Asset management, water quality and leakage control of small water systems: the case of Nicosia Cyprus

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Abstract

Small to medium water systems (SWS) typically do not have the capacity, financial resources, or specialized personnel to effectively address problems related to water quality, asset management, and the implementation of a comprehensive leakage control policy. This case study, aims to examine the procedures and practices of a typical SWS which took a proactive approach with relatively positive results in the time frame of the last 10 years. Specifically, the actions followed by the Water Board of Nicosia (WBN), Cyprus will be examined, as well as future planning to improve even further the good management practices of the island's largest public water utility. To ensure water quality in accordance with the requirements of Cypriot and EU laws, each year a large number of microbiological and chemical analyses are conducted by the State laboratory and an accredited private one. Since the early 1990s, a comprehensive leakage control policy was gradually implemented by the Water Board of Nicosia which consisted primarily of water district and zoning optimization, pressure control, step testing, and the methods of leak noise correlation and acoustic logging. The resulted benefits include, but not limited to, increase revenue, better water quality and customer service.

Keywords

Small water system, asset management, water quality, leakage control, management information systems.

INTRODUCTION

Water shortages are being experienced in virtually every corner of the globe. The problems are usually attributed to climate change, natural droughts, poor infrastructure maintenance, population growth, lack of funding, lack of experienced management and many more. A recent article in IWA clearly states that minimization of loses in distribution networks is as critical as protection of surface waters used as drinking water resources (1).

Cyprus is the third largest island in the Mediterranean Sea, with an area of 9,251 sq. km. Like other countries in the Mediterranean region, Cyprus has a semi-arid climate and limited water resources. Water is by far the most precious resource in Cyprus. The quality of life and almost all economic activities depend upon the presence of an economic water supply (2). The present water situation is not sustainable in spite of the impressive development of the conventional surface water sources in the last four decades. Much has been done but still a lot remains to be done in the realm of water resources development and management.

Nowadays, effectively integrating water management functions such as asset management, water quality, and leakage control on a sustained basis in small water systems requires the application of specialized management information systems (MIS), where a single department handles all the technical functions (including planning, operations, customer services, and management). Such a requirement, if addressed properly, can result in improved customer services/protection and in more efficient and dynamic operational systems that enhance the effectiveness of the water monitoring programmes and the overall efficiency of the organisation. Addressing water management problems in such a manner requires interventions in three areas in the SWS that can be best summarised as follows:

-IT Solutions: The implementation of IT systems with emphasis on the integration with existing IT infrastructure in Distribution Management, Laboratory Management, Maintenance Management, Customer Services, Rehabilitation Planning and Management Reporting.
-Data Quality: all the methodologies of quality assurance and quality control (QA/QC) for sampling and subsequent laboratory and data analysis.
-Institutional Strengthening activities with emphasis on Problem Analysis, Priorities for Change, Business Processes, Training and Action Plans formulation and their implementation (3-4).

Such solutions with attention to the effectiveness and the practical problems experienced within the core business processes of an SWS, such is the Water Board of Nicosia, which is the largest public water utility company on the island of Cyprus. Today the installed domestic water meters are approximately 125,000. Based on the above, this study also aims to address problems related to water quality, asset management, and implementation of a comprehensive leakage control policy, based on the analysis of data collected and the systems implemented by WBN the past decade.

MATERIAL AND METHODS

The Utility's main business processes can conveniently be grouped into a number of management processes such as commercial management, water quality management, technical services, and production. The MIS should cover the commercial, technical and planning functions of the Utility, and seamlessly integrate with SCADA, GIS, LIMS and ERP to provide a coherent enterprise system solution for the modern Utility.

WBN is in the process of implementing some such systems and methodologies that are not yet used today. For the daily operation of the storage reservoirs and the water distribution network (both bulk and area/zone supply) a constant flow of data from the SCADA system, which include among others, pressure, quantity, reservoir water level, and free chlorine. Additionally, the existing telemetry system provides management decision tools such as pre-set alarms, remote operation of key sluice valves, and comparison trends with pre-selected historic data (5).

WBN also conducts monthly, additional to the legal requirements, extensive sampling and testing of the water quality in the entire distribution system. The collected samples are analysed at an independent and accredited private laboratory. The analyses include measurements of pH, conductivity, ammonium, nitrites, aluminium, coliforms, *E. coli*, enterococcus, *pseudomonas aeruginosa*, total bacterial number, and *clostridium perfingens*.

RESULTS AND DISCUSSION

Water quality of distribution system

WBN is responsible for the distribution of water received in bulk primarily from the Water Development Department (WDD) of the Government of Cyprus which is stored in twelve water reservoirs in the Greater Nicosia Area prior to gravitational distribution. The water received is a mixture of water produced at the Tersefanou water treatment facility (Larnaca district) and the seawater reverse osmosis (SWRO) desalination plant in the same area. The percentage of each water type (treated surface water from the Tersefanou plant and desalinated seawater) varies throughout the year based on water availability at the various dams and reservoirs connected to the Southern Conveyor Project, which provides the main bulk supply of surface water on the island. Though both types of water are thoroughly tested by WDD to meet the requirements of Cypriot legislation and relevant regulations related to water quality control intended for human consumption {N87 (I) 2001, N 275 (I) 2004}, WBN is required to monitor and test the water quality within the distribution system (6-7). Therefore, the Public Health Services of Nicosia collect every month samples within the distribution system and have them analysed by the State General Laboratory. WBN, in order to further insure water quality, conducts additional monthly checks to the requirements of Cypriot legislation {N87 (I) 2001, N 275 (I) 2004}, in an independent accredited private laboratory (6-7). Figure 1 depicts all the additional sampling points of WBN in the Greater Nicosia Area. All these checks have assisted in providing better services to WBN's clients and reduce the number of customer complaints. The analyses include monitoring of chemical (pH, conductivity, ammonium, nitrites, and aluminium) and microbiological (coliforms, E. coli, enterococcus, pseudomonas aeruginosa, total bacterial number, and clostridium perfingens) properties of the water (Table 1). Based on Cypriot legislation, for the microbiological analysis, WBN is only required to take in consideration the counts of *E. coli*, and enterococcus.

Table 1: Allowable limits of the parameters monitored by WBN based on Cypriot legislation on water indented for human consumption {N87 (I) 2001, N 275 (I) 2004} (6-7).

Parameter	**Allowable Limit**	**Notes**
Aluminium	200 μg/L	Monitor if it is used as a coagulant
Ammonium	0,50 μg/L	
Nitrites	200 μg/L	
Conductivity	2500 μS cm^4 at 20° C	Water should not be corrosive
pH	6,5 < pH < 9,5	Water should not be corrosive
		Sparkling water can have be equal to the lower limit
Coliforms	0/100 mL	For bottled water 0/250mL
E. coli	0/100mL	For bottled water 0/250mL
enterococcus	0/100mL	For bottled water 0/250mL
pseudomonas aeruginosa	0/250 mL	Valid for bottled water
total bacterial number	100mL &20mL	22◦C & 37◦C, respectively
clostridium perfingens	0/100mL	Including spores, monitored when the source water is surface water

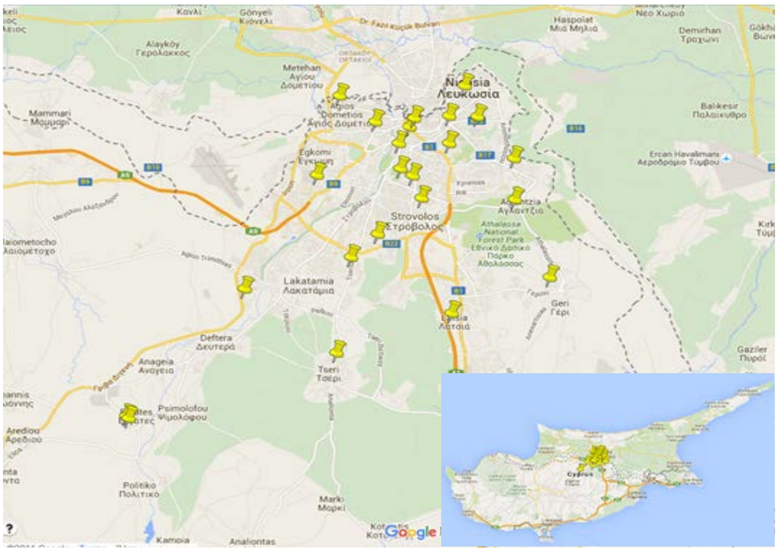

Figure 1: Sampling points of WBN distribution network

The results obtained from both the State General Laboratory and the private accredited laboratory are recorded into tables indicating the number of deviations of all the tested parameters from the allowable limits. The percentage of deviation from the norm is calculated by taking into consideration only the parameters that Cypriot legislation requires. The remaining microbiological analysis are kept for monitoring purposes and if persevere the remaining competent authorities are notified. Figure 2, gives an overview of the deviations from the allowable limits for both chemical and microbiological parameters for the years 2010 until 2015. For example, in the year 2014 the total microbiological analyses conducted were 524 of which 7 (1.3%) were not complainant, while for the additional 214 chemical analyses performed, 18 (8.4%) were not complainant. In general, the discrepancies observed for both the chemical and the microbiological analysis are relatively low and are limited below 9% annually. Microbiological contamination is attributed to aged pipelines, not adequate water circulation due to dead ends, frequent water cuts (especially during the summer months).

An interesting trend was observed for the chemical parameters. All the discrepancies from the allowable limits were caused by elevated levels of aluminum (Al^{+3}). The latter one is used as a coagulant in water treatment trains for the eliminating the surface charge of small diameter suspended particles and accelerate their settling velocity (hence removal) (8). It is commonly used in the form of a salt aluminum sulfate ($Al_2(SO_4)_3.14H_2O$) also known as alum. Its dissolution releases positively charged substances (i.e., $Al(OH)^{2+}$) that eliminate the negative charge of the suspended particles, which in turn create bigger flogs and precipitate. Overdosing with alum, changes in the water pH (acidic), and insufficient removal of the “cake” layer in the sedimentation tanks may cause release and increase of the soluble concentration of aluminum (Al^{+3}) in the water higher than the allowable limit. Overall, the actual values of Al^{+3} in the tested water did not exceeded the allowable limit of 200 μg/L by more than 25%, though specific areas had values as high as 700 μg/L. Subsequent sampling events indicated that those extreme values did not persevered. Surface waters in Cyprus do not have a high natural content in Al^{+3}, since the water is slightly basic pH and clay soils usually have small pores which prohibit water percolation.

Therefore, its source can only be located to the treatment that it undergoes. As mentioned earlier, the distributed water in the district of Nicosia is a mixture of surface treated water and desalinated water with varying ratios. These varying water-type ratios, maybe the reason why the discrepancies' are not observed every month (Figure 3A&B). Year 2013-2014 had the highest number of Al^{+3} deviations and the following year there was a significant drop, whereas no Al^{+3} deviations have been recorded for the year 2016. A possible explanation can be the recent decision of WDD to switched from the aluminum salt to an aluminum copolymer that inhibits the release of free Al^{+3} into the water. The lack of an automated system to measure aluminum online and the time lapse between additional testing by WBN and water residence time in the network, is the reason why the Al^{+3} deviations went on for so long. It becomes apparent that the need for automated control of the water quality is great and research activities should focus on sensors measuring residuals of frequently used in the water industry chemicals.

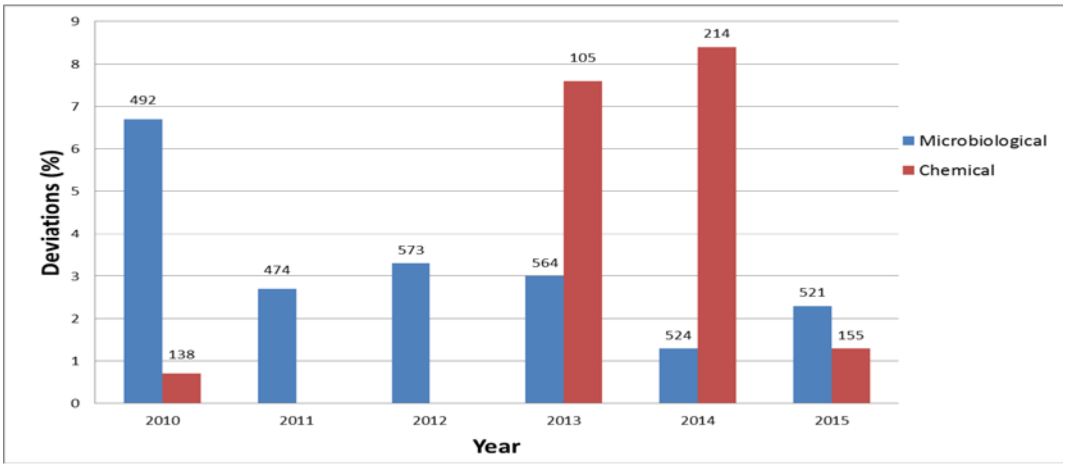

Figure 2: Annual chemical (red) and microbiological (blue) discrepancies for the years 2010-2015. (Numbers on the top of columns indicate the total number of samples analyzed that specific year)

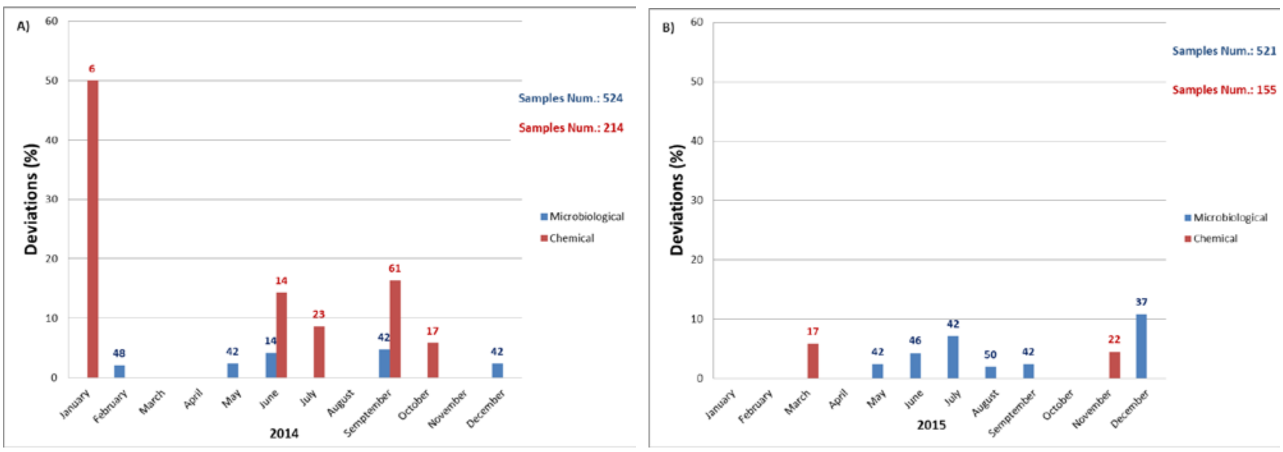

Figure 3A&B: Monthly chemical (red) and microbiological (blue) discrepancies for the years 2014 (A) and 2015 (B). (Numbers on the top of columns indicate the total number of samples analyzed that specific month)

Leakage Control Strategy

Water Loss or Non-Revenue Water (NRW) represents inefficiency in water delivery and measurement operations in transmission and distribution networks and, for some systems, can amount to a sizeable proportion of total water production. In Nicosia, the capital city of the Mediterranean island nation of Cyprus, that proportion reached as high as 30% at certain times. The Water Losses for a whole system or for a partial system are calculated as the difference of systems input volume and authorized consumption. The water losses consist of Real (physical losses of leaks, bursts and overflows) and Apparent Losses (meter inaccuracies and unauthorized consumption) (9).

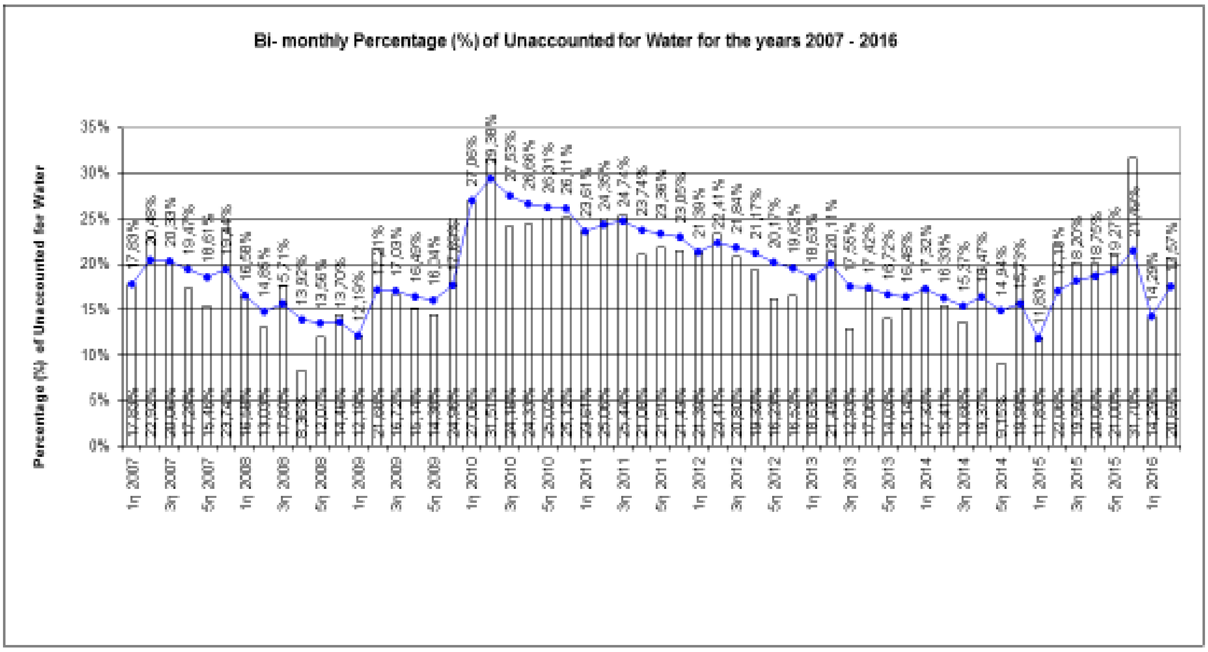

Figure 4: Non-Revenue Water (NRW) expressed as (%) of total quantity distributed in Nicosia, Cyprus from 2007 until 2016 (the blue colored line indicates the year average).

In all water utilities, whether water resources are cheap or expensive, scarce or plentiful, the reduction of NRW and minimization of leakage is currently a key issue. Water Loss is one of the major topics in management of water supply systems, this is largely because diminishing water resources means it is more important to reduce losses of the existing quantities of treated water that are put into transmission and distribution networks.

An acceptable level of NRW depends mainly on two parameters the “economics” and the “availability of raw water”. The reduction of NRW can only be achieved when both physical and commercial water losses are reduced in a systematic way. In many systems it will be more economic to start with measures for the reduction of commercial losses such as customer meter under-registration, as this has a direct impact on utility cash-flow.

The Water Board of Nicosia is a public utility company formed in 1953 and its role is to supply potable water in good quality and in sufficient quantity to the citizens of the Greater Nicosia Area (more than 350.000 inhabitants). The water distribution network covers an area of more than 91 Km^2 and exceeding in length 1,240 km of water mains. Nearly 23, 8 million m^3 of water annually are distributed to approximately 125,000 customer connections. The average daily consumption per inhabitant in recent years is 115 L. As previously mentioned, the required water quantity is received in bulk primarily from WDD and it is conveyed in 12 water reservoirs with total capacity 74.600 m^3. The water is supplied to the consumers mainly by gravity. The WBN operates a SCADA (Supervisory Control and Data Acquisition) system consisting of 53 electronic telemetry stations placed in various points in the water distribution network and in all water reservoirs. From these stations data is continuously collected regarding the flow and pressure of water in the network. From the reservoirs, data is collected regarding the inflow and outflow of water, chlorination, and the level of water. Key valves at major reservoirs and throughout the water districts are operated remotely, by strictly authorized personnel.

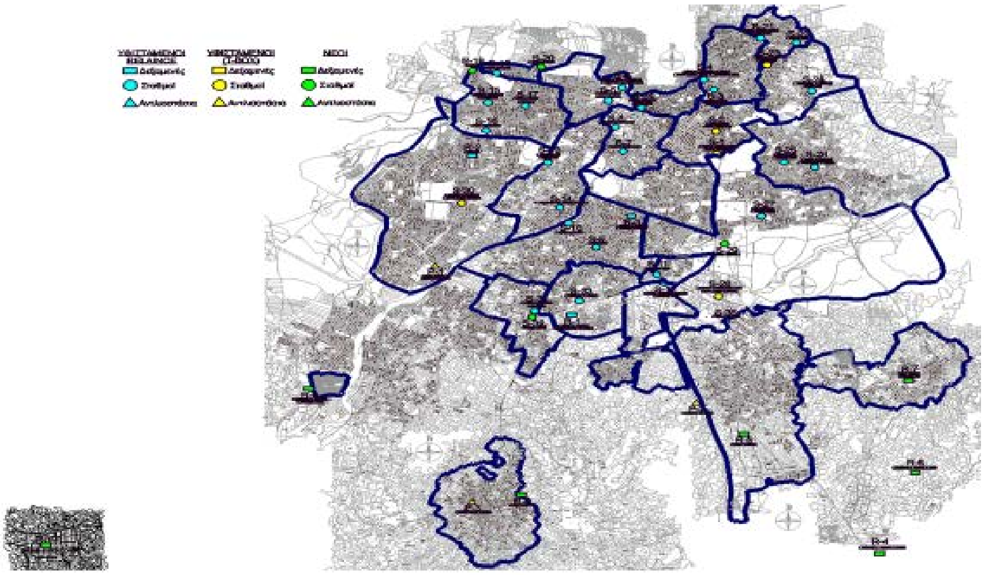

Figure 5: The service area of the Nicosia Water Board divided into specific water districts and pressure zones monitored remotely with a SCADA system.

WBN is implementing an active leakage control policy, which means that every day the data collected by the SCADA system is analyzed for indications of leakage, such as an unusually high minimum night flow or relative pressure loss in a specific area. This enables locating leaks that are not visually evident from the surface. The equipment used in the field is mainly Permanent Data Loggers and Leak Noise Correlators. At WBN, as with all water utility companies, the most important aspect of any water loss strategy is the desired targeted result and therefore the strategy is developed to reduce these losses to an acceptable or economic level and to improve performance and To maintain the strategy and sustain the improvements that have been gained. Although there are several important stages to a water loss management strategy there is no standard approach as each network is different. The strategy needs to be developed in a “tailor made” manner to suit an individual utility and its distribution system. A staged approach of activities is recommended and priorities can only be set under the parameters of which are budget and timescale (10-11).

For any water network the design and introduction of the strategy contains the following components:

-Understanding – a review of any water supply and distribution system should be made in order to gain a full understanding of its behavior and operation.

-Quantifying the level of water loss – this will be ascertained during the water audit.
-Setting targets – short term and provisional long term.
-Planning and design – having the appropriate mix of NRW reduction activities.
-Implementing – introduce initial or pilot study stage followed by second stage to reduce water loss to target level.
-Monitoring and maintaining – sustain the improvements that have been made and undertake annual review of strategy.

To maintain the NRW at low levels and even reduce it further, a relentless effort is required with specifically preset targets, budget, and time required. If left unchecked, even for short periods of time, NRW usually increases rapidly to unacceptable levels with all expected financial and water quality consequences.

As can be seen from Figure 4 the losses from the potable water distribution network in Nicosia average at 19.5% per year for the period of 2007 – 2016. This value is very low compared to 30% of losses in distribution networks in the Ardèche River Basin, South France (12) and leakage in urban areas in Spain, UK and Slovenia around are 20%, 25-30% and 43% respectively (13). Therefore the potable water network in the research area can be considered to be of high efficiency.

Improvements could be made with regards to the potable water consumption in households. This can be achieved by installing water saving fittings in the households and encouraging correct water use by residents. Gardens that are currently being irrigated with potable water should be irrigated with either groundwater or grey water. Improvement on the leakage of the water distribution network may be possible as figures from the water balance for the losses in the system include apparent losses and improvement of the leakage can only be achieved with a relentless effort which should include not only active leakage control but also pressure reduction, optimization of zoning, water meter replacement, and rehabilitation of the older parts of the network.

CONCLUSIONS

The pressure on Utilities to provide a more efficient and cost-effective service will intensify as water becomes scarcer and demands on Utilities to improve their commercial viability increase. MIS and industry specific methodologies can offer SWS the ability to improve the bottom line, achieved through the transfer of knowledge within the framework of viable business processes, implementation of information systems and relevant engineering practices.

Based on the above, it is concluded that a monthly water balance could be carried out for the Greater Nicosia Area as it would establish monthly variations and peak demands. Water consumption and wastewater production in hotels for example would be higher in the summer than in winter. The same would apply for gardens and public green area irrigation demands.

More scenarios could also be investigated and computed, such as savings from connection of all households with grey water recycling systems, the amount of recycled water that could be used to replenish aquifers, etc.

Finally, the model could be applied to other towns on the island, the water balances for the same period computed and comparisons of the water management and savings between the towns could be made.

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