An ICT overview of water management

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Abstract

The aim of this document is to provide a general and preliminary study on the topics related to ICT and water management. In particular the aspects considered are:

- Control and monitoring mechanisms of water distribution networks
- Losses in water distribution networks
- Demand and supply management in water distribution networks
- Energy (electrical) cost for water distribution networks and water management systems
- Service-Oriented Architecture approaches to water management
- Design and analysis of water distribution networks

The investigation does not want to be completely exhaustive at this stage of the research, but the aim is to clarify concepts and themes that could be deeply investigated in a future stage.

The importance of water for society and human beings do not need in this report to be investigated, I think it just worths to remark the importance of the theme that United Nation define water and sanitation as a Human Right[1].

Water losses

Water losses in the water distribution system are a big issue especially for those countries that do not have an efficient water distribution networks, but also in those countries that suffer from the scarcity of water itself (e.g., desert region of Africa and Middle East). A study of International Water Association (IWA) Water Loss Task Force in 2003 [35] showed that 726 millions of liter of water per year are lost. However, when speaking about water losses the problem is more complex than it seems. In fact, according to IWA given a total volume of water in the system different outcomes are possible for part of this volume as shown in Figure 1.

In particular as explained in [37] the IWA gives a specific definition of each of the terms appearing in Figure 1:

- System Input Volume is the annual volume input to that part of the water supply system

[1] `http://www.ohchr.org/en/NewsEvents/Pages/DisplayNews.aspx?NewsID=10403&LangID=E`

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
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<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
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Figure 1: IWA Standard International Water Balance and Terminology. *Source: IWA*

- Authorised Consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- Non-Revenue Water (NRW) is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of:
  - Unbilled Authorised Consumption (usually a minor component of the Water Balance).
  - Water Losses.
- Water Losses is the difference between System Input Volume and Authorised Consumption, and consists of Apparent Losses and Real Losses.
- Apparent Losses consists of Unauthorised Consumption and all types of metering inaccuracies.
- Real Losses are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

For each item belonging to the Non-Revenue Water (NRW) specific assessments can be done and best practices can be adopted. In [37] for each element contributing to NRW explanation of each category is given together with data referring to the situation of countries that have issued international reports on the topic. To counter the real losses of water [37] proposes a combination of the following techniques:

- Pipeline and Assets Management to tackle the natural deterioration of the pipes and equipment. Renewal and replacement of these components provides significant improvements.
- Pressure Management (which may mean increases or decreases of pressure): actively adapting water pressure has been recognized in many countries as an effective leakage management strategy. Results of the benefits (more qualitative are presented in [37]).
- Speed and quality of repairs: this aspect is quite straightforward.
- Active Leakage Control in order to locate unreported leaks.

Pressure Management aims at lowering the water system pressures during periods of lower demands (when system pressures normally would rise) and thus resulting in reducing the flowrate from existing background leakage (those small weeping leaks from fittings and joints). An additional benefit of pressure management is the related reduction in water main break frequencies which in turn help to extend the life of the underground infrastructure.

Although [37] describes percentage (%) measures related to water losses in different countries as a non adequate indicator, since the real value depends of course by the habit of water usage, it is remarkable to see high differences in ranges from below 9% (Germany) to up to 75% (Albania) [31]. And considering the trend shown in [30] for Spain, U.K. and Slovenia the only significant improvement in 10 years are shown by the U.K. situation, while for Spain the trend is slightly increasing and Slovenia has no clear pattern towards increase or reduction. Another example of losses is the case of Theran where the NRW is about 26% of the total water, and of this fraction the 50-60% is due to leakages [46].

The methodologies of IWA to account water losses in the water system have been applied in the study of the water losses in Toronto [32]. The assessment of the losses in year 2004 was calculated in 10% of the total system supply totaling a NRW more than 52 millions of m^3 of which real losses were considered about 103 Million Liter per Day (MLD).[2] The pilot involved a neighborhood of Toronto involving a total watermains of 51.7 km and about 7300 served customers and more than 400 hydrants. The benefits of the pressure management system installed were clear and significant reducing the leakage component about 30% and the total water demand for the area about 4%, with a reduction on the average pressure of around 14%. The authors claim that just by the water savings the implementation of the new pressure management system would payback in just 4.5 years where the expected lifetime of the installation is 25 year. The theme of losses is key also in the information system that help in governing the water supply systems [60]. In the paper the test bed is Brazilian city of Ponta Grossa, Parana (300 thousand inhabitants, 8500 water linking and 1500 kilometers of water distribution tubing) shows interesting reduction of water losses by the introduction of automation system in water system control and the possibility of remote monitoring and actuating through telemetry commands; the automation plant provided a reduction in losses about 15% in the 24 months of installation. The losses started then to increase once again in the following 24 months about 4%. The focus of [60] is to realize a specialized monitoring system that can help more the operators in the control center and guide them to a more rapid detection and solution of the problems. The system is an intelligent system that has a knowledge base, an interpreter to process and infer on the knowledge base, it can acquire new knowledge by an interaction with a system expert. When the system has applied rules and reasoning process to the data base it provides explanations and the conclusions of its reasoning process. A new and advanced mode of having visualization of problems and solutions to be applied together with the results of interventions on the water system have provided a reduction in losses of about 4% in just 4 months since the introduction.

[2] This volume corresponds to filling 15000 Olympic size pools daily.

A different approach in water losses estimation is presented in [5] where a highly statistical-based approach is described and used. It is based on the evaluation of leakage happening at house where homogeneous strata are considered. Strata represent houses belonging to a zone with same characteristic in terms of watering system (e.g., water pressure and leak frequencies); once the strata are defined random samples of houses/users are effectively metered and the data are extended, with statistical corrections, to the households in the strata. The evaluation then proceeds in considering leakages in the main and secondary lines: even in this case the strata concept is applied and zones with similar frequencies of reported leakages and similar consumption of water usage from the strata. The study also takes into account the evaluation of over and under registration of water metering, here the strata are formed by meters with similar failure rates; in addition, losses from unauthorized usage and billing error are also considered by sampling those users that have suspected low water consumption. This method is applied in a real situation of 15 cities in Mexico. On average the results give a 36.4% loss which is composed by 24.5% due to house connections, 10.6% due to mains and secondary lines, while 1.3% is due to under-registered consumption. The main causes of leakage in the house connections are mainly due to the use of low-density plastic material, while for secondary and mains it is due to the aging of the infrastructure.

Causes of leaks:

- soil type
- water quality
- technology and material for network construction
- operating pressure
- age of the system
- operation and maintenance practices

Leaks occur when:

- longitudinal/circumferential breaks
- corrosion
- poor connections
- crushed

Lambert *et al.*[36] define, in addition to the already presented schema in Figure 1 that is used as the base to calculate water losses, a schema with the watering system where in the water distribution networks losses may happen, depicted in Figure 2. In the framework of Figure 1 in [36] a clear definition of each element is given. Here we report those definitions in order to have a clear and complete picture which is essential for this work and at this stage of the project:

Water Abstracted is the volume of water obtained for input to raw water mains leading to water treatment plants.

Water Produced is the volume of water treated for input to water transmission mains or directly to the distribution system.

Water Imported and Exported relates to the volumes of bulk transfers across operational boundaries.

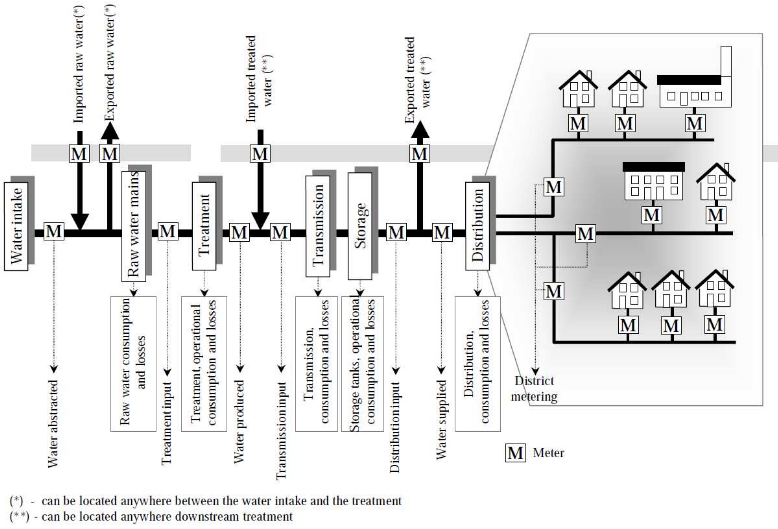

Figure 2: IWA definition of water supply system input and outputs. *Source: IWA*

System Input Volume is the volume of water input to a transmission system or a distribution system.

Authorized Consumption is the volume of metered and/or unmetered water taken by registered customers.

Water Losses of a system are calculated as: $WaterLosses = SystemInputVolume - AuthorizedConsumption$.

Real Losses are physical water losses from the pressurized system, up to the point of customer metering.

Apparent Losses consist of unauthorized consumption (theft or illegal use), and all types of inaccuracies associated with production metering and customer metering.

Non-Revenue Water is the difference between the System Input Volume and Billed Authorized Consumption.

In [36] performance indicators to account losses from a technical point of view are defined. In particular the indicators proposed are:

- % of volume input: this indicator is considered by the authors appropriate for financial and ecological purposes, but not as an indicator of real water losses in the water distribution system.
- Technical Indicator for Real Losses (TIRL): it is given by the volume of Real Losses divided by the number of service connections (Nc), allowing for the % of the year for which the system is pressurized: $TIRL = CurrentAnnualVolumeofRealLosses/Nc$ (liters/service connection/day when the system is pressurized).
- Unavoidable Average Real Losses (UARL): this indicator recognizes the separate roles that length of mains (Lm), number of service connections (Nc), total length of the service connection from the street to the customer meter (Lp) and the average pressure of the system

(P). $UARL = (A \times Lm/Nc + B + C \times Lp/Nc) \times P$ (litres/service connection/day when the system is pressurized) where A, B and C are constants statistically derived from water distribution system in international data [34] which respectively are 18, 0.80 and 25.

Energy (electrical) cost for water distribution networks and water management systems

Water and energy, especially electrical, are closely connected. In fact, water utilities use energy (mainly electrical) to operate the equipment and systems they use to run the water business; at the same time water, in the form of hydro plants, is used to generate electrical energy.

This double valence of water is recognized in [29] where the situation of Ontario is considered and analyzed. The authors mention that water utilities incur in operational costs for electricity that are up to 50% of the overall costs (specific source mentioned in the paper is not verifiable). According to [29] electrical energy in the water distribution networks is required for the following operations:

- Water pumping: for conventional business or running the water distribution networks , but also pumping for water storage in reservoirs.
- Water utility operations: electricity required to run the facilities where the water utility operates. Part of this energy is actually used to run the systems that monitor the water distribution networks itself.
- Water treatment: water purification, filtration and chemical treatment requires systems running on electrical energy.
- Water heating: electricity required to heat water for household or industrial applications. (This last point is not completely clear, since it is more likely at least in Europe that water heating is done locally in the house/company).

The solution proposed are quite natural and include:

- Increase efficiency in water heating (same consideration done above applies).
- Installing energy efficient purification systems.
- Monitoring of the efficiencies of pumping stations, distribution facilities and powerhouses.
- Maintenance to prevent leakage problems in pipes.
- Installation of efficient pumping infrastructure.
- Demand management.
- Pump scheduling.

The estimation of the electricity required for water distribution in the Peel region (suburbs of Toronto) is 8100 MWh [29]. Energy wasted because of savings in eliminating the leakages (according the estimation) could be about 17% of the overall electricity consumed and save of 1377 MWh/day for the test bed examined. Another aspect considered is the possibility of shifting the pumping operations of water in the reservoirs during non-peak electricity hours, this is hypothesized to free up electrical capacity for users, however this is not actually beneficial in terms of energy savings for the water distribution networks . The analysis has some interesting points but the data used should be taken carefully since estimations are done and not all sources are available.

In [16] the idea of pressure reduction in water distribution networks is investigated and simulated based on the data of a real water network of a suburb of Naples. The paper presents basically two ideas: first to reduce pressure in order to minimize the losses due to leakages in the infrastructure and second produce energy in the water distribution networks. The idea presented is related to the substitution of pressure reducing valves in the water distribution networks with turbines or pumps able to acts as turbine. Installation of such systems can be a point of convergence of two problems: reduce losses by reduced pressure and in doing so produce energy with small scale hydro turbines. The simulation of the hydraulic system and the individuation of the best location for the installation of the valves or turbines are obtained through a genetic algorithm solver. Two scenarios are compared: the usage of traditional pressure reduction valves and the turbines to generate energy. It is interesting that the turbine scenario can achieve even better results in loss reduction than the other and generate a considerable amount of electrical energy (the best case in terms of water loss reduction and energy generation is respectively 28.1% in leakage reduction and 778 kWh per day in electricity). In addition the payback of the investment for the scenarios analyzed is quite short between 2.5 and 3 years.

Studies in the USA by EPRI [23] have shown that water utilities are a energy intense user. According to EPRI research the 60000 water systems and the 15000 wastewater systems in the USA consume annually about 75 billion kWh, around 3% of the overall electrical energy of the country. It is also predicted at the time of writing (1999) that more energy would be required in order to meet the better standards required for water (additional treatment and purification). The authors of [12] call for a better re-thinking of the water system and management in which the energy and water related aspects must be addressed together. The advice is mainly on promoting water conservation and water recycling which directly reduce the amount of energy required. Each of the stages in the water cycle (shown in Figure 3) requires a certain amount of energy depending on the specific condition of water (e.g., more treatments may be required) and where the water distribution networks is located (e.g., source and users). [12] also remarks that in California 7% of electricity consumption is required by the water system and in the summer it is about the 5% of the peak electricity demand. The State Water Project which delivers water to two third of California's population with reservoirs in the north of the state and users in Southern California too is the largest single user of energy in the state with a usage on average of 5 billions kWh of energy per year. An estimation of the Metropolitan District of Southern California shows that the amount of electricity to deliver water to customers in southern California is about one third compared to the household electric use in that region.

Another research of EPRI [24] shows various projection of water and associated energy consumption in the USA till 2050. It is interesting to notice an increment of 50% in the electricity required for water distribution for public supply reaching 45 billion kWh per year. These are of course projections based on the population growth in the USA and a baseline scenario in which water saving initiatives are not implemented.

Figure 3: Phases in the water life-cycle that require energy. *Source: NRDC [12]*

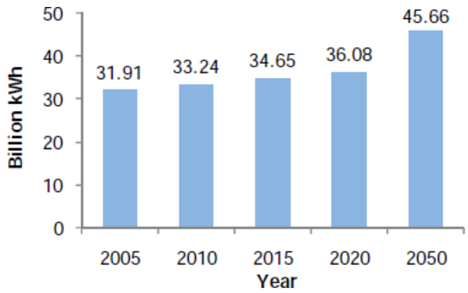

Figure 4: Estimated usage of water. *Source: EPRI [24]*

The situation is represented in Figure 4. It is interesting the result of [28] that shows how the water is consumed in the USA where almost half is used by thermal power plants, those same power plants whose energy is then used to pump and move water to the end users. Figure 5 .

[58] analyzes the situation in Melbourne where Melbourne Water company is among the 15 most energy intensive users in the state of Victoria and among 120 in Australia using about 95 GWh of energy per year whose 47% is just used for pumping water and sewages. Melbourne Water has set challenging targets for its energy requirements (0 Green House Gas emissions by 2018 and 100% renewable sources for its operations). A first step is gaining more efficiency in its operations. After an assessment of the possible options available a simulation phase has been realized. The simulation is based on the ENCOMS (ENergy COst Minimisation System) software whose purpose is to optimize the operational control of pumping systems. Hydraulic modeling is combined with genetic algorithm in

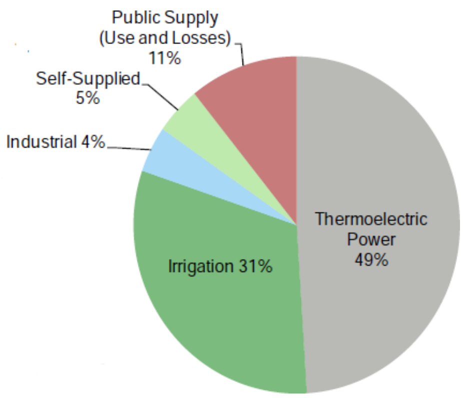

Figure 5: Estimated usage of water. *Source: U.S. Department of the Interior and U.S. Geological Survey [28]*

order to identify the best settings for pumps and valves that maximize efficiency in pumping operations guaranteeing the system safety. The simulations with the goal of achieving an optimal pumping schedule (i.e., real-time adjustment of variable speed pumps in combination with traditional fixed-speed pumps) show obtainable savings around 7-8% in energy usage.

[53] follows these principles in particular defining an optimization problem which wants to minimize the energy cost used for pumping operations (using time of use energy tariffs), find the optimal water storage capacity (cost for reservoir and pumps, and pumping operations i.e., energy). The model created has an objective function (total cost: annual variable and capital cost subject to depreciation) to be solved taking into account several constraints (pump characteristics, min/max volumes in the reservoir, water discharge cannot be more than the values provided by the pumps). The solution of this model are applied to two scenarios: the watering system of an irrigation district and the water distribution system of a fish-farm, both in Spain. In the first scenario the economic savings achieved simulating the optimized system are about 40% and the investment is paid back in about 2 years; with the second scenario the savings are even more impressive: 90% reduction in costs.

In [47] a model for improving the efficiency of a water distribution networks is proposed an tested on a real situation. Basically the model is based on a calibration part which optimizes the location and pressure of the pressure reducing valves for the system using a genetic algorithm optimization approach. Another algorithm also based on genetic algorithm properties optimize two conflicting criteria such as the number of valves to be installed in the system (which have a cost) and the leakages in the system. The model and algorithms are applied to the Italian city of Buja with positive results: more than 40% reduction in water flow supplied and a reduction in energy usage more than 50%.

A control algorithm based on neural network for the simulation of the behavior of the water distribution networks and genetic algorithms to explore the optimal solution in satisfying the objective function is applied to a model of the water distribution networks of Valencia [42]. The optimization is in the operating cost of the water distribution networks which are mainly due to the electrical costs of pumping water in the water treatment facilities while not violating the constraints of the system (min/max level in storage tank, time to reach certain level of storage in tank, maximum power consumption of the pumping stations, pressure to satisfy, minimum flow rate). The neural network is used to represent the behavior of a model realized with the EPANET[3] software (it is commonly used in many other articles), the software representation is slightly simplified compared to reality. An interesting aspect is the substantial difference in operating costs that the two water treatment plants have and that are used to satisfy different needs (one mainly pumps at night as water storage). The control model implemented brings savings of 17.6% in water distribution networks operations (the water system needs a SCADA system to monitor the water status in order to realize the control and actuation proposed). In the framework of the same project (POWADIMA[4]) an analogous approach followed for the simulation of the control of water distribution networks of Valencia is applied to Haifa water network. The approach is analogous: neural network that simulates the behavior of the

[3] `http://www.epa.gov/nrmrl/wswrd/dw/epanet.html`
[4] `http://research.ncl.ac.uk/powadima/index.html`

network (previously simulated on EPANET) and a genetic algorithm to establish the optimal solution for the model in order to satisfy operational constraints (pressure, minimum flow, etc...). The objective is a minimization in the operational costs (costs due to electricity usage for pumping). The pumping stations have electricity contracts whose price for electricity varies hour-by-hour through the day while only a pumping station has a fixed tariff. The benefits achievable with the algorithm proposed are about 25% of the costs; this is anyway achievable if a SCADA monitoring system and the related infrastructure are installed.

SOA and software in water monitoring landscape

In this section it is analyzed what are the Service-Oriented Architecture proposed in the literature in projects of water resource (water distribution system and in a more general sense) monitoring.

[68] presents a high level architecture to monitor water resources based on OPC (OLE for process control) technology. The paper is mainly an explanation of the layers (Data layer, Business layer and Presentation layer) of the OPC and the characteristic of the OPC standard. There are no essential insights related to the specific management of water-related projects or systems. The paper gives very limited added value from a water monitoring perspective.

Yang *et al.* [69] describe a SOA-based architecture realized at Water Resources Agency (WRA) in Taiwan. The aim for WRA is to provide information about the condition of the rivers status related information. The use of SOA is for providing an easy, open and wide access to information and share data to subjects interested in the topic. There is nothing particularly new in the implementation of this platform since the data are not gathered automatically from sensors on the field. The solution is a modular one with a web-based portal interface, a directory service module for service identification, an authentication an authorization module for users access (in addition all information is transferred encrypted therefore a module manages this aspect). A service broker is the core of the information interchange infrastructure module. The creation of new services and integration with other services is managed through BizTalk Server software.

[22] tackles an interesting problem related to the information retrieval and visualization of water-related data. The SOA presented and developed in [22] aims at giving solutions in three subjects: service discovery, data discovery and retrieval and data visualization. This necessity is due to the lack and heterogeneity of the different sources of water-related information to provide standardized information. The architecture is based on 3 components: web service interfaces with service providers, a core component which manages ontology and service matching, and a web portal for the interaction with users' browser. For the web service interfaces several possibilities are implemented given the variety used by the providers: (Web Feature Service, Open Geospacial Consortium, Web Coverage Service). To ease the collection, store and manage of the service an Enhanced Service Catalog has been created based on UDDI. In order to alleviate the semantic heterogeneity issues between data repositories, ontology is employed to provide explicit and machine-understandable conceptualizations of water information and semantically annotate the information content

of web services. Based on the query the user wants a semantic-based service matching is applied to extract the most appropriate service (or set of services) for the query.

The topic of service orientation in water systems is considered in [18]. Compared to [22] where the focus is on creating a service oriented architecture for environmental modeling specifically dedicated to water. **It is not completely in the focus of WIM the type of modeling the authors do since it is more on the hydrological system as environmental scientist consider and not on the infrastructure that is emphasized in WIM, however it might be useful to have a general idea regarding the service-orientation and water-related issues.** Creating a SOA based modeling for water is new according to the authors and it might bring benefits as well as challenges. The authors here too show that the standardization for data exchange related to the water domain is still to come, the situation is even worse in the standardization concerning software oriented architectures and model computation. The two standards that are mostly used such as Web Processing Service and Open Modeling Interface have both strengths and weaknesses. The former lacks any domain specificity and the latter assumes that all model resources are local; a possible solution is a combination of both. The advantages of a SOA approach to environmental modeling (water systems) are the traditional of SOA (loosely coupling, easy deploy, independence from programming language and OS, re-usability), however some disadvantages for environmental modeling arise: performance, reliability and security. The first is due to the amount of data that an environmental model might need to require which might require huge data transfer; reliability deals with the possibility of unavailability of a service since no direct control is possible; security deals with the abuse (i.e., overuse) of a certain service by a user which must be monitored.

[65] describes the main features of a SOA for water-related data and hydrological aspects. As mentioned by [22] there are several sources of hydrological/water information, however there are no standards in their representation and the user cannot access just from one point. To fill this gap Xu *et al.*describe a SOA which has three main goals: 1) integrate several data sources and access them through a single interface, 2) obtain data resources proactively which are customized according user requirements, 3) data are presented to the users automatically without an explicit request. The paper describes a typical SOA-based architecture without much emphasis on water related aspects. The only notable aspects are the use of an ontology to define the domain that enables to access the data information provided by the heterogeneous systems in a standardized way for the user. Other aspect to remark is the proactiveness of the information which are pushed to the user once he has subscribed to the specific content.

Basically in [11] there is not much added value from the point of view of WIM. In fact, the paper describes the implementation of an SOA system in order to achieve application integration in a “virtual enterprise” environment in the South-to-North Water Division Program in China. **The only aspect for WIM is maybe to consider the water management problem as done by several companies (piping company, water treatment, water billing, pipe fixing, etc...) and consider an SOA for the information exchange. Maybe it is just trivial and it is already done.**

[59] proposes a solution for water resources information based on SOA

and grid computing. The author motivates the necessity for such a solution by the need of water information which are essential for today's water conservancy industry. Examples of applications are flood prevention and drought control, water resources management, water environmental monitoring and soil conservation, and other key work fields, there are great application requirements on high-performance computing services, efficient data storage, application service integration. SOA and Grid technology seem, according to the author, the right solution to fulfill the demand of water resources domain. The platform based on SOA is composed by the following elements:

- Representation layer: represents results to users' browser.
- SOA layer: user's request are here processed and combined by a BPEL engine and are then routed to the appropriate basic services.
- Resources layer: provide data resources to upper layers.

In order to benefit of the resources a grid provides the application that needs to be executed must be adapted/built for the grid environment.

[63] describes the implementation of the information system realized to monitor the water treatment system in a petrochemical plant. The paper is really descriptive and provides details about the technologies used i.e., software and PLC controllers to realize a monitoring which is accessible from the web. It is very applied application and there is not much scientific contribution, actually, however it could be used as a reference for building a architecture of the water monitoring system.

[67] describes the implementation of a monitoring water system that is in use at Xi'an Xianyang International Airport. The paper describes the installation realized for the controlling system where two computers are attached to the sensing equipment composed by plurality of ARK4060 / 4017 (monitored parameters are flow rate, pressure and liquid level and switch such as the work frequency, frequency conversion operation and chlorine leakage and collection) modules to which the communication is realized through RS-485 protocol. A graphical interface for the interaction with the user has also been realized. Real-time data is also saved in a SQL Server DB. Since the three sites (2 monitoring stations and a control center) are far from each other at application level the communication exchange is done through TCP/IP stack. As for [63], this paper is more applied and it could be used to take the architecture/infrastructure realized here as a basic example and build a more complex and distributed infrastructure.

[15] presents an high level description of an information system to provide water-related data to interested users (end-users and governmental institutions). The aim of the system is to provide up-to-date information about water resources in order to give the institution valuable information and data on which take decisions. The water resources data management and warehouse system envisioned is composed of a website which enables spatial data to be stored and it is used together with tabular data in a standard database management system, available in response to user needs. In addition to these basic features, users can instantaneously and interactively generate answers to their queries online. The water-related information consist of irrigation schemes, water resources, water disaster monitoring, hydrological data. From an ICT architecture point of view the system is not particularly complex: the core is SQL Server DB and spatial and textual information stored in different DB sources can be easily combined and eventually queried. The importance of the paper is

more on the institutional and communication point of view rather than the technological aspects.

[26] describes a web-service based architecture to provide hydrological information data. **Hydrological data might be far from WIM objects, however the architecture presented is interesting and well described in the paper.** First of all the data provided are those available by NASA in the HDF (Hierarchical Data Format) format that contain lots of data coming from various sensor on board satellites. Data are organized in a database and in order to host the several different type of data formats available for each key-values pairs corresponding to that data format are stored. In addition a sort of ontology for hydrological terms is created, in particular it is a vocabulary which maps terms and descriptions to the specific term used in the dataset. The web service component of the architecture uses first a data discovery web service which receives a hydrological term as input then the user has to specify other parameters (e.g., longitude, latitude, start/end time) for the data retrieval web-service. The author emphasize that web-service in the hydrological landscape are extremely useful when the query is limited to a certain region and time so that the data to be provided are limited; and this is usually the case since hydrologists only need parameters for a specific region to feed their model.

[66] describes a SOA architecture to be used for irrigation purposes. Other than the traditional description of the benefits of SOA the interesting aspect is the possibility of using SOA in such a far field than computer science. Basically the system combines the different services in order to obtain a decision/advice about how to water a certain crop in a certain land. Various parameters and services that deal with granular aspects are considered (soil, weather, temperature). The various services are composed by a BPM logic.

Bunn [7] illustrates the benefits for achieving important savings in energy through a software system (Aquadapt which is a commercial software) that attaches to SCADA systems in order to achieve a real-time solution that automates the water distribution. Basically the software gets the SCADA system on current storage levels, water flows and equipment availability and then creates schedules for treatment plant for raw and finished water flows, pumps and automated valves in the system for the next 48 hours. The claim of the author is that it is extremely fast compared to other solution, although the algorithm is proprietary and not shown. The program is run every half an hour to adapt to changing conditions (primarily demand changes and equipment failure). The steps realized by the system are:

- Initialize any long term settings such as annual water extraction limits.
- Read data from the SCADA system, detect and correct any errors.
- Set the target volumes required in storage to achieve security of supply and turn-over.
- Read any changing third party data such as electricity real time prices.
- Calculate schedules for all pumps and valves.
- Write data to the SCADA system to start pumps or open valves as required.

- Update any analysis such as predicted demand, costs, water production estimates.

Results from implementation show consisten reduction in costs for energy costs 12.5-13% by exploiting the electricity variable tariff mechanism (peak-offpeak). Another installation (at Washington Suburban Sanitary Commission) where this company purchases the electricity on the real time energy market showed savings for a single pumping station up to 1000 $ a day. In order to successfully implement the solution of course integration with the specific monitoring and actuation systems of the water company are required.

Water Resources Monitoring

Monitoring water is an essential aspect for WIM. In this section we look at the approaches that are used in the literature to achieve water monitoring (both open water and water distribution networks are considered).

[51] proposes a monitoring solution for water (in this specific case it is water by a river estuary). The parameters monitored are pH, temperature, conductivity and turbidity. The system is composed by field stations which use FieldPoint technology for electric signal coming from the sensors which have a sample rate of 30s. A pre processing of the data acquired is done at field station where a neural network software system is implemented to correct eventual anomalies in the data. Sampled values are then sent to the base station via a GSM connection (using a RS232 protocol). The land station processes further the data with a software based on the self-organizing maps neural networks (kohonen maps) to identify false/real alarm situations and reconstruct data in case of sensor failures. **For WIM the interesting point might be the architecture used for the measurement, the parameters monitored and the neural network approach used to detect/correct faulty situations.**

The work in [51] is enhanced in [52]: the idea is basically the same however some aspects are improved.

- The sensor can communicate either with a modem to the base station or communicate through WLAN to a gateway station that then sends the data to the base.
- Sampling rate is not constant but varies if the water parameters are far from the “normal” situation.
- The sensor used: GlobalWaterWQ770 for turbidity measurement, ISI OLS50 for conductivity measurement, ISI-11 for pH measurement, and a Pt1000 for temperature measurement.
- FieldPoint bus is used for communication to a primary processing and communication control unit (FP2000) that performs embedded measurement, data logging, and communication tasks.

To have an idea about the developed software on field station and inland station, they are mainly developed using LabVIEW 6.1 and LabVIEW Real Time. MATLAB 6.0 modules for offline MLP-NN design and optimization were implemented using the Neural Network toolbox of Matlab. The field station also include signaling blocks associated to pollution events and faulty operation detection. For that purpose, a comparison is made between the current TU, pH, C, and T measured values and the historical values (last 2 h) of the measured values and the water quality parameter limits for the monitored area (authorities define these values). The processing of data at the base station is done in order to reduce the water quality measures to a concise set of information that are representative for the conditions of the monitored area. Kohonen maps are neural networks widely used in both data analysis and vector quantization because they compress the information while preserving the most important topological and metric relationship of the primary data and also for their abstraction capabilities.

[62] consider the problem of optimal monitoring of water quality in water distribution network. Monitoring and predicting hazard is essential for public health and for the business of water utilities. The paper aims at finding an approach to optimize online water quality monitoring points. It is not feasible to monitor all pipes in a network, therefore the problem is to choose which are the points that are vital to be monitored. The paper individuates 3 categories of monitoring points **(a similar approach could be used in WIM)**:

- monitoring of water at the output of treatments plants
- monitoring at easy deteriorated areas (e.g., at boundaries, at terminal of water distribution, high corrosion pipes)
- monitoring at representative points where water characteristic should reflect the overall water quality

The authors claim that the most interesting parameters to be monitored are Turbidity and Chlorine concentration (however other params Ph, conductivity, temperature may be assessed as well). The method proposed to monitor the nodes uses the water age index of a node that is computed by assessing the water age of a node and the attributes of the pipe are translated to water age. The paper gives the details of the algorithm to sect the nodes. This approach has been applied to a real water distribution system in china covering 4320 km, with 12 main pipes, 6860 pipes, 5397 nodes, 1464 loops. For this network 35 monitoring points have been selected. Sensor used on the field test HACH 1720 series Turbidity Monitoring Instrument and for residual chlorine measuring equipments HACH CL17 and 1870E.

[40] presents a study of a wireless sensor network to monitor water leaks in pipes. The core of the paper is on the determination of the type of channel that a communication below-ground to above-ground has. It is mainly a telco paper investigating the properties of the channel than an IT paper since the very physical aspects are investigated.

[8] describes a method and sensor equipment to locate leakages in pipes. The method is based on the negative pressure wave method propagation. According to this method evaluating the time interval between the drop in the pressure of the head pumping system and the change in the pressure towards a new steady state in a monitored pipe. By knowing the speed of the fluid, density, temperature etc... and the time difference between the pressure drop at the two sites it is possible to locate where the leakage is. The unit that is to be used for the sensing and monitoring is described and has a GSM/GPRS interface to send its sensed data to the base station.

[20] proposes an architecture to automatically monitor and alert parameters of water (in the specific case pond of aquaculture systems). The parameters monitored are:

- temperature

- pH
- dissolved oxigen

The architecture consists of acquisition subsystem: sensors and acquisition system (analog to digital conversion); telemetry subsystem: a GSM/GPRS modem; data processing contains a DB where telemetry data (SMS) are stored; a knowledge base where quality levels for inference purpose are stored; inference component that determine the quality of the water. A last subsystem is the output one which has the task of visualizing and/or alerting the liable person.

[70] proposes a multi agent system to realize water monitoring. The author says that agent systems are not used for water systems (so far indeed this is the only one that mentions agents). The solution proposed is only on paper and there is no evaluation. The structure of the overall system and the agents proposed is basically hierarchical. The water system is composed by a monitoring subsystem and a inquiry-pay subsystem. Several agents are proposed with different roles of monitoring (water pressure, and quality parameters), coordinating and accounting and billing the customer. In water management landscape it is interesting the idea of agents which is not much used in this field yet; another interesting aspect is the interaction with the customer with an agent that is responsible of billing and monitoring water consumption on behalf of the customer (raise awareness of usage is the first step of consumption reduction as proved by electrical Smart Grid initiatives [50]).

[4] is a very applied paper where a new monitoring solution for a river estuary is described in details. Interesting is the precise definition of the requirements and needs for an improved monitoring system (before monitor was done manually once a week, data were recorded manually and than passed to other organization to be published on the web, part of the tests on the water were outsourced to local college) since the previous was not efficient and not real time. So based on a set of requirements (data every 15 mins, more analysis to be done such as pH, salinity, phosphorous, nitrogen, automated analysis and data on the web) a set of sensor and communication alternatives are evaluated. In addition, from the initial data obtained a correlation analysis is performed to suggest the optimal sampling point.

[14] describes a system (very high level description and a bit chaotic) that combines GIS extracted information (e.g., high resolution pictures and spatial information) and remote sensing data for an emergency quality water monitoring system. The only nice thing is the combination of the two techniques that consider GIS, so high level information, and local remote monitoring. This approach is mainly applied to sources of drinking water (lakes, basins etc).

[25] describes how to realize a Wireless Sensor Network (wireless sensor network) in order to monitor the quality of water. The system is composed of 3 elements:

- Sensor node: it is a custom created device that can host multiple types of sensors (temperature, salinity, dissolved oxigen) a control and communication module which obtains the data from the sensors and deals with wireless communication (zigbee based), a power supply.
- Sink node: acts as coordinator for a set of sensor nodes, it also acts as getaway for the data (it has both zigbee and 3G interface to communicate with land station).

- Data monitoring center: it stores the data coming from the sink nodes and has 3G modem connectivity. It can display real-time data and also performs historical queries.

In [9] considers water analysis on images obtained from satellites. Various techniques are applied from patter recognition to filtering, gray analysis.

[48] describes a system architecture to realize distributed and automatic water control. The claim is (as other papers explain) that usually water monitoring, especially near near factories and industrial complexes is done manually by sampling, then bringing samples to labs, which is time consuming and far from being real time. The overall system is composed by:

- Substations which realize the measurements and send the data to the main station. In addition to substations, mobile station for specific analysis are proposed and envisioned.
- Main station is where data is aggregated
- Management station receives the data from the main station. (Management station is a public department which is responsible for water-related parameters management.)

Details about the hardware equipment used are provided. Importance is in the more scientific type of data obtained with this solution, more frequent data, easy scalable solution to monitor more locations. The author claims that this solution is monitoring at the moment 37 locations.

[45] presents and interesting framework for water pipe monitoring taking into account water demand patterns (very high level) and water quality parameters. The system proposes the idea of RFID sensors in the pipes that communictes to an access point which then transfer them to the data server. The framework is composed by 6 tiers:

- Sensing tier: continuous monitor of pipe system and also provisioning of location.
- Processing tier: data cleansing.
- Modeling tier: data are fed in an Hidden Markov Model which is used to compute demand patter prediction and water contamination speed.
- Decision fusion tier: decision are made according to the learning process that is in place in the system.
- Human tier: human are present in the feedback and can overtake the decision of the system; the human decision is also used as a part of the learning process of the system.
- Actuator tier: valves and pump (either automatic or manual) are used to stop flows isolate sections etc

The system is based upon the concept of multi agent system where each element in the system is modeled by an agent. To evaluate the future pattern of water demand, quality and contamination a Hidden Markov Model with Bayesian Inference is used. No field results are given and it is specifically stated that the Markov Model is not fed (at the moment) with real data. It is interesting the future work they want to implement: enhance the system with administrative functions and map service for the normal user.

[64] It only describes how 3G technology can be beneficial in the water management issues.

[2] describes a wireless sensor network infrastructure to monitor pressure in pipes in the city of Mashhad (Iran). It is an architecture composed of sensor devices (CPS181 from Sense Instruments) which is attached to a zigbee wireless module. Zigbee technology is used to exchange data from the sensing unit to the coordination unit, which is basically a gateway that then routes the data to the control center using GPRS communication. The system of sensor and coordinators have been designed with the aim of power consumption minimization (data are sent every 15 minutes and the remaining time the devices are in sleep mode). Data are then saved in a DB at the control center. The infrastructure has proved reliable in the measurements in the field test.

[19] presents the architecture of a SCADA system to control water distribution system. The various components are described both for monitoring and actuation. They emphasize the possibility of using OPC satndard to eneable the communication between different devices of different producers (e.g., PLC, SCADA). Once again the communication system used between the SCADA station and the monitoring/actuating stations is done via GSM/GPRS.

[73] is a low level description in the design of the components and architecture for creating a zigbee based data exchange solution. The only aspect considered is the communication and no information are actually given to the water monitoring aspects.

[56] describes an architecture for water management, mainly urban waste water. The architecture has been realized on the field in Valencia in real production situation. The architecture is interesting since it combines different types of measuring stations with sensors and different communication technology inside. The stations are:

- Environmental Control Stations: a fixed permanent stations which can push messages, be interrogated and report alarms.
- Mobile units: these are temporary units that can be deployed in places where permanent stations cannot be built or when necessary (period of the year more subject to flooding). Time marking and georeference are important for these stations; they also have cameras to provide visual inspection inside/outside station.
- Quick deployment sensor network: it is a network that uses sensors that communicates through zigbee technology and a gateway interfaces to the central station.

Central control station has a Web server, a Database server and a firewall, as well as communications equipment necessary to interface the public network for external users and the private network that interconnects the stations via IP. In the equipment which houses the Control Station, the OPC Server (Ole for Process Control) is to manage the connections with remote stations. Important aspects of the paper are the motivations and benefits achieved: from a manual data collection done once a month time consuming, the solution is automated and with real-time data (every 5 min.) which might give real benefits in critical conditions/situation.

[3] describes an expert system to monitor water status of a river. The system is based on a continuous sensing of information and application of the rules based on expert knowledge (embedded in the system) and a fuzzy-style algorithm to evaluate the probability of critical situations. The sensed parameters in this context are pH, conductivity, turbidity,

ammonium concentration and dissolved oxygen (DO) concentration. As information for the expert, as a sort of calibration of the system, parameters coming from critical situations have been used. The output of the system provides level of risk for: urban discharge, euthropication and fish risk. Motivation of the work is always the same: the deployment of the stations with the Automated Information Water Quality System allows to obtain automated and continuous information from the state of rivers. Automated information is different from those usually collected through manual measurements. Unlike the latter, which are timely and accurate measures, the automated ones present the advantages of immediacy and continuity. However, this solution involves the management of large quantities of records spread across multiple variables that are supposed to be less precise.

[41] describes an interesting method to individuate which nodes in a water distribution networks to be monitored in order to minimize the amount of sensor/equipment but still have the maximal significance in the amount of water monitored. The method is an extension of the Demand Coverage called Demand Coverage Index (DCI) which takes into account the variability of demand during time (DC method assumes the demand constant). To find the optimal solution the maximal DCI is searched by using a genetic algorithm.

[10] is mainly a description of the undergoing projects and the objectives to be obtained rather than a set of results and applied practices (the projects are ongoing). The idea is to use wireless sensor network with several type of sensors to monitor various parameters of the water distribution networks (e.g., soil moisture, water flow, pressure, noise detector) all attached to wireless sensor network device that then transmits the data to a gateway and then to a base station. The proposed system wants to achieve all the following (in my opinion it is a bit ambitious):

- Wireless sensors for the collection of operating network parameters (pressure, flow, humidity, noise).
- Data on system characteristics (such as pipe diameter, length, material, installation date, zoning, etc.).
- Historical data on pipe break incidents (date of incident, response time and cost to repair/replace, number of previously observed breaks, reason for and classification of break incident, etc.).
- A statistical analysis tool for the analysis of pipe break incidents.
- An artificial neural network component for data pattern identification.
- A fuzzy logic processor, for the development of fuzzy logic rules describing the behavior of the network.
- A risk assessment module (primarily a survival analysis module).
- A geographical information system (GIS) for visualization.
- A life cycle costing module for the aggregation of costs by area and pipe.
- A prioritization-of-work module.
- A data query and reporting system for the retrieval of needed information.

Demand-Supply management

Control problem is usually associated with water losses and energy reduction, other relevant papers that present valuable solution applied to these aspects are in the related sections. This section contains the main findings about the literature studies related to the demand-supply satisfaction of a water distribution networks. It is mainly a control theory problem which has to consider the network and its state and identify which control to apply to satisfy the goal of cost minimization and at the same time avoid the violation of operational constraints.

In [54] a control process for water distribution networks is described and the results are shown. Novelty of the approach is the application of neural networks in the model representation of the operation of the water distribution networks and a genetic algorithm to identify the optimal (near-optimal) solution for the model. These two techniques (NN and GA) have been applied usually in the design of networks but not for control purposes the author states. The objective function used aims at minimizing the energy costs of the system operation; in an extension it could also take into account the cost of a specific source of water (i.e., costs of water treatment). Initially the control algorithm is applied to a 24-h schedule then also to a 1-h (near-real time) schedule. The water distribution networks in which it is applied is a small synthetic network.

In [27] a control problem is created considering the need to balance water demand and supply. This problem is more on a higher time scale than the control problems of the water distribution networks , in fact here the key is the availability of water resources in environments where population and urbanization grow (the example is China). The paper is quite mathematically complex and mainly with a control theory/system theory approach. The same authors in [39] propose a different control approach (robust control) to the same problem of long term water supply given an increasing demand in order to foresee the type of investment necessary.

Leirens *et al.* [38] present a control algorithm to control urban water distribution networks by using a coordination mechanism between local controllers. The issue the authors mention is that a complete central control of all the elements in the system is not tractable, and, at the same time, autonomous local decisions if not coordinated are not satisfactory. The paper uses the theory of model predictive control and applies it to the water distribution networks of Bogota (Colombia) for simulation purposes. Actually a small section of the water network is used which is then further divided into 3 sub-networks which are used with the control algorithm. The interesting aspect is that in each sub-network the controllers compute the optimal control parameters and then they exchange the sequence of input and output variables influencing the neighboring network. Simulation results show that if controllers operate alone they do not choose the best actions when changes in water demand appear (resulting in poor performance and economic losses due to dissatisfaction of required functional quality limits); on the other hand the coordinated mechanism allows a working mechanism that stays in the quality limits imposed.

The concept of multi agent systems is developed in [44] in the area of realizing a decision support system related to transportation networks (e.g., gas/fuel transportation, water). Decision are made from the contribution of various interacting agents who have the common goal (e.g., minimize transportation cost). The aspects related to the decision of control on the pressure of the pipes is given to a control module uses a team of controller agents one using a fuzzy-based controller and a PID controller.

A side problem of the water distribution networks is the forecast of water demand. This problem is tackled in [6] that consider the increase in water demand due to the expected population expansion of a suburb of Ottawa. The analysis performed is a short term analysis to determine the peak water demand (they only use summer water demand data) and investigates the most suitable model to estimate future water requests. Basically the paper compares various statistical techniques (regression, time series, neural networks) to find the best model that is able to predict water demand. The model that provides the best result is based on the usage of neural networks.

The problem of leakage reduction through appropriate control is investigated in [46]. The water distribution networks that is considered and that is simulated is a part of the network of Theran (Iran). The study gives a good overview of the literature on the theme of leakage reduction and approaches to optimization of water distribution networks . The work then concentrates in developing a pressure reduction solution based on an artificial neural network (ANN) to simulate the water distribution networks (the ANN is trained on the EPANET software simulator). To compute the optimal parameters for the storage tank that supply the area and influences the pressure reduction a genetic algorithm approach is used. Applying the algorithm presented can provide an yearly average saving in leakages about 30%.

Demand side management of water can be interpreted not only from a technological/control point of view, but it can also be seen as an instrument that policy makers may use to reduce water usage. In [55] instruments for policy makers to manage situations of droughts are considered and an econometric model is derived in order to capture the essence of the policy applied. The policy applied are: water price increase, water capping, water saving technology introduction. The paper might bring to the raise of the following questions: is there a possibility for demand-response in water management as electricity in the Smart Grid? Usage patterns are different in winter/summer due to irrigation purposes. For prices, could they be as volatile as the ones of electricity? In water management the the system balancing problem that is key for electricity (i.e., difficult to store) since water can be easily stored.

In [17] the benefits of pressure management system in water distribution networks are assessed and presented. A model is created to estimate the losses during a traditional condition (i.e., no implementation of pressure management) and the situation is compared with a solution that involves pressure management. The method used in the paper to assess the water losses, follows rules provided by international best practices (e.g., Minimum Night Flow, Bursts and Background Estimates [33] and Fixed and Variable Area Discharges [43]). These best practices are applied in creating the model and running simulations with a software. Two case studies are considered: a small water distribution networks with just 10 nodes and a 6.5 km length of pipes, and a bigger network with more than 100 nodes and 9.2 km length. Reduction of losses is accounted about 8%, in addition there is also a side effect of billed water which decreases to 0.83%. In addition, the different benefits achievable are shown taking into account the elevation of the water reservoir that plays a role: the less is the elevation the smaller the benefits achievable.

Water infrastructure analysis and design

Another important topic in the water distribution networks is analysis and design. It is essential to understand how a water distribution networks system has been realized, which are its properties and vulnerabilities in order to improve it or to design a new water distribution networks that is optimal. The analytical study of how to design a water distribution networks are not new and lots of literature is available on the topic. Here with the aim of giving a general idea of the state of the art for WIM project we provide some works. In a later stage of the project if the design and analysis topics want to be taken into account a more sound reseach of additonal works should be done.

In [1] a design method to realize a water distribution networks is described using the Linear Programming Gradient. First a simplified version of the method (using only linear programming) is applied in a simple condition that is without considering valves and pumps, then a generalization is applied to have a more comprehensive solution. This method enables to find all the parameters and sizing of the system (pipes diameters, pump capacities, valve location, reservoir elevation) in order to satisfy constraints of the system. The solution found is applied to a real infrastructure installation and the solution found is close to being optimal.

The same problem approached in [1] is tackled in [13]. The objective is the same: find the lengths of pipes, diameter and flows that are necessary to build a water distribution networks given the constraints in of number of possible loops, the loss of energy in the system (it translated in a pressure reduction), distances between points of distribution of water. The authors approach the problem that is non linear and non-convex by a dual formulation of the problem (using Lagrangian duality) which brings to an equivalent linear problem. The algorithm implemented is able to reach a sub-optimal solution within a tolerance to the optimal one. The resolution claims also to be fast compared to the previous design methods.

A Complex Network Analysis approach to water distribution networks is presented in [72, 71]. The structural properties of 3 samples of water distribution networks are analyzed and typical measures/metrics of Complex Network Analysis are evaluated. The structure of the networks is planar and quite sparse, there are no hubs. Robustness and vulnerability are also assessed.

A different approach to water distribution networks design is proposed in [21] where the emphasis is put on the flexibility of the water system. The idea of the work is to design a system that is able to adapt to the changes in water demand given different scenarios of population growth. The problem is reduced to an optimization problem with constraints on water quantity to provide, and pressure to be guaranteed. The optimization parameters are found through a genetic algorithm. The life-cycle cost savings in the flexible solution compared to a rigid one are 9%.

[61] proposes a method to assess the risk of break of pipes based on a Discriminant Analysis Classification (DAC). In extreme synthesis the DAC method classifies the pipes into two groups (failures/successes), based on simple variables (pipe/network characteristics) and dimensionless joint ones. The method has proved successful in the assessment of oil and gas pipes, while the water case is more tricky, mainly due to the absence of properly recorded data. Some adjustments to data and additional variables had to be included in the water scenario. The result of the study with DAC method showed that the most important parameters that

influence the risk of a pipe are (ranked in a descending order): previous failures; diameter; DIM2 (DIM2 expresses the dimensionless proportion of a pipe's length over its diameter); pressure; length; age; material; soil; load; and DIM1 (DIM1 expresses a dimensionless operational safety coefficient for a pipe concerning its operational pressure and its grade).

In [57] the expansion of a water distribution networks is considered and a simple model based on matter (i.e., water) and energy conservation is provided. The aim is to find the optimal control alternatives to minimize the impact of connecting new water sources to the existing distribution system with the constraints of ensuring safe water supply, energy-saving operation and cost-effective system expansion. The paper lacks a formal definition of constraints and it also states that to find the best solution to the problem a genetic algorithm is applied, however there is no explanation of it.

An approach in identifying the most flexible configuration for a water distribution networks is analyzed in [49]. By flexible configuration the author means a configuration of the network (a directed graph) that is able to satisfy conservation laws (mass and energy) and deliver water to the nodes (here they model customers) even when a link (pipe or valves) fail. The method developed takes a measure called Frequency Connectivity Diagraph (similar to the concept of betweenness) and from this a Flexibility Score is provided. The computation intensive method (i.e., considering all diagraphs) is not efficient for big graphs while another approach using a genetic algorithm is more suitable even if not guaranteeing the reach of the optimal solution (sub-optimal is found).

General Remarks

In this section some general aspects and remarks are highlighted that need to be clarified for our project proposal.

- Almost every work on control of planning of water distribution networks refers to the usage of genetic algorithms to find sub optimal solutions. It seems a proven and well explored approach.
- Many papers use neural networks to simulate the behavior of the network once trained with the input/output of a real hydraulic simulator.
- The simulator of the hydraulic systems that every work uses is EPANET.
- Wireless sensor network seems the right solution to realize a remote monitoring of water (open or water distribution networks). We might use the same approach.
- SOA in the water domain seems more concentrated in the integration of several/different hydrological data sources and less attention is given to the architectures for water distribution networks monitoring.
- Monitoring is almost always done, actuation is done at level of pumps and valves through PLC or OPC interfaces. It could be interesting to perform actuation on other devices for instance those that control the quality of water (pH, turbidity, etc.) by adding chemical additives. We might ask our industrial/utility partner if this is already done and how.

- One aspect that might be worth investigating is a agent oriented architecture which is not much used. An aspect that could be considered is the interaction with the consumer through a specific agent for billing and consumption monitoring (usually increasing awareness on consumption brings a reduction in the usage of the resource, examples are available in the electricity domain [50]).
- It is essential to understand what type of monitoring our partner do since that could be the right motivation to provide a more advanced ICT infrastructure for the monitoring. Many paper state that monitoring is usually done in old-fashioned way through manual sampling and analysis and manual data handling. If our partner has already an advanced infrastructure for measurement, how could we justify another ICT infrastructure?
- Usually in the water distribution networks domain there are considered: design and operations.
- An interaction between the water domain and the Smart Grid domain could be interesting.

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