

# Water leakage management by district metered areas at water distribution networks

Özgür Özdemir

Received: 2 December 2016 / Accepted: 19 February 2018 / Published online: 1 March 2018  
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**Abstract** The aim of this study is to design a district metered area (DMA) at water distribution network (WDN) for determination and reduction of water losses in the city of Malatya, Turkey. In the application area, a pilot DMA zone was built by analyzing the existing WDN, topographic map, length of pipes, number of customers, service connections, and valves. In the DMA, International Water Association standard water balance was calculated considering inflow rates and billing records. The ratio of water losses in DMAs was determined as 82%. Moreover, 3124 water meters of 2805 customers were examined while 50% of water meters were detected as faulty. This study revealed that DMA application is useful for the determination of water loss rate in WDNs and identify a cost-effective leakage reduction program.

**Keywords** Water distribution network · Water supply network · Non-revenue water · District metered area · Water meter failures

## Introduction

Water loss is the difference between the volumes of input flow and billed consumptions (Lambert 2002; Lambert et al. 1999; Mutikanga et al. 2009). Failures

in a WDN occur due to poor-quality pipe material, unaware workmanship, high traffic loads, and pressure. On the other hand, reduction of failures and water losses in older WDNs are labor-intensive and costly. Detection of water loss needs continuous monitoring by leak detection devices to cost-effective management of failures in a WDN. Various methods and tools have been proposed to determine, prevent, and reduce water losses (Wu and Sage 2006; Decker 2006; Kanakoudis and Tsitsifli 2010). Furthermore, many researchers have recommended DMA application which is a useful tool for successful WDN management (Farley 2001; Walski et al. 2003; Thornton 2004; Herrera et al. 2010; Diao et al. 2013; Trojan and Morais 2015). Mutikanga et al. (2011) proposed a strategic planning method using multiple parameter decision support systems to reduce water losses. Gomes et al. (2012a, b) used a support decision system to separate the WDN into sub-components. Kanakoudis et al. (2014) carried out a study based on standard water budget for identifying water losses and system performance. Xin et al. (2015) evaluated the components of “unmetered consumptions” and “physical losses” to evaluate the water losses at WDNs. In literature, many different methods and algorithms have been proposed for creating a DMA in order to control and manage the water losses in WDNs. Izquierdo et al. (2011) used a multi-agent approach to divide the WDN into DMAs. Gomes et al. (2012a, b) aimed to identify the optimal inlet point of DMA and to determine the optimal location of pressure reduction valves to reduce the leakages by using simulated annealing optimization algorithm. Di Nardo et al. (2013) developed and

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Ö. Özdemir (✉)  
Malatya Water and Sewerage Administration General Directorate,  
Malatya, Turkey  
e-mail: ozgurozd@hotmail.com

proposed a methodology based on shortest-path techniques for automatic sectorization of water networks. The proposed model was tested using various performance indices in real water distribution systems. Alvisi and Franchini (2014) proposed a technique based on graph theory in order to identify DMA boundary. Di Nardo et al. (2017) studied the weighted spectral clustering method to create DMA which helped to find the best-fit solution and increase the hydraulic performance of WDNs. Kanakoudis and Gonelas (2014) revealed that the WDN should be divided into smaller DMAs for getting successful results for successful pressure management. Additionally, high-quality pipe materials and continuous leakage control are essential for cost-effective and proper WDN operation.

In this study, a DMA was created in a pilot region for determination and reduction of water losses. The study was performed in the WDN of Malatya Municipality by considering the characteristics of the pipe materials, leakage ratio, and water losses. The main focus of this work is the creation of a DMA in the existing network conditions to be used in the analysis of the water budget. The advantage of this work is that it is applied to a real network that already serves and has large water loss rates and contributes to solving a major problem. Determination of appropriate DMA boundaries in a system that is currently in operation, making site studies according to these boundaries, and ensuring complete isolation make this work different. With the DMA created, it will be possible to detect, monitor, and control leaks and minimize the losses without rehabilitation of the network in areas with very large water losses.

## Material and method

### Water loss management

Water loss management basically consists of stages recognizing water loss, locating the leakage, repair and maintenance, application of sustainable detection, and protection methods. During the WDN operation, continuous measuring of water volume supplied to network, regular recording of billed consumptions, and monitoring of the water balance are significant for a proper water management. A standard water balance methodology proposed by IWA/AWWA was used to calculate the rate of water loss (Lambert et al. 1999; Farley and Liemberger 2005). The result of water balance for

Malatya WDN in reference year of 2016 was as given in Table 1.

As seen in Table 1, the level of water loss in Malatya WDN is quite high. The WDN was divided into smaller zones by creating a DMA, made an advantage for operating and monitoring the system. It also contributed to manage the network properly with efficient determination of water losses and locations of leakages (Gomes et al. 2012a, b; Xin et al. 2015; Farley and Liemberger 2005).

### District metered area

To provide efficient water service to the entire network in the city, clear definition and isolation of the boundaries in the study area along with the determination of the inlet and outlet points of the flows in neighboring regions are important during the creation of a DMA region and precise measurement of study. A lot of methodologies based on optimization and hydraulic simulation models have been proposed and applied for creating the DMA and isolating the network from other pipes. In this study, a methodology including a total of six steps was developed and applied in a real WDN in Malatya city. The details of these steps consisting of the simulation and field works and tests were explained in “Results and discussions.” DMA was created and boundaries were defined based on the following basic rules given below:

- Operational conditions and data of current network
- Hydraulics simulation model of network
- Identifying the inlet and output points in region
- Defining the location of isolation valves
- Defining the location of flow rate and pressure gauging points
- Checking the DMA standards proposed in literature
- Testing the DMA performance by real field measurement and works
- Applying the step pressure test

### Study area and data

Drinking water demand in the city of Malatya is supplied from Pınarbaşı water resource located at the elevation of 1204 m. The flow rate of the water resource is

**Table 1** Water balance table of Malatya WDN

System input volume ( $84.18 \times 10^6 \text{ m}^3$ )	Authorized consumption ( $40.45 \times 10^6 \text{ m}^3$ )	Billed authorized consumption ( $25.14 \times 10^6 \text{ m}^3$ )	Billed metered consumption Billed unmetered consumption	Revenue water ( $25.13 \times 10^6 \text{ m}^3$ )
	Unbilled authorized consumption ( $15.31 \times 10^6 \text{ m}^3$ )	Unbilled authorized consumption ( $15.31 \times 10^6 \text{ m}^3$ )	Unbilled metered consumption Unbilled unmetered consumption	Non-revenue water ( $59.04 \times 10^6 \text{ m}^3$ )
	Water losses ( $43.73 \times 10^6 \text{ m}^3$ )	Apparent losses ( $25.99 \times 10^6 \text{ m}^3$ )	Unauthorized consumption (theft)	
			Customer meter inaccuracies	
			Data handling errors	
		Physical losses ( $17.74 \times 10^6 \text{ m}^3$ )	Leakage transmission or mains	
			Leakage and overflows an tanks	
			Leakage on service connections	

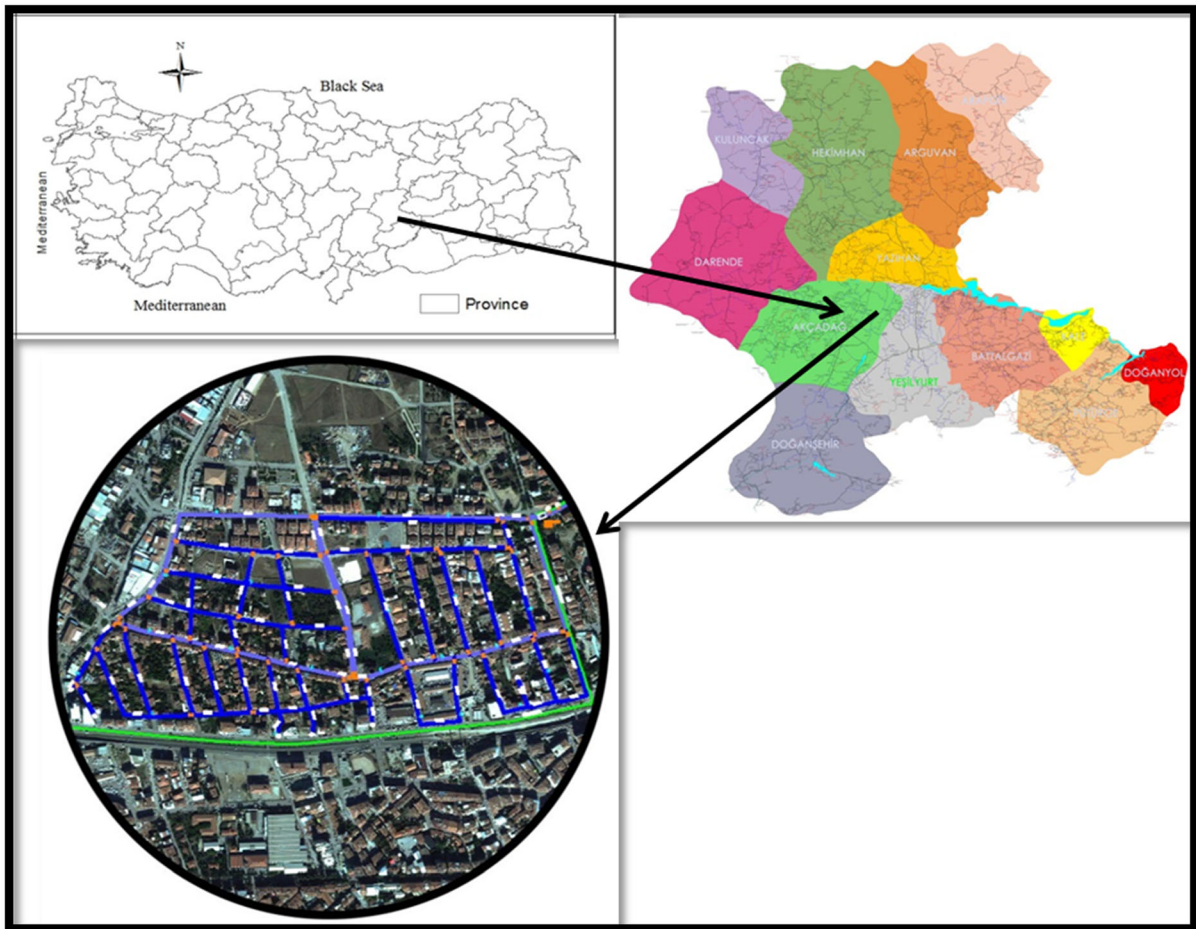
between 1800 and 3500 l/s. Drinking water is distributed in the city WDN with two transmission lines by gravity. The first line has a flow rate of 2800 l/s which is transmitted by steel pipes with the a diameter of 1400 mm while the second line having a capacity of 350 l/s is transmitted by steel pipelines with the a diameter of Ø600. The leakage ratio in the WDN is 65–70% since the current water network is made of mainly old pipelines. The current WDN consists of PVC with 996.2 km, ACP with 278.50 km, steel with 120.4 km, cast-iron with 64.35 km, polyethylene with 34.46 km, and ductile with 1 km, respectively. A general view of study area is given in Fig. 1. Between the year of 2006 and 2012, a total of 21,000 failures have been reported in the city WDN while 5111 of them was due to the low quality of the pipe material (Aydogdu 2014).

Furthermore, failure in the WDN was disturbed as 56.53% in PVC, 21.19% in ACP, 17.68% in cast-iron, and 1.60% in PE lines. These results indicated that most of the failures occurred in PVC pipes since the present network consisted of 69.10% of PVC material (Aydogdu 2014; Aydogdu and Firat 2015).

Failure rate indicates the ratio of number of failures to unit length of the pipeline and it is more accurate to use in WDN evaluation. Failure rate in the city WDN is calculated as 9.64 for PVC pipes, 8.5 for ACP pipes, and 84.6 for cast-iron pipes (Aydogdu 2014; Aydogdu and Firat 2015). The City of Malatya Metropolitan Municipality Water and Sewerage Administration (MASKI) General Directorate Authority has defined the sub-zones called DMA in the year 2015 for an effective water management. Cavusoglu and Salköprü districts were selected as pilot areas in this study (Fig. 2).

Figure 2 explains that most part of the pipelines had been serviced since 1997 while the rest was constructed in the year 1972. These figures indicated that pipelines were quite old and almost completed their economic life span. It is obvious that old and destroyed pipes in WDNs may cause frequent failures and leakages. Regarding ages and material characteristics of pipes in the application area, it can be concluded that the strength of the WDN is inadequate to work properly under pressure and external loads. The picture of the field study at application area is shown in Fig. 3.

Water distribution network lines that are not constructed in accordance with the best technical instructions and specifications are frequently causing serious pipe failures due to heavy traffic loads. Figure 4 shows the change observed in the past failure rates of



**Fig. 1** Study area

Cavusoglu and Salkopru areas between the years of 2012 and 2015 before the DMA was established.

The failures were obtained in two different ways, reported and unreported failures. The records of reported failures are saved by using “failure information system database.” On the other hand, unreported failures were determined by applying active leakage control based on listening devices in the field. The faults given in the charts include these two different faults.

According to failure statistics (Fig. 4), it is very clear that the rate of the service connection failures is higher than the failures that occurred at the network and valves. Each year, about 100 failures occur in the study area, which seriously increase the operating cost of the network and amount of water losses through the leaks. This situation reveals the difficulties in terms of system operating. Another reason increasing the leakage and problems during network operation is not being able to reach

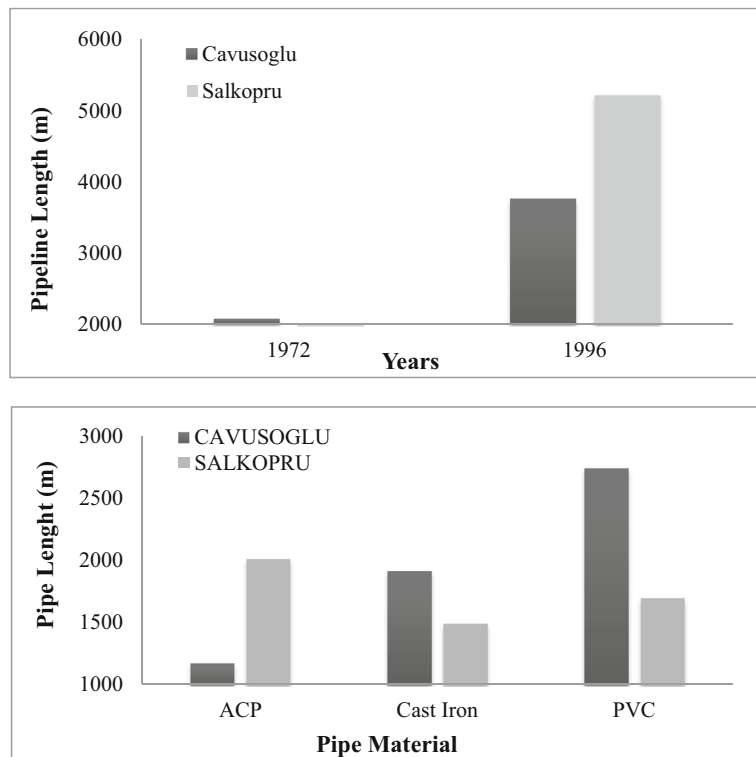
the needed material specifications and usage of improper material because of economical factors. Therefore, existing pipes at WDNs should be rehabilitated to improve the operating conditions and reduce the rate of leakage and to transmit enough and required quality water to customers in time.

## Results and discussions

### Creating the DMA

A DMA for a pilot area was created to minimize the leakage in this area by measuring flow rate and pressure. The DMA was created by following the flow chart (Fig. 5). The figure proved that a total of six steps including data collection, defining the DMA standard, filed works,

**Fig. 2** Network characteristics in application area



and test and application were followed in creating the DMA.

*Data collection*

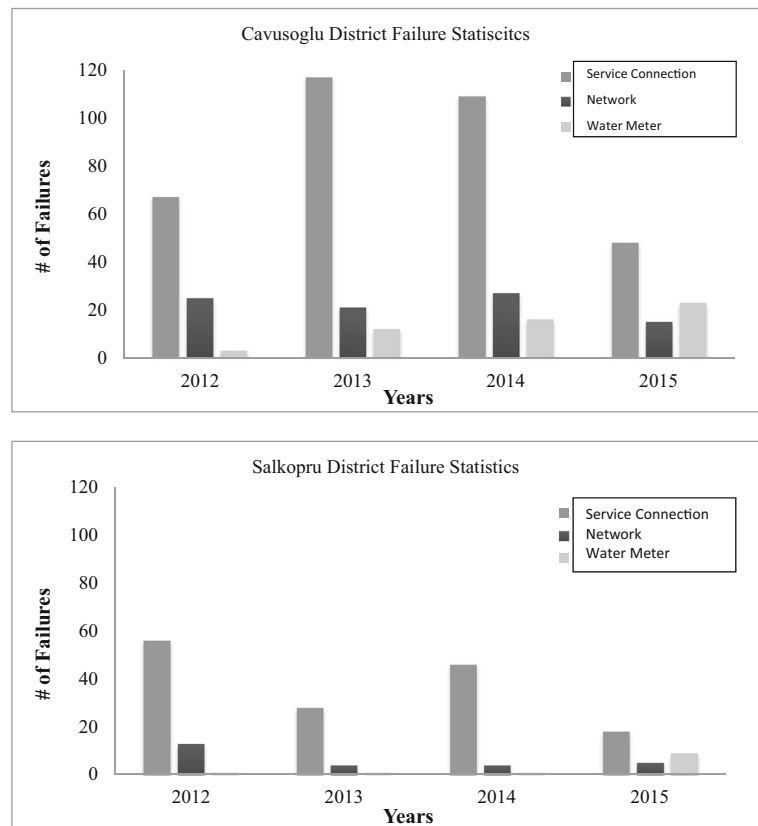
Determination of existing valve locations at the study area which have disappeared during the road

maintenances is quite important for correct isolation of the DMA from other regions. The locations of existing 47 valves which are mostly Ø100 were determined during the field study. The minimum and maximum elevations were determined as 940.3 and 952.5 m, respectively. Accordingly, the difference between highest and lowest elevations is around 12 m, and overall field

**Fig. 3** The field study at the application area



**Fig. 4** Failure statistics in application area



of application area does not contain too much elevation changes. As conclusion, pressure values of existing network at each street were obtained by using pressure measurements, which ranged from 2 to 5 bars.

In the study area, the total number of service connections and customers were 736 and 3058, respectively, which are acceptable values for an optimum DMA design. The calibration of customer water meters was controlled by field measurements for evaluation of apparent losses and its effect on total water loss at the application area. For this aim, a total of 3124 water meters that belong to 2805 customers in 735 building were controlled and physical properties of these were checked (Fig. 6).

A total of 40 testing meters have been installed in order to determine the errors by controlling the calibration of all meters. According to the results given in Fig. 6, it was determined that 36% of customer water meters were older than 10 years, 23% were older than 20 years, and 6% were older than 35 years. The results of testing meters and customer's meters revealed that about 50%

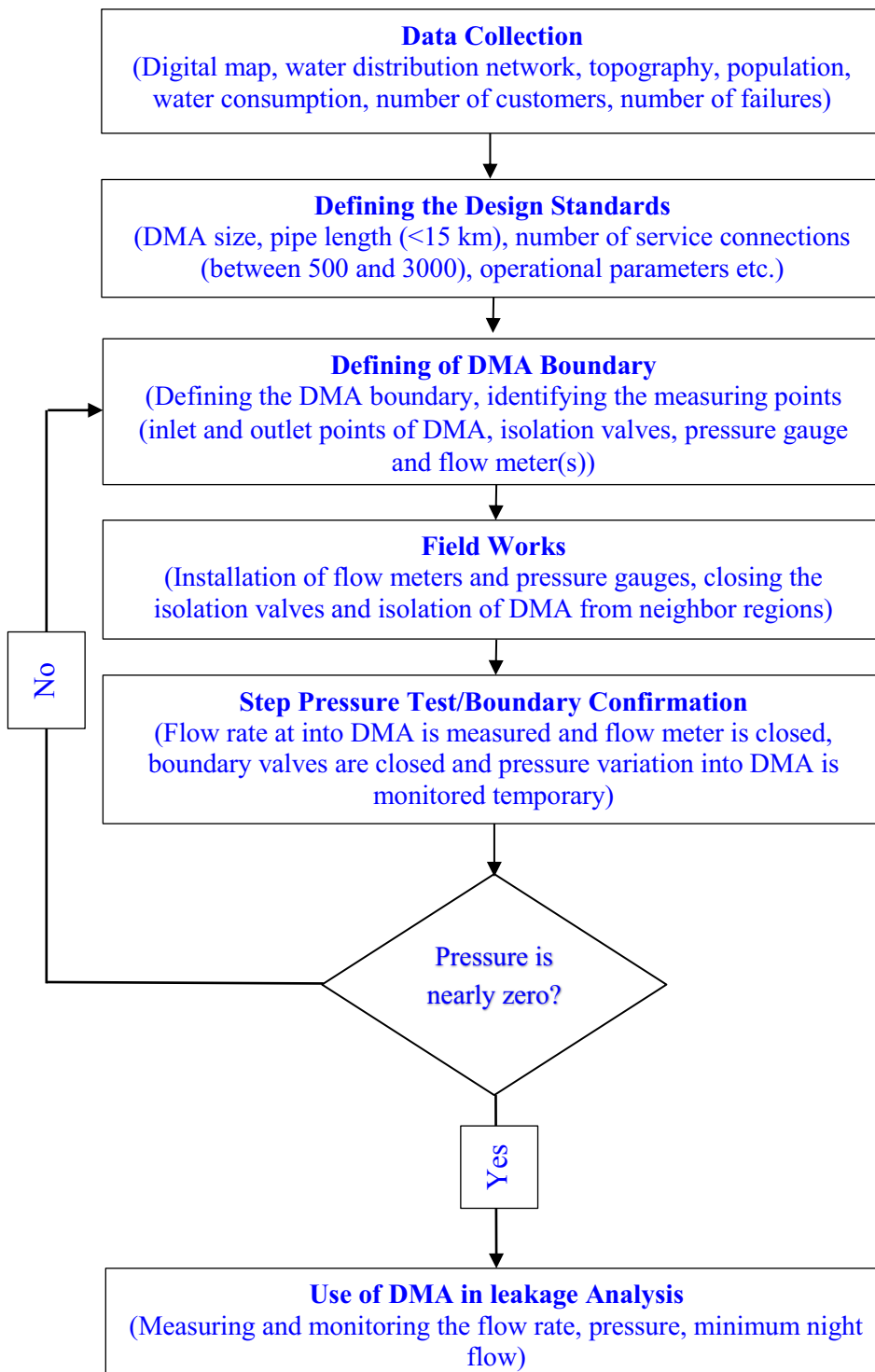
was faulty. Failure rates for customer water meters in the age range of 10–15 years were about 20%.

#### *Defining the design standards*

In literature, the number of service connections is recommended between 500 and 3000. In cases of more than 3000, monitoring of system, evaluating of night flows, determination of failures, leakage, and apparent losses could be difficult at DMAs. On the other hand, when the number of service connections is low, investment and operating cost of DMAs may increase depending on the number of flow and pressure meters, valves, and other components.

#### *Defining of DMA boundary*

The boundaries of the DMA have been defined after the current situation has been revealed in the study area. When the boundaries are determined, the boundaries are selected from the constituents so that the existing

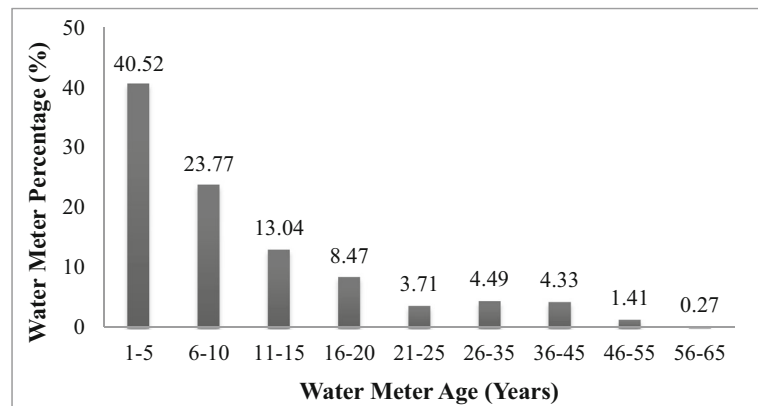


**Fig. 5** Steps in making a DMA

formed region could be more easily separated than the other regions. After defining the boundaries, the

remaining network length and number of service connections within the zone have been determined. It was

**Fig. 6** Distribution of water meters at application area (February 2015)



determined that there are 738 service connections and 12.240 m main line in the selected area.

#### Field works

Water inlet and outlet points were determined in the DMA zone whose boundaries are clear. A single water inlet point for the region was identified and the point was set to flow meter and pressure gauge. Isolation valves are installed at the water outlet points of the region. Thus, the region was completely isolated from other regions.

#### Step pressure test/boundary confirmation

A zero pressure test was performed to test the isolation process for the region where the water inlet is located. After completely closing the isolation valves, the valve at the water inlet point was also closed and the pressure drop was observed at every point within the zone. The pressure of the whole region has reached to the result

that the region could be separated completely from the other regions.

#### Use of DMA

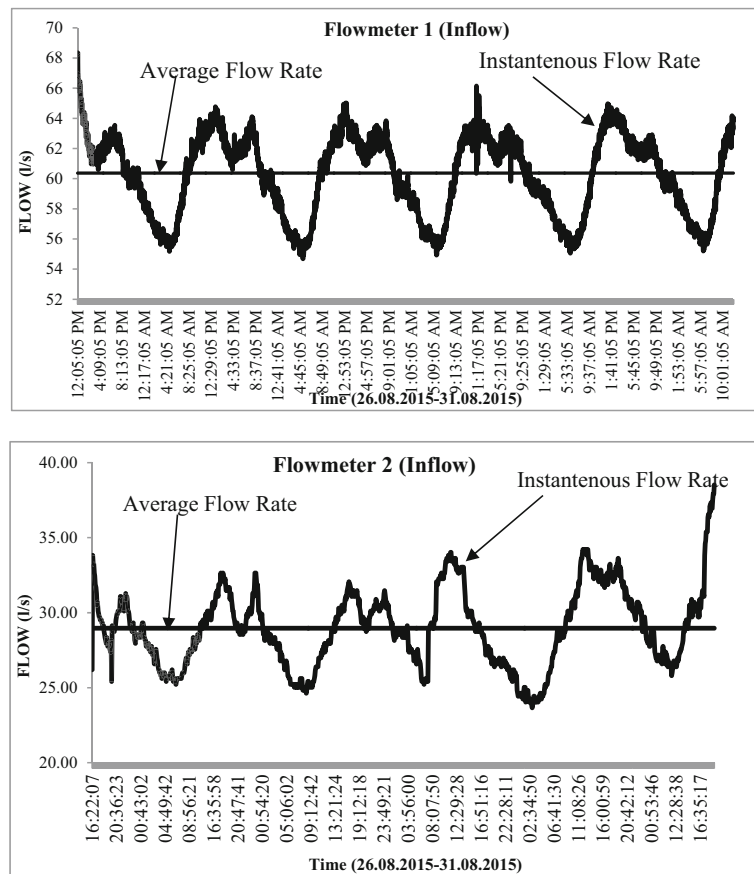
Within the created DMA, it is quite important to measure the inflow rate for establishing the water balance and determine the amount of water losses. In the application area, two inlet and one outlet flow points were determined (Fig. 7). These flow rates were measured to determine the water consumption characteristic of the system in the same period. While the flow rate of the output flow meter was 8.43 l/s, the flow meter records at input points were 60.71 and 28.96 l/s, respectively. According to these data, total discharge flow rate used in the system was obtained as 81.94 l/s. The input flow volume and billed consumption volume were compared and water balance table was formed for DMAs. The flow records of flow meters at input points at the period of 26.08.2015–31.08.2015 are plotted (Fig. 8).

**Fig. 7** Flow meter measurements at DMA and planned network





**Fig. 8** Changes in flow at application area



The input flow rate decreased to a minimum value between the service time of 00:00 and 05:00 (Fig. 8). During this period, flow meters 1 and 2 recorded the inlet flows as 50–55 and 1–25 l/s, respectively, while the total inflow was 75 l/s. Within the considered period in the DMA, the total billed consumption was determined as 42,500 m<sup>3</sup> while the total volume of inflow was 212,000 m<sup>3</sup>. This figure indicates that non-revenue water (NRW) rate was about 170,000 m<sup>3</sup> and 82%, respectively. It can be concluded that the main reasons of this high rate of water loss were old water meters and pipes. Old pipes almost completed their economic life and have lower operational strength.

As described in detail above, the low quality of network operation depended on the factors such as the low-quality pipe material, old pipeline, network failures, and broken water meter. Furthermore, it can be concluded that rehabilitation of existing network at selected DMAs should be done in short time to enhance water distribution service quality. According to the analysis and assessments carried out above, a network rehabilitation project has been

prepared and locations of valves, flow meters, and pressure measurement points in the network have been determined. The works of network renewal according to a rehabilitation project planned for DMAs was started by MASKI to minimize the failure rates, water losses, transmit the high-quality water to customers in time, and reduce the operational cost. Results of this study for this pilot DMA would be a reference for rehabilitation and design of WDNs in other regions.

**Conclusions**

This study was conducted to establish a DMA to determine water losses at the established DMA in the pilot region. In the pilot region, the rate of NRW in the DMA was calculated as 82%. To analyze the water losses, customer water meters were installed in the DMA and they were controlled by using testing water meters. With respect to the age of water meters, 36% of them is 10 and more years old, 23% of them is 20 and more years old, 6% of them is 35 or more

years old. The failure rate of customer water meters was found about 50%. On the other hand, during the measurement period of the flow meter 1 and 2 recorded the inlet flows as 50–55 and 1–25 l/s, respectively, while the total inflow was 75 l/s. Within the considered period in the DMA, total billed consumption was determined as 42,500 m<sup>3</sup> while total volume of inflow was 212,000 m<sup>3</sup>. This figure indicated that the NRW rate was about 170,000 m<sup>3</sup> (82%). It can be said that the main reasons of this high rate of water loss were old water meters and pipes. Old pipes almost completed their economic life and have lower operational strength. The results of the evaluation indicate that WDNs should be rehabilitated to locate leakages, decrease failure rate, and increase service quality in Malatya city. It can be also concluded that the DMA approach is more advantageous to manage the network, create correct water balance, and decrease the water losses in water distribution network.

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