling and Urban Water Distribution Networks. Ant Colonies: Behavior in Insects and Computer Applications, Nova Science Publishers Ltd, Hauppauge, NY 11788, USA (editor: Richard Schortemeyer III), ISBN 978-1-61122-023-0.

[14] Christodoulou, S. Beyond Politics: Water Loss Management, Sustainability and Commodification of Water. The Water Crisis in the Mediterranean: Losing Paradise, Ashgate Publishing Ltd, Gower House, U.K. (editors: Holst-Warhaft, G., Steenhuis T. and Porter K.), ISBN 9780-7546-75730.

[15] Agathokleous, A. and Christodoulou, S. (2011). Waterloss Modelling for Urban Water Distribution Networks. Proceedings, European Water Resources Associations Sixth International Symposium (Catania, Italy, Jun. 29 Jul. 2, 2011).

[16] Christodoulou, S., Agathokleous, A. and Charalambous, B. (2011). Urban Water Distribution Network performance Under Intermittent Water Supply Conditions. Proceedings, European Water Resources Associations Sixth International Symposium (Catania, Italy, Jun. 29 Jul. 2, 2011).

[17] Agathokleous, A., Papadopoulou, C. and Christodoulou, S. (2011). Real-Time Monitoring of Water Distribution Networks. Proceedings, International Water Associations Eighth Symposium on Systems Analysis and Integrated Assessment, (San Sebastian, Spain, Jun. 22-22, 2011).

[18] Christodoulou, S. and Agathokleous, A. (2011). A Study on the Effects of Intermittent Water Supply on the Vulnerability of Urban Water Distribution Networks. Proceedings, The 6th IWA Specialist Conference on Efficient Use & Management of Water, Dead Sea, Jordan, Mar.29- Apr.2, 2011).

[19] Agathokleous, A. and Christodoulou, S. (2011). In-Situ Water Loss Modeling and Detection. Proceedings, The 6th IWA Specialist Conference on Efficient Use & Management of Water, Dead Sea, Jordan, Mar.29- Apr.2, 2011).

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NIREAS SPEAKER SERIES

WHEN IDEAS FLOW

Dr. Xavier Albets

Senior Researcher of Nireas-IWRC

University of Cyprus

Saltwater intrusion of coastal aquifers

Development of an integrated numerical tool for its prediction and control

Brief CV

Xavier Albets-Chico is a graduate from the Polytechnic University of Catalonia (Barcelona, Catalonia, Spain) as a Thermo-Mechanical Engineer (2001). He pursued an MSc of Thermal Engineering and Energy Technology (2002) and a PhD on Thermal Engineering (2006) at the Heat and Mass Transfer Technological Center of the aforementioned university.

His research work was based in the CFD implementation and developing of RANS two-equation turbulence models for both natural and forced convective turbulent flows. In 2006 he joined as a Post-Doc the Dynamics of conductive flows group at ULB, Brussels, Belgium; where his main work was based in the analysis and developing of finite volume techniques for the simulation of liquid-metal flow under the influence of strong-magnetic fields (high Ha numbers), fringing magnetic fields and DNS of turbulence interaction at relevant parameters for nuclear fusion applications.

In 2008, he became an associate researcher at UCYCompSci group of the Mechanical and Manufacturing Engineering of the University of Cyprus, where he has actively participated in several projects such as liquid metal flow simulations for Nuclear Fusion applications and the development of turbulent atmospheric dispersion models, to name a few.

Since January 2011 he is the researcher in charge of the development of a numerical tool for the monitoring and prediction of saltwater intrusion of coastal aquifers in the water research center (NIREAS) of the University of Cyprus.

Xavier Albets-Chico has published more than 20 articles in international conferences and scientific journals. He is a reviewer of several scientific journals such as Physics of Fluids, Fusion Science and Technology and Solar Energy. His main research interests are based on the ability of numerical methods to understand nature and their potentiality to produce knowledge with a high social impact.

REPUBLIC OF CYPRUS | STRUCTURAL FUNDS | EUROPEAN UNION | Research Promotion Foundation | ΔΕΣΜΗ 2008

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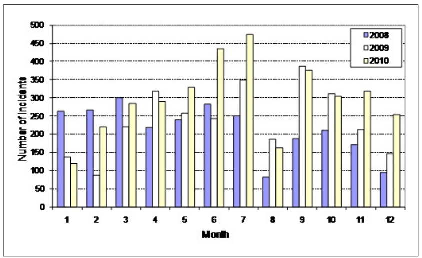
SECTION B - TECHNICAL

A Study On The Effects of Intermittent Water Supply On The Vulnerability Of Urban Water Distribution Networks

Excerpts from paper to appear in IWA's Journal of Water Science and Technology, by Dr. S. Christodoulou and A. Agathokleous

Dr. Symeon Christodoulou &,
Agathoklis Agathokleous, **Nicosia**



Incidents per month, for three-year period of intermittent supply (Lemesos dataset).

20.11 13:25 h — **Abstract:** Faced with extended periods of drought and short supply of water, arid-weather countries have turned to intermittent water supply as a means to reduce water consumption and to prolong their national water reserves. Unfortunately, such drastic measures usually fail to consider the effects of intermittent supply on the condition of the piping networks and the resulting water losses, inefficiencies and overall maintenance cost on these networks. Presented herein is research work on the effects of intermittent water supply on the vulnerability of urban water distribution networks (UWDN) based on a three-year dataset from major urban centres in Cyprus. The dataset includes information on breakage incidents, operating network parameters, external factors and vulnerability assessment and by use of data-mining and survival analysis techniques evaluates the effects of such intermittent supply strategies on the vulnerability of the water pipes and on the sustainability of the strategy.

Introduction: Intermittent water supply is a piped water supply service delivering water to users for less than 24 hours in one day, and is used when the available supply and/or the hydraulic capacities of the water supply system are insufficient to meet water demand. Such piped networks, which are commonly found in many developing countries, even though aim the optimisation of water and/or of the economic resources available to the water provider they usually cause severe operational and economic problems. Typical problems caused are the increase in water wastage and thus the increase in operational costs due to the added need for heavy technical and human adjustments compared to continuous-supply systems. Moreover, intermittent water supply is the source of major inconveniences and serious health risks among urban populations.

The study's primary research objective was the evaluation of the effects of intermittent water supply (IWS) on water distribution networks normally operating under continuous water supply (CWS) regimes and the re-examination of fragility metrics for CWS networks in light of IWS operations.

In 2008, after 4 years of drought and increasing water consumption, the Republic of Cyprus was forced to take drastic measures to safeguard the diminishing national water reserves and to prepare for worsening drought conditions. Among the measures taken was the import of water by ships from a neighbouring country (Greece), the enforcement of an intermittent water supply policy (city residents were provided with water through the city water pipelines for about 12 hours every 48 hours) and the construction of several desalination plants. The intermittent water supply lasted for about 2 years (Mar. 2008 - Oct. 2010) and was presumed to have reduced the overall water consumption by about 20% (by volume of water) compared to previous years. This savings estimate, even though calculated based on the total water consumed, was actually the direct result of the reduction in water supply by the Water Development Department of the Republic, which in numbers was about 20%-30% less than the volume of water supplied to the networks under normal (continuous) operating conditions. Furthermore, the presumed water savings do not take into consideration the side-effects of the intermittent water supply policy on the piping networks and the resulting water loss thereafter. In fact, should standard IWA terminology be used, the Water Development Department may have indeed witnessed a drop in revenue water (thus their presumption of decreased water demand) but the non-revenue water may have increased as a percentage of the total system input volume. Alternatively, should one examine the total system volume, the revenue water and the non-revenue water (apparent losses and real losses) in the subject piped networks before and after the continuous and the intermittent water supply periods, only then can one deduce the effectiveness of such policies and their effects on the piped networks. It is thus imperative to examine the performance of the piped network under the various operating conditions and through its analysis arrive at better operations and management policies.

The intermittent water supply lasted for about 2 years (Mar. 2008 - Oct. 2010) and was presumed to have reduced the overall water consumption by about 20% (by volume of water) compared to previous years.

Relevant studies in literature: To-date a number of studies on infrastructure assessment and deterioration modelling of urban water distribution networks (UWDN) have been undertaken. The intent of such studies has traditionally been to assist UWDN operators in improving their understanding of the network's behaviour over time, its deterioration rate and its reliability with respect to presumed risk factors. A primary goal has been the arrival at "repair-or-replace" decisions on a more scientific basis. The studies, thus, usually attempt to identify statistical relationships between water main break rates and influential risk factors such as a pipe's age, diameter and material, the corrosiveness of the soil, the operating pressure and temperature, possible external loads and recorded history of pipe breaks.

Unfortunately very little, if anything, has been reported in literature with regards to UWDN modelling under abnormal operating conditions such as the ones related to intermittent water supply. This aspect of UWDN modelling is the subject of this research work, with some preliminary findings reported herein.

Most of the published work on intermittent water supply (IWS) focuses on the design of systems under IWS operating conditions and on the effect of IWS policies on water quality. Very little work has been reported on the effect of IWS on the vulnerability of UWDN, issues related to water-meter under-registration and comparisons of continuous water supply (CWS) with intermittent water supply (IWS). Among the key findings of one of the studies was that under the IWS mode of operation the domestic water consumption depends on the adequacy of water supply, whereas water consumption does not change appreciably under CWS presuming that the consumers' water demand is satisfied under IWS. In both cases though (IWS vs CWS), little is reported on the vulnerability of the underlying UWDN as a result of intermittent water supply.

The Case-Study Water Distribution Networks: The UWDNs in study have been the centre of several related studies in the past and documented in literature (2–5; 7; 8). The first UWDN (the Water Board of Nicosia) consists of about 1200km of water mains, 103,000 house connections (water meters) and services about 330,000 city residents. The network carries an annual volume of about 19.5 million cubic meters of water, with an estimated volume of 19.7% unaccounted for. The second UWDN currently under review (the Water Board of Lemesos) is over 50 years of age and serves approximately 170,000 residents through approximately 64,000 consumer meters in an area of 70 km2. The annual volume of potable water distributed through the piped network, of approximate length 795km, is about 13.7 million cubic meters and of value 7.0 million.

Prior to the enactment of the IWS policies in 2008 both the Lemesos and Nicosia networks had always operated in continuous water supply mode, a mode which the networks were designed for.

The first dataset, from the Water Board of Nicosia, covers a period of 6 years and includes approximately 25,000 service calls related to water-loss or pipe-inspection incidents (years 2003-2008). The second dataset, from the Water Board of Lemesos, includes approximately 11,000 service calls from a period of 3 years (2007-2010). The subject IWS dataset from Lemesos (2007-2010) supplements a previous dataset for the same network under CWS operations (2004-2007), which was extensively reported on by Christodoulou et al. (2006, 2009, 2010a, 2010b).

Past UCyAMR-related research studies identified as most influential risk-of-failure factors to be (i) the number of previously observed breaks (NOPB), (ii) the material type (MAT), (iii) the length (L) and (iv) the diameter (D) of each pipe.

Analysis techniques: Further to classical statistical analysis, a number of other techniques are currently utilized for the analysis of the IWS dataset, with the dominant method used being the survival analysis. Survival analysis is a method used in modelling the behaviour of a component over time (time-to-event data), especially in the presence of incomplete time data. Further to the estimation of time-to-failure metrics, the method allows for the computation of survival and hazard curves, hazard ratios and cumulative hazard metrics for the underlying datasets which can in turn be clustered by any number of desired data subsets. For exam-

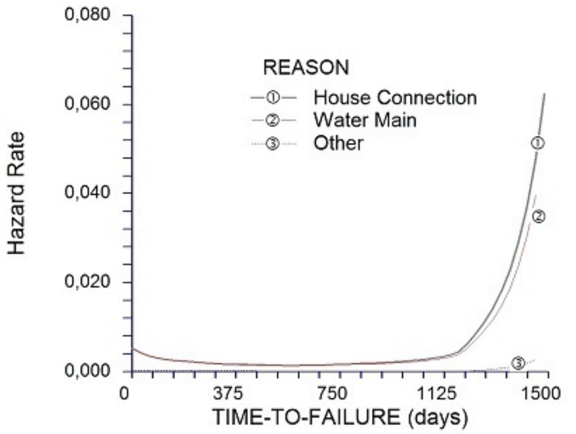


Figure 11. Hazard rate plot of IWS incidents, stratified by type of water pipe (Nicosia dataset, 2003-2008).

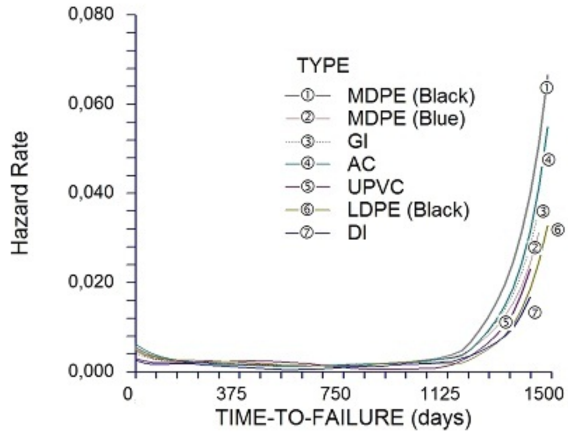


Figure 12. Hazard rate plot of IWS incidents, stratified by type of water pipe (Lemesos dataset, 2008-2010).

ple, the pipe breakage dataset can be clustered by the pipes' material type and hazard curves be developed for each material type giving us insight on the level of proportional hazards between the various material types in the population of network pipes.

Knowledge from past studies on subject networks: As aforementioned, previous studies by Christodoulou et al. (2006, 2009, 2010a, 2010b) have reported on the effect of several potential risk factors on the fragility and probability of failure of UWDN pipes. The studies initially identified as most influential risk-of-failure factors to be (i) the number of previously observed breaks (NOPB), (ii) the material type (MAT), (iii) the length (L) and (iv) the diameter (D) of each pipe. The authors then deduced rules about the relative importance of these factors, by use of several analytical and artificial intelligence techniques such as survival analysis and pattern recognition with neurofuzzy systems.

For example, Christodoulou et al. (2010b) report that by using several data stratifications on the Lemesos dataset spanning the 5-year CWS period (2002-2007) and about 2,000 observed break incidents, they were able to deduce that:

- Data stratification based on the pipes' material type reveals that the hazard rate of the black-colour medium density polyethylene (MDPE) pipes is higher than galvanized (GI), asbestos cement (AC) and MDPE-blue pipes.

- Data stratification based on the type of incidents reveals that the hazard rate related to pipe deterioration greatly outpaces the hazard rate of the other incident types (corrosion, interference by others, tree roots, connection hose, other).

- The hazard rate related to corrosion accelerates in time and surpasses the rate of increase of interference-related, tree-roots and connection-hose incidents.

- Data stratification based on the pipe diameter reveals that medium and large diameter pipes have approximately the same hazard rate over time but small-diameter pipes have an increasing hazard rate.

Also documented, in Christodoulou and Deligianni (2010a), is the criticality of the "number of previously observed breaks (NOPB)" risk factor. The hazard rate for the NOPB factor was subsequently shown to be a dominating parameter, especially for the range of $4 \leq NOPB \leq 8$, wherein if NOPB is increased by 1 incident then the hazard rate increases by 20.49%.

The effects of intermittent supply: As previously stated, the IWS policy lasted for about 2 years (Mar. 2008 - Oct. 2010).

In the case of Nicosia the IWS policies had increased the vulnerability of house connections.

During the first year alone, the Water Board of Nicosia reported a total of more than 12,000 service calls related to water-loss or pipe-inspection incidents. The number of incidents has since then risen to about 70-80 per day; a number which is disturbingly high. The majority of these incidents were related to house connections and small-diameter pipes (Fig. 1), with an increase in incidents during the intermittent supply period of about 28% compared to the normal operating conditions period (uninterrupted supply). This finding is in agreement with the fourth finding of the analysis by Christodoulou et al. (2010b) on the increased risk of failure of house-connection pipes.

Additionally, application of the survival analysis method to the IWS dataset shows an increase in the hazard rate of house connections compared to the hazard rate of water mains (Fig. 1), thus indicating that in the case of Nicosia the IWS policies had increased the vulnerability of house connections.

In the case of Lemesos the IWS policies had increased the vulnerability of water mains.

The Lemesos dataset is even richer in terms of the quality of leak-related data. The dataset covers the period of 2007-Jan.2011 and includes 11,354 incidents of which 9,034 occurred during the intermittent supply period (2008-2010). The total number of incidents per annum increased from 2,092 in 2007 (the presumed steady state condition) to 2,565 in 2008, 2,853 in 2009 and 3,566 in 2010. This, compared to the steady state condition (year 2007), translates to an increase of 23% for 2008, 36% for 2009 and 70% for 2010. The numbers are again alarmingly high. The dataset also shows an increase in the incidents on water mains of about 85% in year 2010 compared to the base year of 2007 (9,700 vs. 5,236). A similar situation is observed on the incidents pertaining to house connections (71% increase, 598 vs. 350 incidents). The IWS policy seems to have burdened the UWDN with additional loads and increased the risk of failure.

Application of survival analysis on the Lemesos IWS dataset, clustered by pipe material type, shows that the hazard rates for MDPE (Black) pipes and for AC pipes surpasses the hazard rates of the other pipes (Fig. 2). More importantly, as Fig. 4 depicts, the deviation in hazard rates among the different material types increases from 0.002 in the initial stage (at t=1,125) to 0.042 at the end of IWS period (at t=1,500). This is an indication that a pipe's material type is a contributing risk factor in the time-to-failure metric and that the hazard rate for certain pipe types is very sensitive to IWS operations. In fact, the hazard rate for MDPE and AC pipes increases by approximately 1500% in a very short period, from 0.004 to 0.060 in 3 years (Fig. 2).

Conclusion: The article presents results of a study on the effects of intermittent supply on the reliability of an urban water distribution network. The study spans a 4-year period (2007-2010) and includes about 20,000 water-loss incidents from two metropolitan water distribution networks in Cyprus in which intermittent supply policies were enforced during the period 2008-2010.

The results show a dramatic increase in pipe-burst incidents that can be attributed directly to the intermittent water supply policy. This increase is especially evident in deteriorating pipes (with $NOPB \geq 4$) and small-diameter pipes (primarily house connections).

Even though it is understood that the primary reason for enacting an intermittent-supply policy is to reduce water consumption as forced upon us by extreme drought conditions, the post-policy analysis indicates that side-effects of such policy are equally significant and worthy of consideration. Such side-effects are the increase in pipe-burst incidents, the increased water loss due to intermittent-supply induced leaks in the network and the increased cost for maintaining the networks under such abnormal operating conditions.

■

'To AMR, Or Not To AMR? That Is The Question!'

Dr. Symeon Christodoulou

EDITORIAL - Even though being a relatively new technology, Automatic Meter Reading (AMR) is a proven and scientifically reliable technology that is rapidly improving and spreading across the globe. The technology, which has been well-documented in literature, has already manifested itself in various commercial products and real-life implementations and has furnished implementing agencies with several benefits in automation, consumer satisfaction, water and money savings.

Among the aforementioned benefits, one cannot emphasize strongly enough the promise offered by AMR technologies for water savings through improved operations and maintenance.

When it comes to AMR, the question asked should be 'when?' rather than 'should?' agencies implement AMR technologies

Urban water distribution network (UWDN) operators/managers, desperately seeking ways to improve the efficiency and sustainability in their management of UWDN will find AMR to be a powerful tool in their arsenal. Real-time data collecton is not enough though. What makes AMR such an indispensible tool is its suitability as a real-time decision support and waterloss detection tool. It is its vast return on investment, not only financially but most importantly in terms of water resources! So, let's put aside any financial and/or technology barriers we may have in implementing AMR and let's speedily march onward with rolling it out.

UCyAMR NEWSBRIEF

Snapshots Of Our AMR World

Work Presented at EWRA Conference (Italy, Jul. 2011)

Two manuscripts were successfully presented at the European Water Resources Association's (EWRA) 2011 Conference in Catania, Italy (Jun. 29- Jul. 2, 2011).The UCyAMR project seems to be coming at a city near you.

Work Presented at IWA WATERMATEX2011 Conference (Spain, Jun. 2011)

One manuscript was successfully presented at the International Water Association's (IWA) Watermatex2011 Conference in Spain (Jun. 20 - 22, 2011).

Work Presented at IWA Conference (Jordan, Apr. 2011)

A first look at the proposed platform and related research work was presented at the International Water Asociation's (IWA) Efficient2011 Conference at Dead Sea, Jordan (March 29 - April 2, 2011). The reception of our work has been very enthusiastic. More presentations have already been scheduled.

Work Presented at the MEDIWAT Conference (Cyprus, Mar. 2011)

A presentation of the UCyAMR project was given at the MEDIWAT (Sustainable Management of Environmental Issues Related to Water Stress in Mediterranean Islands) Stakeholders Event in Lemesos, Cyprus (18 March 2011).

Journal Papers Accepted for Publication

Three journal papers on recent work of the UCyAMR team have been accepted for publication in the follwing refereed journals:

- IWA's *Journal of Water Science and Technology*,
- Springer's *Journal of Water Resources Management*,
- EWRA's *European Water* Journal

New Team Member: Ms. Sofia Kranioti

Ms. Sofia Kranioti has recently joined the UCyAMR research team to help develop the software platform for the AMR project. Sofia holds a BEng in Electrical Engineering and an MBA degree, both from Aristotle University of Thessaloniki (Greece).

New Team Member: Mr. Anastasis Gagatsis

Mr. Anastasis Gagatsis has recently joined the UCyAMR research team as a GIS Specialist, to help in development of the GIS platform for the AMR project. Anastasis holds a BSc in Environmental Sciences (York University, UK) and an MSc in Geographic Information Science (University of Edinburgh, UK).

MSc Thesis, University of Edinburgh

Mr. A. Gagatsis, who recently joined the UCyAMR project, has completed his MSc thesis at the University of Edinburgh. The thesis, titled "A spatio-temporal analysis of pipe-failure incidents in the Water Distribution Network of Limassol, Cyprus" is based on water-loss data from the water distribution network of Lemesos, Cyprus. The processes and knowledge-how developed by Mr. Gagatsis are currently transferred to the UCyAMR team and implemented in a GIS-based platform for the UCyAMR project.

UCyAMR Device Successfully Lab-Tested

The first working prototype of the AMR device add-on has recently been lab-tested by UCyAMR partner ***SignalGenerix Ltd.*** with excellent results. The device uses SignalGenerix's in-house technology on computer-vision algorithms and digital signal processing.

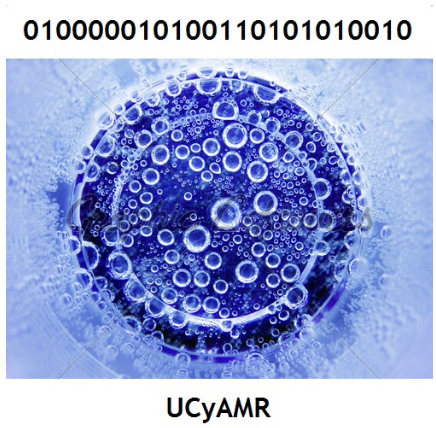
UCyAMR Database and GIS Platform in Development

A working prototype of an extensive database management system has recently been rolled-out by UCyAMR partner ***FWS Ltd.***. The database is the backbone of the UCyAMR project, providing not only real-time communication with the AMR devices and data management, but also a neurofuzzy decision-support system for loss detection and 'repair-or-replace' decisions for urban water distribution networks.

FORTHCOMING ARTICLES

To Appear In ‘AMR Chronicle’, March 2012 Issue

The UCyAMR Platform



A brief overview of the UCyAMR technology, the signal and data management platform and the system architecture (by Dr. S. Christodoulou & Dr. A. Kounoudes).

The UCyAMR Decision Support System

A brief overview of the decision support system used in UCyAMR, its features, the technology and its user-interface (by S. Christodoulou & S. Kranioti).

A Spatio-Temporal Analysis Of Pipe-Failure Incidents In The Water Distribution Network of Limassol, Cyprus

A summary of the findings from the spatio-temporal analysis of the pipe-failure Lemesos dataset utilized in the study of the effects of intermittent water supply (by A. Gagatsis & Dr. S. Christodoulou).

Seismic Vulnerability of UWDN

A brief overview of ongoing research work on seismic vulnerability analysis of urban water distribution networks (by Dr. M. Fragiadakis, Dr. D. Vamvatsikos & Dr. S. Christodoulou).

NIREAS International Water Research Center

nireas
International Water Research Center

A brief overview of NIREAS-IWRC and its relation to the UCyAMR project (by Dr. D. Fatta-Kassinos & Dr. S. Christodoulou).

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Where Water and Data Flow!

AMR Chronicle

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Public Agencies

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NYC Department of Environmental Protection, USA

SMEs

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