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Real time monitoring and control in water distribution systems for improving operational efficiency

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ABSTRACT

The global water sector faces challenges to maintain safe, healthy, and adequate water supply to its consumers. Control of water quality and quantity by real-time monitoring (RTM) plays an important role in the management of water distribution systems (WDSs) and protection of consumers' health. RTM could be used for monitoring and analyses of water quality parameters to ensure its suitability for drinking. Additionally, RTM system warns operators to stop water supply to save water and minimize risks when needed. WDS of Antalya City is monitored and controlled by an advanced RTM and Supervisory Control and Data Acquisition (SCADA) system. Integrated RTM–SCADA system monitors and controls both hydraulic and water quality parameters to improve the WDS's operational efficiency. The system automatically controls pumps and valves and it has security alarms if any of the monitored water quality parameters fail to comply with the drinking water quality standards. This feature helps to protect WDS from the adverse impacts of an intentional or unintentional contamination event. Furthermore, RTM system is very helpful to detect water losses. Integrated RTM–SCADA system in WDSs provides many operational benefits (improved water quality, decreased operational costs, reduced customer complaints, reduction in water losses, and modeling capability) but it requires a good management system to assess huge amount of collected data.

Keywords: Hydraulic modeling; Real-time monitoring; Water quality; Water distribution system; Water losses

1. Introduction

One of the main responsibilities of water utilities is to supply and distribute water to its consumers in adequate quantity, quality, and pressure throughout the whole water distribution system (WDS). The potable water is initially treated to meet the drinking water quality standards before distribution. However, some contaminants may enter WDS during transmission and distribution that adversely affect water quality and cause health risks for the consumers. On the other hand, insufficient water flow or pressure

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may result in intermittent water supply which is an undesired condition for both water utilities and consumers. Occasionally, reported or unreported pipe breaks may occur underground and contaminants may enter through the leak points during pressure drops, maintenance, and/or repair of the breaks [1,2]. In addition, water distribution elements are gradually aging and this increases frequency of pipe bursts [3]. In case of extreme conditions, such as terrorist attacks, a contaminant may intentionally be injected into WDS to harm public health or at least threaten the public. All of the above described facts and/or problems necessitate a safe and reliant WDS to gain public confidence in the drinking water supply services. Consequently, water utilities need to continuously monitor both the quality and quantity of the distributed water to protect public health and enhance confidence, welfare, and comfort [4]. The continuous efforts of the water utilities to monitor the drinking water should be communicated to the consumers so that they can safely drink the supplied water through their taps at homes without any concern [2].

WDSs are usually composed of many elements to serve very large areas with safe and continuous supply of drinking water that needs a systematic management, maintenance, and control. Therefore, monitoring of WDSs is not an easy task and either conventional and/or advanced methods are applied by water utilities. In conventional monitoring, a group of trained staff of the water utility visit the preselected monitoring locations for *in situ* water quality measurements and sampling at predetermined frequencies. The data collected through conventional monitoring provide discontinuous information for few points in the whole network. The collected data are usually not enough to warn water utilities about possible water quality and quantity problems in the whole WDS. In this manner, problem detection and solution is not direct or under control. Alternatively, an integrated real-time monitoring (RTM) and Supervisory Control and Data Acquisition (SCADA) system is an advanced way to continuously monitor, manage, maintain, and control water quantity and quality parameters at many points in WDS. Obviously, it is impossible to monitor all water quality parameters on WDSs, so there is a need to balance cost and ease of operation. As a result, RTM systems usually employ on-site instruments to measure hydraulic parameters (water pressure and flow rate) and some water quality indicator parameters such as pH, temperature, turbidity, electrical conductivity (EC), dissolved oxygen, disinfectant level (in general chlorine) and sometimes oxidation reduction potential and total organic carbon [5–7]. Unlike conventional monitoring, RTM system is always ready and active with the available sensors to observe water quality and quantity changes in WDS. RTM systems can cover as many points as requested with automatic sampling and measurement at prescribed time intervals. The collected data from RTM system are commonly sent wirelessly to a control center and stored in there for further interpretation, analysis, and modeling [3,8,9].

Integrated RTM–SCADA system provides significant real time information about the approximate location of contamination and pipe bursts. Additionally, RTM system automatically warns water operators if any of the monitored parameters deviates from predetermined limits, and consequently remote commands can be given to stop water supply if necessary [2,10]. This action aims to protect from the adverse impacts of possible intentional or unintentional contamination event on time. Recently, an advanced RTM and SCADA system has been installed in Antalya City-Turkey by the Water and Wastewater Authority (ASAT) of Antalya Metropolitan Municipality for the purpose of advanced management, operation, and control of WDS [8]. In this study, integrated use of RTM and SCADA systems to improve operational efficiency in Antalya WDS is described, as an example. Trend analysis of monitored parameters, achievement of hydraulic and water quality modeling applications, water loss reduction, and improvements in energy efficiency are presented to demonstrate beneficial uses of the numerous high-quality data obtained from the integrated RTM–SCADA system of Antalya City. The presented case study provides a reliable application for systematic monitoring of WDS and increases the resilience of water infrastructure to solve operational problems.

2. Material and Methods

2.1. Study area

Antalya Metropolitan City, with a population of approximately one million inhabitants, is one of the most important tourism destinations along the Mediterranean coast of Turkey for native and foreign tourists. Groundwater and springs are the main drinking water resources of the City where about 250,000 m^3 of water are abstracted daily from these resources and distributed through the WDS after applying only chlorination. No further treatment is applied to the supplied water because it has high water quality except the relatively high hardness levels [9,11–13]. Sodium hypochlorite solution (15%) is used for chlorination to maintain certain concentrations of residual chlorine all over the water distribution network [9,14]. Drinking water quality of Antalya City is continuously monitored, analyzed, and assessed by an integrated RTM–SCADA system and the collected data-sets are sent wirelessly to the SCADA Center of ASAT for storage and further processing. Water quality parameters measured by RTM system are turbidity, EC, pH, temperature, and free residual chlorine (FRC). Additionally, water pressures and flow rates are measured.

The integrated system covers all pumping stations, balancing/service reservoirs, water wells, and many stations located on the water mains. The system monitors water levels in the reservoirs, operation of pumps in the pumping stations, and position of valves (open, closed, and partially open) in the network in addition to energy and water consumption (Fig. 1). The display screen at the SCADA Center shows instantaneous water flow rate, stored water volume, instantaneous and previous day system input volume of Antalya WDS. Schematic presentation of data collection and transfer between key components of the system and further assessment tools are presented in Fig. 2. The collected data-sets are archived at the SCADA Center for evaluation besides hydraulic and water quality modeling applications. An advanced geographical information system (GIS) is also available at ASAT to provide details about the WDS and pipe network (length and diameter of pipes, location and elevation of nodes, pipe layouts and connections). RTM system gives automatic alarms when the measured data are not within the predetermined limits and it also produces reports and charts for multipurpose analyses.

2.2. Integrated RTM–SCADA system description

The integrated RTM–SCADA system of Antalya City started to operate in 2006 and it was modified in 2011 with the addition of extra analyzers at additional

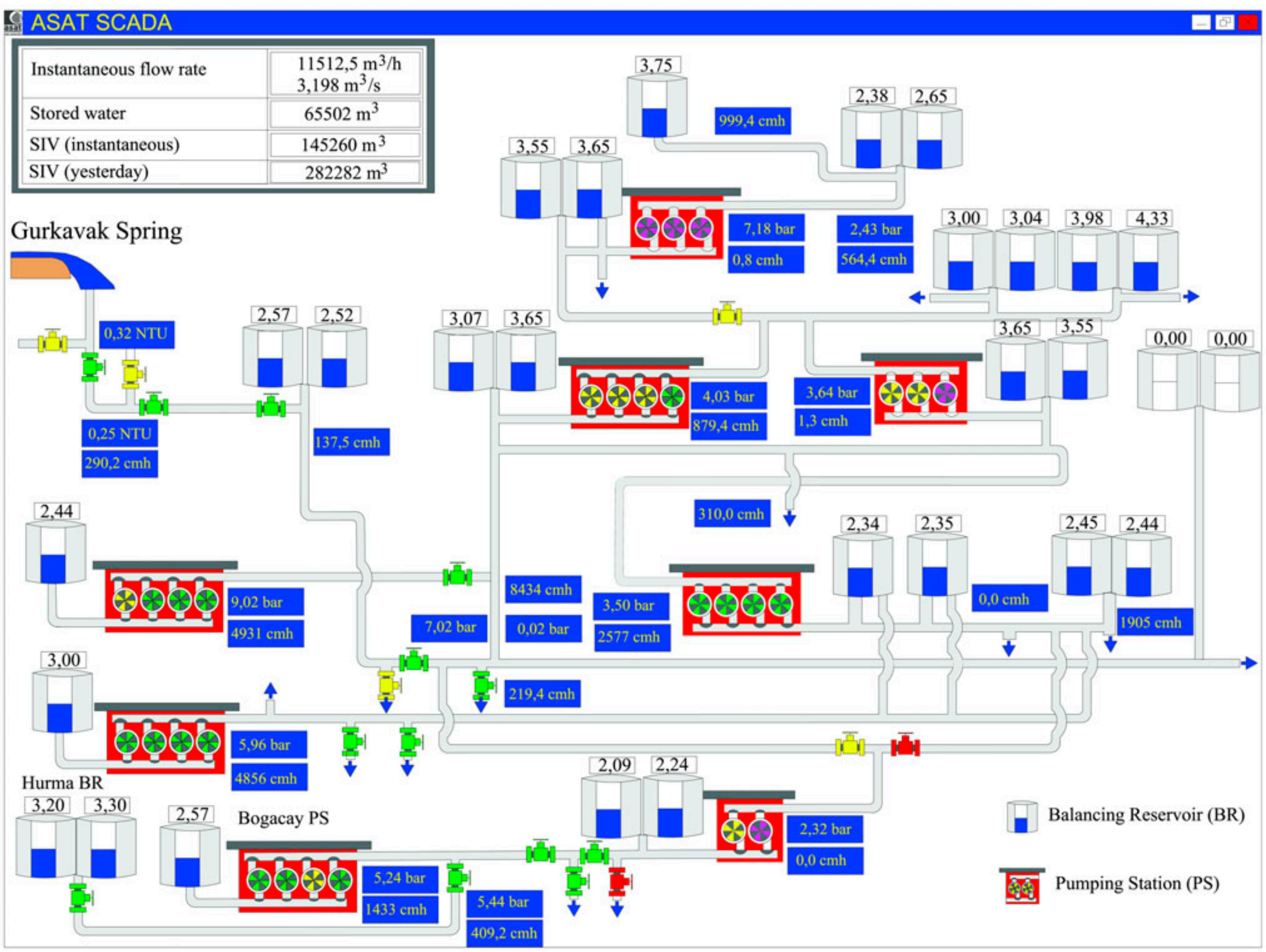

Fig. 1. The general display screen of integrated RTM–SCADA system.

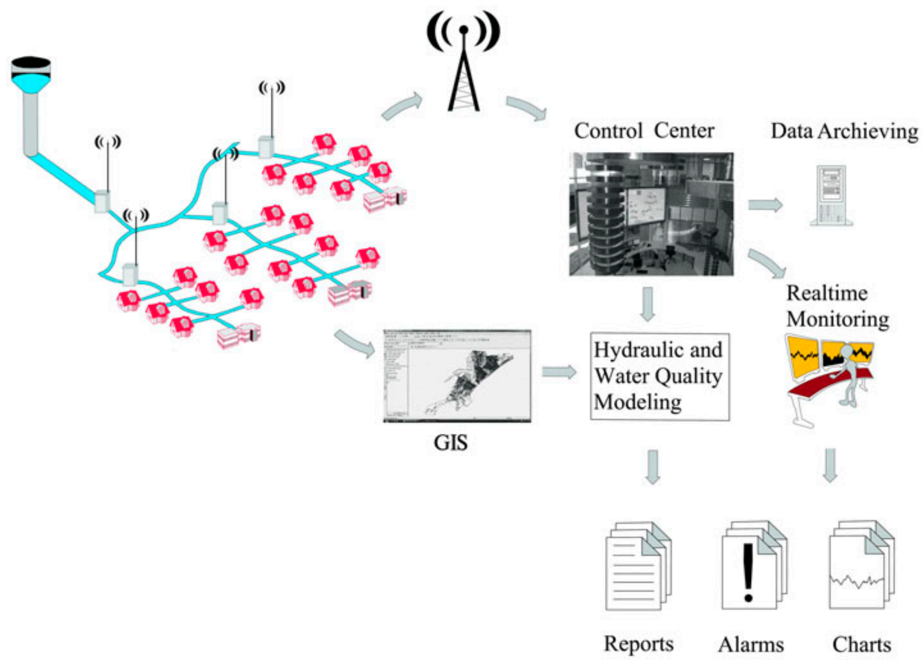

Fig. 2. Schematic presentation of data collection, transfer, and interpretation.

measurement points. The system, with a cost of over four million Euros, covers nine pumping stations, 24 service reservoirs, 74 deep well pumps, and 98 network measurement points to improve the efficiency and security of the WDS. There are more than 110 electromagnetic flow meters installed on pipes, where the pipe diameter is up to 1,000 mm. Motorola MOSCAD remote terminal units (RTU) are used for remote data collection and control. IBM servers are used as SCADA server computers at the SCADA Center which is located at ASAT headquarters. Historical archiving computers and IBM business stations are used for data analyses. The server computers operate in redundant logic and the used software is Citect SCADA. A digital UHF MAS radio system with two dual redundant repeaters provides citywide communications between the SCADA Center and the field stations. Motorola MCP-T is used as the SCADA communications gateway device. RTM hydraulic data provides detection of anomalies such as immediate peaks in flow rate and immediate drops in pressure, indicating pipe bursts, and leaks. The system has an interactive data display and retrieval. All the RTM–SCADA stations are shown on a map and when a station is selected, the RTM data are displayed and assessed by the WDS engineers and/or operators. Near real-time graphs and historical data can be retrieved and viewed to follow trends on the order of minutes to months. The data-sets are available for file export in different formats to allow users to process data using their preferred software. The infrastructure of RTM–SCADA system ensures that all stations transmit data to the SCADA Center in a timely and reliable manner and 5-min time interval is set for data transfer for normal operational condition. Maintenance, drained batteries, software bugs, malfunctions in data transfer, or extreme weather conditions may cause data losses or interruptions (short outages in the order of a few seconds or long outages in the order of a few hours). At each RTM station, one above ground unit and another below ground unit are available (Fig. 3).

Above ground unit is designed as a closed cabin, where flow meter, pressure meter, and the online water quality analyzers of pH, temperature, FRC, and turbidity are connected with their main display screen and RTU unit to transfer data. The below ground unit is constructed within a manhole, where flow meter, pressure meter, and automatic valve control are installed on the pipe. The specifications of the sensors and devices for measurement of hydraulic and water quality parameters at RTM stations are presented in Table 1. There are additional sensors to warn operators for unintentional interferences (when the above ground unit is opened by unauthorized people) and flooding (when the water level in underground unit exceeds a predetermined level).

Fig. 3. Above ground unit: (a) RTM online sensors and display screens, (b) station cabin and the antenna used for RF data transfer by the RTU system, below ground unit: (c) automatic valve control unit, and (d) the surrounding manhole.

3. Results and discussion

The integrated RTM–SCADA system offers many advantages to improve WDS operational efficiency by (i) visualization of trends to analyze spatial and temporal variations of the monitored parameters, (ii) remote control of all reservoirs, pumps, and valves in the whole WDS providing energy efficiency in operation, (iii) detection and approximate localization of leaks and pipe bursts, and (iv) integration of monitoring and modeling of hydraulic and water quality parameters.

Advantages of using an integrated RTM–SCADA system to improve operational efficiency of Konyaalti WDS (KWDS) are presented in the following sections, as an example. KWDS represents about 8% of the whole WDS of Antalya City and serves more than 60,000 inhabitants. The whole drinking water demand of KWDS is supplied from groundwater wells at *Bogacay* Pumping Station, where chlorine is dosed to protect against possible contamination in the network. The groundwater resources in the region have high water quality and are mainly fed with rainwater and melting snow from Taurus Mountains. *Hurma* Reservoir is the only balancing reservoir in KWDS. KWDS was divided into 18 district metered areas (DMAs) for better management and monitoring of water quality and quantity and to reduce water losses (Fig. 4).

3.1. *Analyses of spatial and temporal variations of monitored parameters*

Currently, there are 19 RTM–SCADA stations along the water mains in KWDS, all equipped with online flow and pressure meters (Fig. 4). Also, there are three RTM–SCADA stations installed at *Bogacay* water wells, *Bogacay* Pumping Station, and *Hurma* Reservoir.

Table 1
Hydraulic and water quality parameters measured at RTM stations and specifications of the sensors and instruments

Parameters/ Specifications	Turbidity	pH	FRC	EC	Pressure meter	Flow meter
Brand/Model	Hach Lange/1720E	Hach Lange/ pHD sensor with automatic NTC 300 Ω thermistor	Hach Lange/CLF10 with Combo pH	Hach Lange/ 3412 sc with Pt1000 temperature sensor	Endress Hauser/ PMC71 with pressure transmitter	Siemens/ SITRANS F M MAG 6000 with MAG 5100 W transmitter
Units	mg/L, NTU, TE/F, FTU, Degree	pH unit	ppm, ppb, mg/L	μS/cm	bar, psi	m^3/h
Range of measurement	0–100 NTU	−2 to 14 pH	0–10 ppm	1–2,000 μS/cm	From –100/0 to 100 mbar (–1.5/0 to 1.5 psi) to –1/0 to 40 bar (–15/0 to 600 psi)	0–10 m/s
Accuracy	Defined according to ISO 15839. ±2% of reading or ±0.015 NTU (whichever is greater) from 0 to 40 NTU	±0.2	±3% of the reference test (DPD) at constant pH < 7.2 (±0.2 pH unit), ±10% of the reference test (DPD) at stable pH < 8.5 (±0.5 pH unit from the pH at calibration)	$1.00\ cm^{-1}$ (accuracy of cell constant ± 2%)	Up to ±0.075%	0.2% ±1 mm/s
Limit of detection/ sensitivity	±0.0032 NTU	±0.01 pH	30 ppb (0.030 ppm)	$1.00\ cm^{-1}$ (accuracy of cell constant ±2%)		
Repeatability	Better than ±1.0% of reading or ±0.002 NTU	±0.05 pH	30 ppb or 3%, whichever is greater	±0.5% of reading		
Measurement method	Light scattering	Differential electrode measurement	Reagentless, electrochemical, three-electrode amperometric system	2 electrodes contacting conductivity		Electromagnetic
Primary compliance method	USEPA 180.1; ASTM D 6698; Standard methods 2130B		US EPA method 334.0			
Operation conditions	0–70˚C	0–50˚C, 0–6.9 bar (100 psi)	5–45˚C, pH 4–9	−20 to +60˚C, max 10 bar	−25 to +125˚C, max. 60 bar (900 psi)	−20 to 50˚C, max. 16 bar (150 psi)

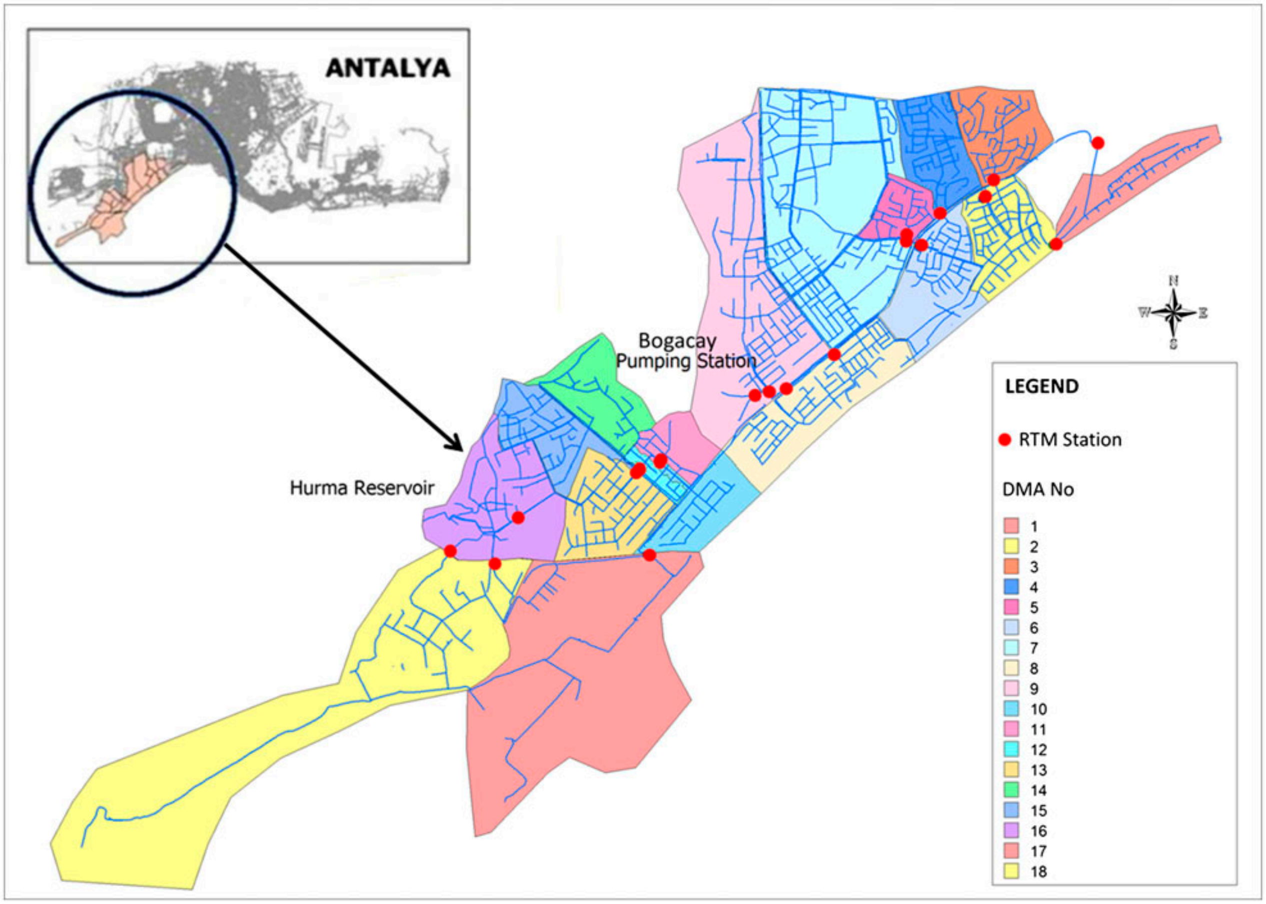

Fig. 4. Locations of main pipe RTM–SCADA stations at KWDS.

Eight of the above mentioned stations (*Bogacay* Pumping Station, *Hurma* Reservoir, and six stations on the water mains) are equipped with online analyzers for the continuous measurements of temperature, turbidity, EC, pH, and FRC. Fig. 5 depicts temporal variation of flow rate, pressure, and FRC concentration at a selected RTM main pipe station (DMA No: 6) and *Bogacay* Pumping Station, as an example. In the presented case for DMA No: 6, it is seen that water flow rates fluctuated between 20–60 m^3/h in summer season and the pressure values were mostly above five bars, which is a relatively high network pressure. In this particular DMA, minimum night flow (MNF) was determined around 20 m^3/h of which the major part was considered as physical water losses. In case of chlorine levels in KWDS, FRC levels ranged between 0.25 and 0.40 mg/L in winter season at the chlorine dosing station (*Bogacay* Pumping Station), while FRC concentrations ranged between 0.20 and 0.35 mg/L at the RTM network station. The relevant Turkish Standards state no limit for FRC concentration in the WDS, except the dead points where FRC concentration should be between 0.2 and 0.5 mg/L [15]. However, WHO guidelines recommend FRC levels to be above 0.2 mg/L in the whole WDS [16]. It is essential to continuously monitor FRC levels both at the dosing station and WDS for operational safety.

RTM system produces a good database for temporal trend analyses of the monitored water quality parameters. As an example, Fig. 6 presents pH, temperature, EC, and turbidity measurements at DMA No: 6 for February and March in 2012. In Fig. 6(a) and (b), pH measurements were in a narrow range between 6.5 and 7.5 complying with the relevant Turkish Standards that require pH values between 6.5 and 9.5. Water temperature showed minor daily fluctuations. In the Turkish Standards, upper limit of allowable EC value for drinking water is set as 2,500 μS/cm, and all the measured EC values (Fig. 6(c) and (d)) in the monitored stations were far below this limit.

A turbidity value of 4 NTU in drinking water is considered unacceptable to consumers due to esthetic

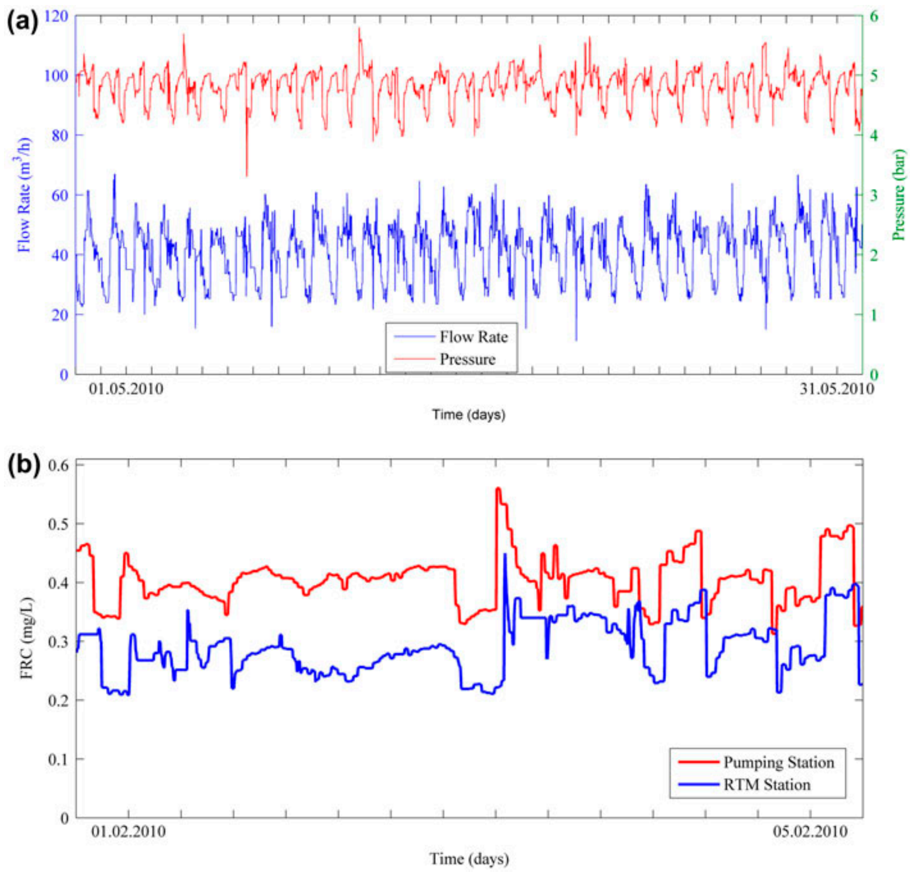

Fig. 5. Temporal variation of (a) flow rate and water pressure at DMA No: 6 and (b) FRC concentration measured at DMA No: 6 and *Bogacay* Pumping Station.

reasons [17]. The current Turkish Standards [15], EU Drinking Water Directive (98/83/EC) and the European Communities Drinking Water Regulations [18] state that the levels of turbidity at the water tap must be "acceptable to consumers with no abnormal change" and "in the case of surface water treatment a parametric value not exceeding 1.0 NTU in the water ex treatment must be strived for". In the presented case, the monitored turbidity values were all below 1.0 NTU. The integrated RTM–SCADA system gives warning alarms when turbidity values exceed 1.0 NTU. Turbidity levels at one of the water supply springs of Antalya, namely *Gurkavak*, occasionally exceed 1.0 NTU, after heavy rains in winter season, and at that time the valves are automatically closed to stop water supply from this source.

3.2. Detection of pipe bursts and leaks

Pipe bursts may occasionally occur especially in high-pressure WDSs causing interruptions in water supply, additional costs for repair and damage to nearby properties and infrastructure. Therefore, water utilities try to minimize the occurrences of pipe bursts and search for techniques for detection and localization of bursts [19]. Integrated RTM–SCADA system enables continuous monitoring of hydraulic parameters and therefore is very helpful in detecting water losses. Approximate locations of bursts can be detected by monitoring the abnormal increase in flow rate and decrease in water pressure besides customer complaints. Fig. 7(a) shows a typical increase in flow rate that was measured during a pipe burst in Antalya WDS [20]. In this event, no water flow was noticed on the ground surface due to the karstic characteristics of the area [21]. Additionally, no complaints were received from the customers regarding water breakdown or shortage of supply. However, the integrated RTM–SCADA system gave warning alarms to inform about the event. The approximate location of the pipe burst was determined by monitoring the changes of flow rates at the related RTM station and the nearby ones. Additionally, monitoring the volume of water input to the water reservoirs prevented the overflow and helped in detecting leakages. As an example, RTM data for *Caglayan* Reservoir showed that there was 100 m^3/h of water leakage originated from a serious crack in the outlet pipe (Fig. 7(b)). Similarly, RTM–SCADA station at *Bogacay* Pumping Station showed that the pumped flow rate was less than the expected value as there was a rubber ring stuck before the pump (Fig. 7(c)). Solving this problem led to increasing the flow rate by 300 m^3/h [10]. The integrated RTM–SCADA system helped in quick detection and repair of frequent bursts in Antalya WDS. As a result, total water losses were reduced from 169,000 to 120,750 m^3/d with a reduction of 28.55% in the first 4 y of operation between 2006 and 2010 [22]. Recently, 1,200 customer Automated Meter Reading (AMR) systems have been installed at *Kaleici* DMA of Antalya City to determine water losses in a more accurate way. In this new application, the total water input volume to the DMA is measured by the available RTM station. The total volume of consumed water is provided by the AMR readings and the difference between the total input volume to the DMA and the consumed water gives the accurate volume of physical losses. In this application, inaccuracy of AMR reading is neglected because the meters are new and also have high accuracy. The use of AMR is new in WDSs and it is expected to provide operational efficiency for billing purposes and potential use in leak detection.

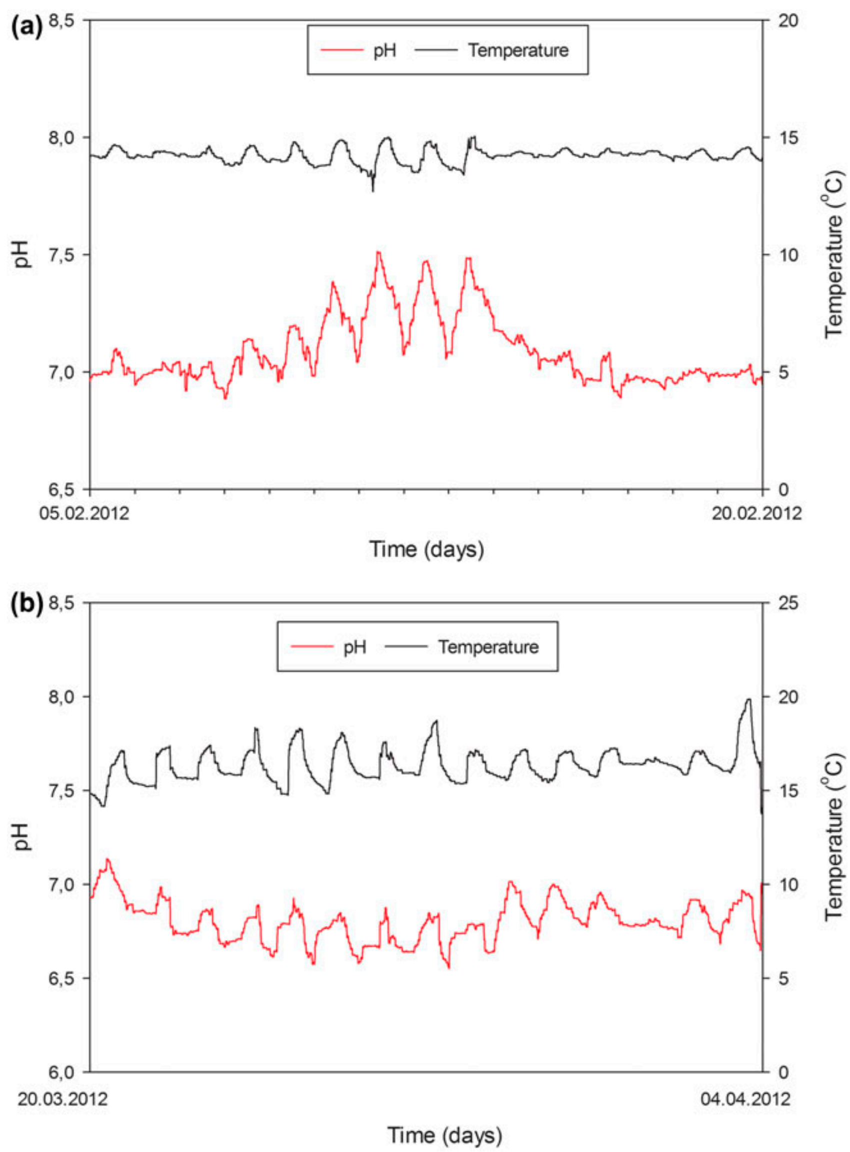

Fig. 6. Variations of pH, temperature, conductivity, and turbidity measurements at DMA No: 6.

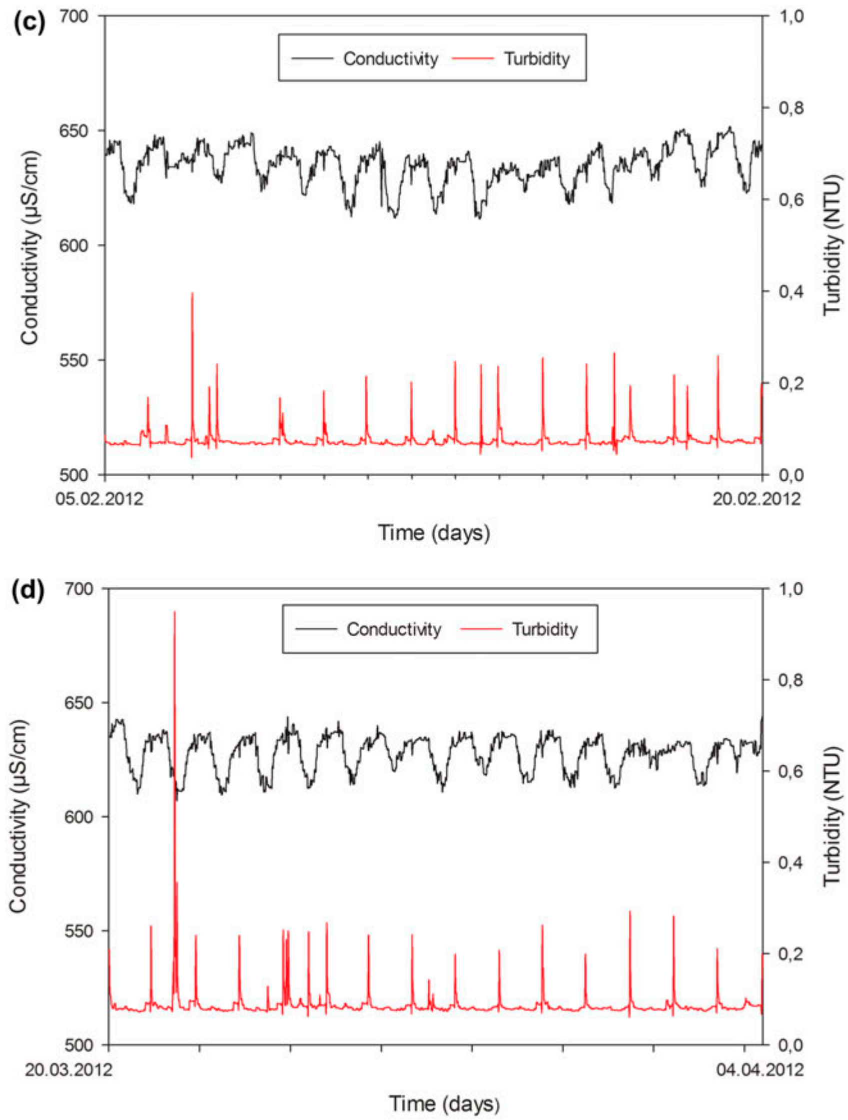

Fig. 6. (*Continued*).

3.3. Improving operational efficiency in Antalya WDS

Remote control of all reservoirs, pumps, and valves in Antalya WDS is achieved by the integrated RTM–SCADA system to improve operational efficiency. Using the capabilities of the integrated system, (i) average flow rate of supplied water was reduced from 260,000 to 230,000 m^3/d (11.54% reduction), (ii) daily energy consumption was reduced from 208,000 to 138,000 kWh (33.65% reduction), (iii) energy consumption for water production, pumping, and distribution was reduced from 0.8 to 0.6 kWh/m^3 (25% reduction), (iv) energy consumed for water losses in WDS was reduced from 135,200 to 72,450 kWh/d (46.41% reduction) in the first four years of operation between 2006 and 2010 [10,22]. Only the annual total reduction in consumed energy (70,000 kWh/d equals 25,55 MWh/y) leads to an annual saving of 3,321,500 Euros (price of 1-kWh electricity in Turkey is 0.39 TL which equals 0.13 Euro). Therefore, payback period of the integrated RTM–SCADA system is estimated to be less than one year when all the other benefits are considered. The integrated RTM–SCADA system proved to be very efficient in reducing energy consumption and improving water services to the customers in addition to water losses reduction and better control of water quality which leads to an increase in the reliability of the whole system in a cost-effective manner.

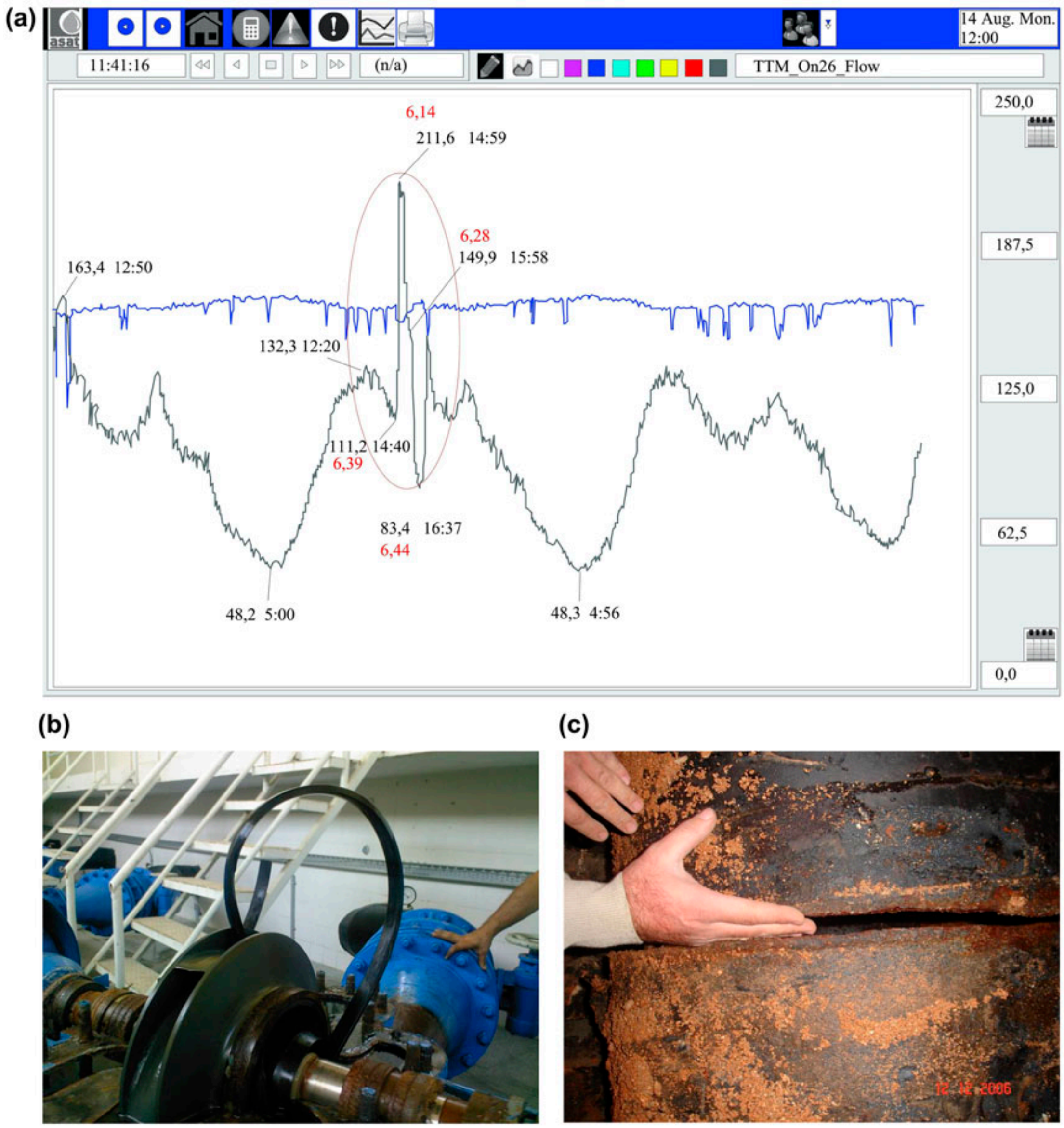

Fig. 7. (a) The display screen at Control Center of ASAT which shows a pipe burst event and repair, (b) crack in the outlet pipe of *Caglayan* Reservoir, and (c) rubber ring reducing the capacity at *Bogacay* Pumping Station [10].

Pressure is one of the main design and operational parameters for WDSs and it should be kept within certain limits. Excess water pressure is usually reduced down to optimum operation levels in WDSs using PRVs. Energy recovery from the excess pressure is possible by the use of turbines and/or Pumps as Turbines (PAT) although energy recovery is usually low. Micro-scale energy generation in WDSs using PAT is rather a new application which contributes to sustainable management in WDSs. A recent research project has been initiated to install a PAT on one of the main WDS pipes in Antalya City to generate energy from the excess water pressure which will be the first on-site application in Turkey [23]. This system is expected to generate between 5 and 10 kWh of electricity at the application site where there is an excess pressure of 1 bar and the flow rate is between 150 and 500 m^3/h. The automation of the newly proposed PAT system is planned to use the continuous flow rate and water pressure data monitored at the nearby RTM–SCADA station. Technical and economical feasibility studies will be conducted to evaluate the performance of the proposed PAT.

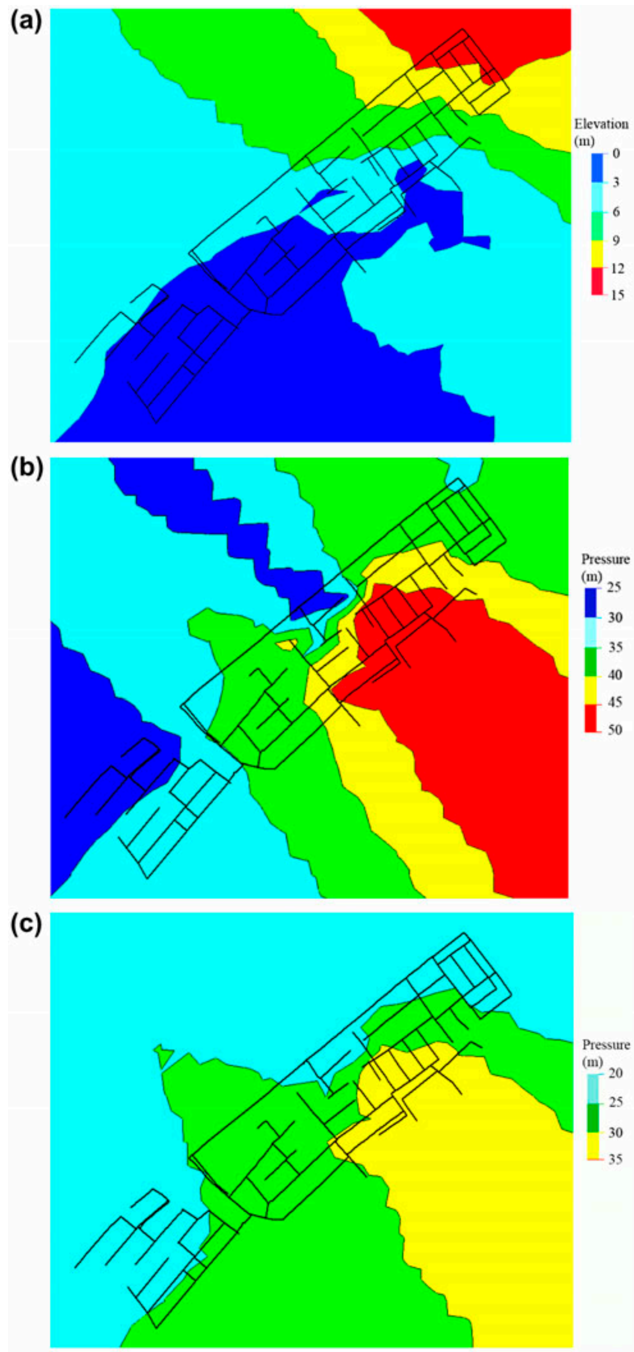

Fig. 8. EPANET model outputs for DMA No: 8 (a) the spatial changes of elevation, the spatial changes of pressure before (b), and after (c) installation of PRV during maximum water consumption [13].

3.4. Hydraulic modeling study

The integrated RTM–SCADA system of Antalya City provides long periods of intensive field data-sets for flow rates and water pressures. Additionally, the pipe network and details of pipes are available at the GIS system. The availability of these data groups creates a good opportunity and capability for hydraulic modeling studies. Results of hydraulic modeling study in KWDS for reducing physical water losses by reducing water pressure to an optimum level is presented in this section. The data obtained from the integrated system were used to develop, calibrate and verify the hydraulic model for each DMA within KWDS. The monitored data revealed that a number of DMAs exhibited high pressures, greater than 3.5 bars, and high MNF throughout the year. As a result of these findings, several PRVs were installed at the related DMAs. The optimum pressure level for setting the PRV was determined for each DMA using EPANET model [24]. Considerable reduction in water losses was achieved by setting the optimum pressure levels to 2.0–3.0 bars. Fig. 8 depicts EPANET model outputs for the spatial changes of water pressure levels (before and after installation of PRV) at DMA No: 8 during maximum water consumption, as an example. The same model was used to predict water savings due to pressure reduction and the predicted water savings were verified using field measurements of flow rates and water pressures. The average total water savings in all DMAs in KWDS, where pressure management could be applied, was estimated at 45.5 m^3/h. The predicted water savings correspond to 12.5% of the total water supplied to the whole KWDS. The price per cubic meter of water in Antalya is about one Euro. Thus, the annual revenue of water savings in KWDS is about 400,000 Euros. The findings of the mentioned hydraulic modeling study were applied by ASAT to realize pressure management in KWDS. This application of pressure management provides a good

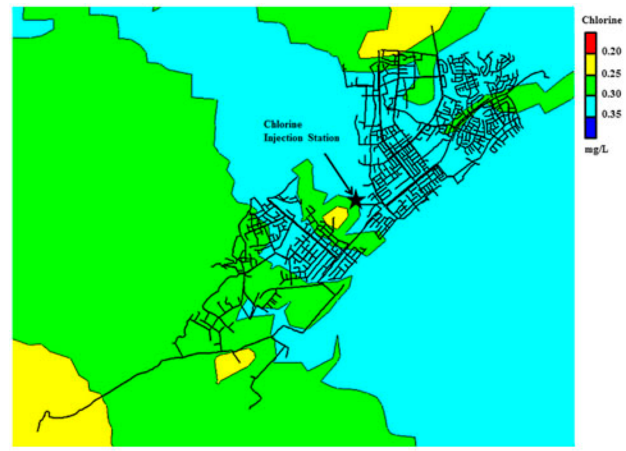

Fig. 9. Spatial changes of FRC concentrations at 11:00 pm on July 21st, 2010 for chlorine dose of 0.35 mg/L [26].

example for many cities and municipalities facing similar leakage problems. The study revealed that hydraulic modeling is essential for applying appropriate pressure management strategies. The details of the modeling work are presented in the study of Karadirek et al. [13].

3.5. Water quality modeling study

Low chlorine concentrations in WDSs increase the risk of waterborne diseases in case of contamination in water, whereas high chlorine concentrations may cause the formation of disinfection by-products (DBPs). Some of these DBPs may cause cancer or other chronic and acute adverse health effects to human beings and animals [25]. As a result, chlorine concentrations should be kept within certain limits in WDSs to minimize health risks. The chlorine dosing rates are generally determined by the experienced water operators considering the monitoring results of FRC concentrations in the WDS. This method of operation is inappropriate because insufficient chlorine dosing rates could be adjusted only sometime after their inspection. Therefore, it is essential to predict the right dosing rates that always keep FRC levels within the required range. The integrated RTM–SCADA system of Antalya City provides several data-sets for FRC concentrations in addition to hydraulic parameters that create a good opportunity and capability for FRC modeling in WDS. Once a hydraulic model is calibrated and verified, it is relatively easy to add chlorine modeling. In this study, EPANET model was used to determine optimum chlorine doses at Bogacay Pumping Station in KWDS to achieve FRC that always comply with the Turkish Standards [15]. Required data-sets for chlorine model setup, calibration, and verification were supplied by the integrated RTM–SCADA and GIS systems. EPANET model prediction for areal distribution of FRC concentrations for the whole KWDS during maximum water consumption and water temperature is presented in Fig. 9. Several chlorine management scenarios and different chlorine doses were considered for the extreme conditions. The study revealed that RTM system provides excellent data-sets for chlorine modeling and management that enables automatic application of chlorine dosing. The details of the modeling work are presented in the study of Karadirek et al. [26]. Recently, ASAT has installed automatic chlorine dosing equipment at *Bogacay* Pumping Station to keep FRC concentrations always above 0.40 mg/L at the dosing station to minimize risks.

4. Conclusions

Water utilities play the highest importance on providing safe and reliable water services among other responsibilities. In addition to routine operation, extreme events such as flooding, drought, and intentional or unintentional contamination risks create new challenges for water sector. In this respect, water sector needs advanced tools to increase resilience of water infrastructure by providing long-term secure and sustainable water supply services. Especially, large and complex WDSs require an advanced management system to operate, monitor, control, and maintain the system components. The integrated RTM–SCADA system in Antalya proved to increase confidence in water services by improving water quality, decreasing operational costs, reducing water losses, and increasing energy efficiency. Total water losses in Antalya WDS were reduced from 65 to 52.5% between the years 2006 and 2010 with the help of the integrated RTM–SCADA system in addition to other actions (pipe replacement, repair of burst pipes, pressure management, active and passive leakage detection, customer meter replacement). It is recommended to install traditional hydraulic (flow and pressure meters) and water quality monitoring equipment (e.g. pH, chlorine, temperature, EC, and turbidity) to provide the most reliable data in the main focus of water utilities. The integrated RTM–SCADA system provides valuable data for hydraulic and water quality modeling studies to perform several scenarios for better management of WDS in terms of quantity and quality. On the other hand, high capital costs, considerable operational and maintenance costs could be mentioned as disadvantages of the system. Furthermore, trained staff is required to calibrate, maintain, and repair the on-site instruments. In this respect, RTM and control systems should be constructed in a cost-effective manner to balance cost and ease of operation.

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References

[1] H. Methods, T.M. Walski, D.V. Chase, D.A. Savic, W. Grayman, S. Beckwith, E. Koelle, Advanced Water Distribution Modeling and Management, Haestad Press, Waterbury, 2003.

[2] EPA, Research Report: Technologies and Techniques for Early Warning Systems to Monitor and Evaluate Drinking Water Quality: A State-of-the-Art Review, EPA/600/R-05/156, Office of Science and Technology, National Homeland Security Research Center, Pennsylvania, 2005.

[3] M. Allen, M. Iqbal, S. Srirangarajan, H.B. Lim, L. Girod, A.J. Whittle, Real-time in-network distribution system monitoring to improve operational efficiency, J. AWWA 103(7) (2011) 63–75.

[4] V. Kanakoudis, D.K. Tolikas, The role of leaks and breaks in water networks: Technical and economical solutions, J. Water Supply Res. Technol.-Aqua, 50(5) (2001) 301–311.

[5] M.M. Frey, L. Sullivan, Practical Application of On-Line Monitoring, AWWA Research Foundation Report, Denver, CO, 2004.

[6] W.M. Grayman, R.M. Deininger, R.A. Males, Design of Early Warning and Predictive Source-Water Monitoring Systems, AWWA Research Foundation Report, Denver, CO, 2001.

[7] M.V. Storey, B. van der Gaag, B.P. Burns, Advances in on-line drinking water quality monitoring and early warning systems, Water Res. 45 (2011) 741–747.

[8] I.E. Karadirek, S. Kara, G. Yilmaz, T. Altindal, H. Muhammetoglu, A. Muhammetoglu, M. Kitis, S. Soyupak, N.O. Yigit, B.I. Harman, I. Palanci, T. Ozden, K. Cengiz, Monitoring and management of drinking water quality of Antalya Konyaalti Region, J. Environ. Sci. Technol. 4(1) (2012) 35–40 (In Turkish).

[9] M. Kitis, N.O. Yigit, B.I. Harmanci, H. Muhammetoglu, A. Muhammetoglu, I.E. Karadirek, I. Demirel, T. Ozden, I. Palanci, The occurrence of trihalomethanes in chlorinated groundwaters with very low natural organic matter and bromide concentrations, Environ. Forensics 11(3) (2010) 264–274.

[10] I. Demirel, T. Ozden, I. Palanci, I.E. Karadirek and H. Muhammetoglu, Monitoring and management of water distribution network in Antalya city, using the SCADA system, in: Hani Sewilam (Ed.), Capacity Development for Drinking Water Loss Reduction: Challenges and Experiences, UN-Water Decade Programme on Capacity Development, DreesbachVerlag, Bonn 2011, pp. 107–111.

[11] E. Çelik, H. Muhammetoglu, Improving public perception of tap water in Antalya City—Turkey, J. Water Supply Res. Technol.-Aqua 57(2) (2008) 109–113.

[12] S. Soyupak, H. Kilic, I.E. Karadirek, H. Muhammetoglu, On the usage of artificial neural networks in chlorine control applications for water distribution networks with high quality water, J. Water Supply Res. Technol.-Aqua, 60(1) (2011) 51–61.

[13] I.E. Karadirek, S. Kara, G. Yilmaz, A. Muhammetoglu, H. Muhammetoglu, Implementation of hydraulic modelling for water-loss reduction through pressure management, Water Resour. Manage. 26(9) (2012) 2555–2568.

[14] O. Tiryakioglu, A. Muhammetoglu, H. Muhammetoglu, S. Soyupak, Modeling chlorine decay in drinking water distribution network: Case study of Antalya—Turkey, Fresenius Environ. Bull. 14(10) (2005) 907–912.

[15] CWIHC 2013, Turkish Ministry of Health Regulation Concerning Water Intended for Human Consumption, vol. 28580, Public Health Instution of Turkey, Ankara, 2013.

[16] WHO, Guidelines for Drinking Water Quality, fourth ed., Geneva, Switzerland, 2011.

[17] European Union Council Directive Relating to the Quality of Water Intended for Human Consumption (80/778/EEC), J. European Communities, No. L. 229, August 1980.

[18] European Communities, Drinking Water No.2 Regulations, Statutory Instruments, S.I. No. 278 of 2007, Dublin, Stationery Office, 2007.

[19] V. Kanakoudis, H. Muhammetoglu, Urban water pipe networks management towards non-revenue water reduction: Two case studies from Greece and Turkey, Clean Soil Air Water 42(7) (2014) 880–892.

[20] I. Palanci, T. Ozden, I. Demirel, I.E. Karadirek, H. Muhammetoglu, District Metered Areas (DMAs) for the Management of Water Losses in Antalya City-Turkey, 2nd Regional Workshop on Water Loss Reduction in Water & Sanitation Utilities, Sofia, Bulgaria, November 16–18, 2009, pp. 140–144.

[21] F. Kaçaroğlu, Review of groundwater pollution and protection in karst areas, Water Air Soil Pollut. 113(1–4) (1999) 337–356.

[22] ASAT, Progress Report of SCADA Center for 2009, ASAT, Antalya Metropolitan Municipality, Antalya, Turkey, 2009, (in Turkish).

[23] A.Muhammetoglu, Investigation of the Renewable Energy Recovery Potential for Sustainable Water Supply Systems, TUBITAK (The Scientific and Technological Research Council of Turkey) Project Proposal No: 114Y203, 2014, (in Turkish).

[24] L. Rossman, EPANET-2 Users Manual, US Environmental Protection Agency, Cincinnati, OH, 2000.

[25] W.D. King, L.D. Marrett, Case-control study of bladder cancer and chlorination by-products in treated water (Ontario, Canada), Cancer Causes Control 7 (1996) 596–604.

[26] I.E. Karadirek, S. Kara, A. Muhammetoglu, H. Muhammetoglu, S. Soyupak, Management of Chlorine Dosing Rates in Urban Water Distribution Networks Using Online Continuous Monitoring and Modeling, Urban Water J., (in press), doi:10.1080/1573062X.2014.992916.