DEVELOPING A METHODOLOGY FOR FINDING NETWORK WATER LOSSES USING INFORMATION TECHNOLOGIES: A CASE STUDY

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HAYRETTİN ONUR BEKTAŞ

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submitted by **HAYRETTİN ONUR BEKTAŞ** in partial fulfilment of the requirements for the degree of **Master of Science in Geodetic and Geographic Information Technologies Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Dr. Mahmut Onur Karslıoğlu ______________________
Head of Department, **Geodetic and Geographic Inf. Tech.**

Assoc. Prof. Dr. Nuri Merzi ______________________
Supervisor, **Civil Engineering Dept., METU**

Assoc. Prof. Dr. Zuhal Akyürek ______________________
Co-Supervisor, **Civil Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Melih Yanmaz ______________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Nuri Merzi ______________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Zuhal Akyürek ______________________
Civil Engineering Dept., METU

Prof. Dr. Uygur Şendil ______________________
Civil Engineering Dept., METU

Gökhan Bağcı ______________________
Env. Eng., ASKİ

Date: 17/12/2010

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Hayrettin Onur Bektaş

Signature:

ABSTRACT

DEVELOPING A METHODOLOGY FOR FINDING NETWORK WATER LOSSES USING INFORMATION TECHNOLOGIES: A CASE STUDY

Bektaş, Hayrettin Onur

M.Sc., Department of Geodetic and Geographic Information Technologies

Supervisor: Assoc. Prof. Dr. Nuri Merzi

Co-Supervisor: Assoc. Prof. Dr. Zuhal Akyürek

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This study aims to develop an integrated methodology for finding water leaks in a water distribution network. The integrated methodology is formed from SCADA System, Customer Information System (CIS), and Geographic Information System. The methodology is based on forming district-metered areas (DMA) and sub-DMAs in pressure zones by isolation of the network. Leaking spots in the network are localised by step testing within the DMA. With leak noise loggers leaking spots are localized with an increased accuracy and finally pinpointed by ground microphones. Minimum night flows are observed from the SCADA system before and after the repairs of the leaks to calculate physical water loss percentage in the DMA. Monthly non-revenue water percentage is calculated using the data obtained from SCADA and CIS. With a buffer analysis on the water distribution network data, the benefit of the leak noise loggers is maximized and the working time with the ground microphones are minimized. The methodology is applied in two different DMAs in Antalya water distribution network with different characteristics. In the first DMA, only the developed methodology is applied and a decrease of 19.2% is achieved in physical water losses. In the second DMA, pressure reduction is added to the methodology and a decrease of 4.9% is achieved.

Keywords: Geographic Information System, Customer Information System, SCADA, water leakage, minimum night flow, district metered area, leak noise logger, ground microphone, pressure management, Antalya.

ÖZ

BİLGİ TEKNOLOJİLERİ KULLANILARAK SU ŞEBEKESİNDEKİ KAYIPLARIN BULUNMASINA YÖNELİK METODOLOJİ GELİŞTİRİLMESİ: BİR UYGULAMA

Bektaş, Hayrettin Onur

Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri Bölümü

Tez Yöneticisi: Doç. Dr. Nuri Merzi

Ortak Tez Yöneticisi: Doç. Dr. Zuhal Akyürek

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Bu çalışma, bir içme suyu dağıtım şebekesindeki fiziksel kayıpları bulmak üzere bir yöntem geliştirilmesini hedeflemektedir. Söz konusu çalışma üç ayrı bilgi teknolojisinin bütünleşmiş bir şekilde kullanımını içermektedir. Bu teknolojiler, SCADA, Abone Bilgi Sistemi (ABS) ve Coğrafi Bilgi Sistemidir (CBS). Yöntem temel olarak, içme suyu şebekelerindeki basınç bölgelerinde izole ölçüm bölgeleri ve bu ölçüm bölgelerinin içinde daha küçük, geçici alt bölgelerin oluşturulmasına dayanmaktadır. Olası fiziksel kaçak noktaları önce alt bölgelerde yapılacak adım deneyleri ile belli alanlara sıkıştırılmakta, daha sonra gürültü kaydedici cihazlar yardımıyla bu alanlar iyice daraltılmaktadır. Son olarak yer mikrofonları ile kaçakların noktasal yerlerinin saptanması yapılıp, arızalar onarılmaktadır. SCADA sisteminden günlük en düşük gece debisindeki düşüşler gözlenmekte ve onarılan arızaların debileri ölçülmüş olmaktadır. Minimum gece debileri yardımıyla fiziksel kayıp oranları bulunmakta, SCADA ve ABS sistemlerinin aylık olarak çakıştırılması ile de tahakkuk oranları takip edilmektedir. Ayrıca gürültü kaydedicilerin daha etkili kullanımı ve yer mikrofonu ile dinlemenin en aza indirilmesi için CBS verileri üzerinde tampon bölgeler oluşturulmaktadır. Önerilen yöntem, Antalya içme suyu dağıtım şebekesindeki değişik özellikteki iki ölçüm bölgesinde saha çalışması ile uygulanmıştır. İlk uygulamada yalnızca önerilen yöntem ile fiziksel su kayıp oranında %19.2'lik bir düşüş gözlenmiştir. İkinci uygulamada önerilen yöntem basınç düşürme yöntemiyle desteklenmiş ve bu çalışmada da fiziksel su kayıp oranlarında %4.9'luk bir düşüş elde edilmiştir.

Anahtar Sözcükler: Coğrafi Bilgi Sistemleri, Abone Bilgi Sistemleri, SCADA, su kayıpları, minimum gece akımı, ölçüm bölgesi, gürültü kaydedici, yer mikrofonu, basınç yönetimi, Antalya.

To the beautiful and sunny days ahead,

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C: Hazen Williams Roughness Coefficient

V: System Input Volume

C_1: Authorized Consumption

C_2: Billed Authorized Consumption

C_3: Unbilled Authorized Consumption

C_4: Billed Metered Consumption

C_5: Billed Unmetered Consumption

C_6: Unbilled Metered Consumption

C_7: Unbilled Unmetered Consumption

C_8: Unauthorized Consumption

L_1: Water Losses

L_2: Apparent Losses (Commercial Losses)

L_3: Real Losses (Physical Losses)

L_4: Leakage on Transmission and/or Distribution Mains

L_5: Leakage and Overflows at Utility's Storage Tanks

L_6: Leakage on Service Connections up to Point of Customer Metering

I: Customer Metering Inaccuracies

RW: Revenue Water Volume

NRW: Non-Revenue Water Volume

Q_S: Total Monthly Inflow to the DMA Measured from SCADA.

q_{S1}: SCADA Index at the Beginning of the Month

q_{S2}: SCADA Index at the End of the Month

T_S: Duration of the Month in Terms of Days

t_{S2}: Last Day of the Month

t_{S1}: First Day of the Month

I_T: Daily Average Inflow to the DMA

t_{Cn1}: First Meter Reading Day of the n^{th} Customer

t_{Cn2}: Second Meter Reading Day of the n^{th} Customer

q_{Cn}: Consumption of the n^{th} Customer Between Two Meter Reading Days

T_{Cn}: Water Usage Period of the n^{th} Customer

D_{Cn}: Daily Average Consumption of the n^{th} Customer

D_T: Total Average Daily Consumption in the DMA

WL: Water Loss Percentage

dB: Sound Level of the Noise Data Loggers in Decibels

I_L: Unitless Intensity Value of the Noise Data Loggers

Ø: Pipe Diameter Prefix

A_0: Reference Amplitude of the Noise Data Loggers

A_1: Field Measured Amplitude of the Noise Data Loggers

CHAPTER 1

INTRODUCTION

1.1. General

World population increased considerably in the last century. According to the United Nations Population Fund, world population will reach 7 billion people in the year 2012. According to present estimate, 6.8 billion people are living on the earth (Web 8). With the increasing population, demand to sound infrastructure services increased enormously. Domestic and industrial demand for electricity, natural gas, telecommunication (including high-speed internet) and potable water are the most widely used infrastructure services.

Potable water resources all around the world became extra important with the increasing usage. Having limited supplies of this valuable resource, the water authorities are forced to focus on the physical water losses.

Although water loss detection studies go back up to 150 years from now, in the last years detection studies became much more effective with the improved acoustic and electronic devices. In spite of that, cities grew and became more complicated with all kinds of infrastructure including water distribution networks.

Jones (2006) draws attention to highly developed leak detection technology. Jones also states the importance of easily monitoring and detecting leaks before they come above the surface. By early recognition of leaks, pumping additional water to compensate for leaks is prevented. In addition, damages caused by undetected leaks (paving, sidewalk costs, etc.) are minimized.

From the information technologies (IT) point of view, Geographic Information Systems (GIS) combined with various IT elements broadens the horizons of leak detection studies. Summers (2001) emphasizes the importance of automated meter reading combined with GIS and says; "Automated meter-reading (AMR) using GIS technology enables real-time monitoring of water use and a degree of trouble management were not before possible".

Another subject Summers (2001) states is quickly pinpointing leaks on water mains with GIS based water readings. Also according to him, locating leaks quickly will instantaneously save time, labor, resource and money.

Another aspect on importance of leak detection is water quality aspect. Hunaidi et.al. (2000) emphasizes the risk of leaky pipes in public health risk point of view, as contaminants can enter the pressurized system in any case of water shortage or pressure drop.

1.2. Objective and Scope

The objective of this thesis is to develop a methodology for finding water leakages in water distribution networks using information technologies. The methodology is developed by integrating the data obtained from geographic information systems (GIS), supervisory control and data acquisition systems (SCADA) and customer information systems (CIS). In order to find the leaks district metered areas (DMA) are formed on GIS system and they are verified on the field. In addition, several acoustic and electronic leak detection devices are used on the field to locate and pinpoint water leakages.

Novelty of this study is using CIS data for the calculation of physical water loss and revenue loss amounts. Collecting and integrating customer information data with GIS is a very recent development in Turkey in some pilot areas only.

The study consists of eight chapters. In the second chapter, some basic concepts about water distribution network elements and theoretical equations of hydraulic solutions are given. In the third chapter, concepts about modelling of the water distribution networks are explained. In the fourth chapter basic knowledge about the water loss concepts are explained. In the fifth chapter, methodology that is developed in the thesis is explained. As applications of the methodology, chapter six contains two case studies that were conducted in Antalya water distribution network that have different characteristics in most aspects. In chapter seven, discussions of the results are given. Finally, in chapter eight, some conclusions and suggestions for future studies are stated.

CHAPTER 2

THEORETICAL CONSIDERATIONS

2.1. Elements of Water Distribution Networks

2.1.1. Pipes

The major elements of all water distribution networks are pipes. They are major carrier elements in the network in which water is transmitted from one place to another. Pipes are produced by using different materials and in different sizes.

Various materials are used in the production stages of pipes. Prestressed concrete, asbestos cement, cast iron, ductile iron, steel, high-density polyethylene (HDPE) and polyvinyl chloride (PVC) can be given as major pipe materials. Some materials like asbestos cement and cast iron are not used widely nowadays, on the other hand ductile iron and HDPE pipes are often used in many places especially in water distribution networks.

Pipes of diameters varying from 19mm to 2200mm are produced by using different types of materials. Larger diameters can also be produced upon special requests.

Pipes are mainly used for three distribution purposes:

- Transmission Lines
- Distribution Lines
- Customer Service Connections

Transmission lines are the major carrier pipes between the source and the distribution network. Usually they are the pipes between source (pump stations) and storage tanks. At various points, connections to the distribution networks are placed in order to feed the network properly. Larger diameter pipes are used in transmission lines compared to distribution lines, and their materials are usually prestressed concrete, steel, HDPE and ductile iron.

Distribution lines are the pipes that distribute the water coming from transmission lines to the streets of the network. These pipes are used to transmit water to the consumers with the help of customer service pipes. Mostly steel, ductile iron, HDPE or PVC is preferred in distribution pipes.

Service connections are the pipes delivering water from the street pipes to the customer. After the service connection pipes, interior pipes in the building distribute water to different customers and deliver water to the taps. Mainly HDPE is used in service connection pipes.

2.1.2. Pumps

Pumps are devices converting electrical energy into mechanical energy for moving water volumes by increasing their potential energy. This energy is used to overcome friction losses in the pipes and raise the water to topographically higher points.

Pumps are selected carefully depending on various factors in the network, such as topography, water demand of the consumers, efficiency requirements, etc.

2.1.3. Valves

Valves are the elements used to control water flow in the distribution network. Controlling water flow can be done by blocking flow, directing flow from one path to another path in the network, increasing or decreasing the amount of flow in the pipes, etc.

There are many types of valves used for many different purposes. The exact locations of the valves on the network are extremely important for operation purposes. The types and places of the valves should be known precisely in order to make correct operational decisions.

2.1.3.1. Isolating Valves

As the name implies, isolation valves are used to separate a part of the network from the rest. This action interrupts water flow in the line and creates a dry part in the network for repair and maintenance purposes. Generally, gate valves are used for isolation actions. Gate valves are not intended to control the flow amount in the network by partial closure. They are intended to permit flow or stop flow by complete opening and closing.

Another usage area of isolation valves is to separate water distribution networks into separate pieces without creating water shortages. It is especially useful while forming district-metered areas

(DMA) explained in Chapter 5.

2.1.3.2. Control Valves

Control valves are used to control the amount of flow in the water distribution network. They are usually butterfly type valves. By adjusting the butterfly valve's interior mechanism, diameter of the pipe section can be reduced. This will enable adjustment of amount of flow in the pipe.

2.1.3.3. Check Valves

Check valves are the type of valves that permits water flow in one direction only and blocks water flow if an opposite directional flow occurs. The flow inside the pipe controls this type of valves. Unlike other valves, it works without any operator. It is used widely after pumps in order to prevent backflow towards the pump.

2.1.3.4. Air Release Valves

Air is to be avoided in a water distribution network. It enters to the water distribution network generally while installation or during repair works. Air Release valves are the fittings that remove air from the pipes. They are especially placed at the highest points in the transmission lines and distribution pipes as air bubbles accumulate at the top sections of the pipes. Like check valves, air valves do not require any operator to work.

2.1.3.5. Drain Valves

Drain valves are gate valves one end open to atmosphere (often connected to the sewerage lines) placed at the lowest points of transmission lines and distribution networks, for emptying the pipeline whenever necessary. At the low points of the pipe, it is possible to empty the pipes that are at higher elevations. Emptying pipes are useful during repair works, rehabilitation studies, etc.

2.1.3.6. Pressure Reducing Valves (PRV)

PRVs are used to decrease high inlet pressures in the network. Water passing through the valve is forced to create friction losses in the valve mechanism. Therefore, pressure is reduced at the desired level. Preventing high pressures decreases water leakages in the network, as the amount of water flowing through the leaks are directly proportional with the pressure in the system. PRVs have many types. They may only reduce pressure at constant amounts, or adjust the pressure reduction amount by considering some other parameters like hours of the day or demand of the consumers in the network.

2.1.4. Distribution Reservoirs

Distribution reservoirs are the major water sources of a water distribution network. They are usually dams or water treatment plants storing large volumes of water.

2.1.5. Storage Tanks

Storage tanks are water-storing structures to provide extra water to the network when needed. The needed periods are usually when pumps do not work. At those times, storage tanks work as the only water sources of the system. Similarly, storage tanks help pump flows at peak demand hours. In addition, storage tanks are useful to overcome pressure fluctuations in the system and provide an even pressure distribution. Having a storage tank also provides excess water for fire demands and emergency cases.

2.1.6. Fire Hydrants

Fire hydrants are useful fittings placed in the water distribution networks mainly for fire extinguishing purposes. The important property of these fittings is that they are connected to the network with relatively large diameters when compared to a house connection. This allows the user to draw large amounts of water from the hydrant.

Street washing, network flushing, sewer cleaning are some more usage areas of fire hydrants. In addition, while modelling the network, calibration studies can be performed by using fire hydrants.

CHAPTER 3

MODELLING THE NETWORK

Modelling water distribution systems with the help of computer software products became indispensable in the last years. Modelling study is done for many purposes like designing the network before construction, and operating the network after the construction is completed. For all kinds of modelling purposes, basic data about the network is needed. Needed data consists of pipe layout data (including pipe characteristics) with all elements (valves, pumps, tanks, reservoirs, etc.) of the water distribution system, consumption data, and topographic elevations of the network elements.

The reason to create a water distribution model can be stated as having a copy of the reality that lies under the ground, inside computerized applications. Using the stated data, modelling of a water distribution system can be done. The important thing about modelling data is the quality of the data. Every piece of data should be representing the reality in the field accurately. Otherwise, every error in the source data will introduce bits of uncertainties into the model. With a model having too much uncertainties, means a model that does not represent the reality at all. That kind of a model can be useful for theoretical studies, but will not be appropriate for designing a system or operating an existing network.

Geographic information systems are one of the most useful tools in water distribution system modelling. They are useful because in a comprehensive GIS used by the designer or by the water authority, usually all the needed data are included. With some data transfers or with the help of some developed modules, it is easy to generate a working model. Shamsi (2002) defines three methods to link GIS data with computer models. They are:

1. Interchange Method
2. Interface Method
3. Integration Method

In interchange method, GIS and the model are not linked together. Input parameters are transferred from GIS to the model, they are processed in the model independently and the output values are transferred back into the GIS as a new layer for presentation purposes.

In interface method, model is still executed independently elsewhere from the GIS, but a pre-processor for extracting input values and a post processor for displaying the results are available in the GIS environment. Helping menus or buttons can be added into the GIS environment. It is simply automation for manual actions stated in interchange method. Some knowledge of computer programming is necessary for this automation.

Integration method is the combination of GIS and the model. The combination is provided both GIS functions and model capabilities. In this method, either model is integrated into GIS or vice versa. However, it is a better choice to integrate water distribution capabilities into the GIS software, as geographic information systems are systems that are more inclusive.

3.1. Water Distribution Network Modelling Principles

Shamsi (2005) summarizes hydraulic modelling process into three major steps:

1. Development of spatial database
2. Extraction of model layers
3. Linkage to computer models

Development of spatial database is one of the main works done in GIS. Extraction of model input parameters are done mainly with the data exporting features of the GIS software solutions. Computer model links can be developed using one of the three methods stated in Chapter 3. This summarization again shows the importance of GIS in modelling issues.

Shamsi (2005) emphasizes three input parameters used in hydraulic models. These are skeletonized pipe layouts, nodal demands (consumers) and nodal elevations.

3.1.1. Modelling of Pipes

Pipes in a water distribution network are drawn on paper as linear features in the past years. Those drawings are stored on plain paper or tracing paper in archives. Some very old pipes are not even drawn on paper, staying as mysterious infrastructure elements that nobody knows enough or correct information. At these times, modelling studies relied on existing projects of the pipes and verbal knowledge (if there are any) of the personnel.

With the improved technology, paper sourced data are transferred into CAD or GIS environment. Additionally, newer projects are prepared as CAD drawings mostly. Therefore accessing the needed pipe data became easier.

Assuming properly scaled pipe layouts, lengths and interrelations with other pipes can be obtained. With schematic pipe layouts, either assumptions about the length should be done or field measurements should be done preferably with pipe locator devices.

Additional pipe characteristics are also needed. These characteristics are diameter and roughness coefficient. Diameter data is usually available on the layout plans with some margin of error. However, pipe roughness coefficient is one of the most difficult parameters to determine. As roughness of a pipe is determined by a dozen of factors, including pipe material, age, water quality, etc., some predetermined values for Hazen-Williams C coefficient are used for newly installed pipes. According to the performance of the pipes, several calibration studies for the roughness coefficient can be done to determine a realistic value for C.

As GIS layers may contain unnecessary details of the pipes (like tees, corners, valves, fire hydrants, service connections, etc.), simplification is essential before modelling the network. This process is called skeletonization. By getting rid of the unneeded details in the pipe layout, model-processing speed is increased incredibly. In addition, model results are not affected significantly.

Considering the type of model usage, level of skeletonization can be determined. For analysis requiring only storage tank elevations, modellers do not need any house connection pipes and distribution networks. Transmission lines are enough for modelling. On the other hand, if pressure changes at every house connection during the day are a matter of concern, then every consumer pipe is needed for a healthy model.

3.1.2. Modelling of Consumers

Nodal demands indicate the consumption rates in volume per unit time; mostly, litres per second (l/sec) and meter cubes per hour (m^3/hr) are used for consumption rates.

Consumers and their consumption values used to be kept in databases or spreadsheets. This situation did not allow the modeller to use consumers one by one in a complicated model. Instead, modeller used individual users' consumption values accumulated at one point. As a result, consumption variations in different customers were not clearly seen in the analysis.

However today, some of the municipalities and water administrations have attempts on collecting houses as point features using GPS. With these data collected and combined with the formerly used consumption databases in GIS environment, every customer and corresponding consumptions can be used as precise modelling data. In addition, customer types can be used to determine demand patterns and time-based analyses can be possible.

As data collecting is a cumbersome issue, positioning the customers with GPS and matching them with correct address information should be done carefully. One of the most important issues about consumption modelling is to determine the exact point of service pipe and network pipe connection. This knowledge will help modeller to determine the pressure zone of the consumer, which in some cases modeller may not be able to determine this knowledge by positions of consumers and pipe layouts. It is a common situation at pressure zone borders to have two different network pipes under different pressure zones.

Water losses can be modelled by distributing them to the customer nodes, as their exact spots are not known. Alternatively, leak spots can be clustered to some part of the network if it is known that it is a weak part of the network.

3.1.3. Modelling of Nodal Elevations

Determining exact topographic nodal elevations of an existing water distribution network can be a difficult job. If pipes are installed at a constant depth from the ground surface, then determining ground elevations, then subtracting the depth from ground elevations will yield the elevations of the nodes. However, in practice installing the entire network at a constant depth is not possible at every location. Existing infrastructure elements or difficulties faced due to stiff soils, depth of the pipeline does not stand constant. If elevation data at every node are not collected, then it is a difficult task to determine the nodal elevations after the installation. Therefore, usually ground elevations are assumed as nodal elevations of the network (Shamsi 2005). Additionally ground elevations are the easiest data that can be obtained.

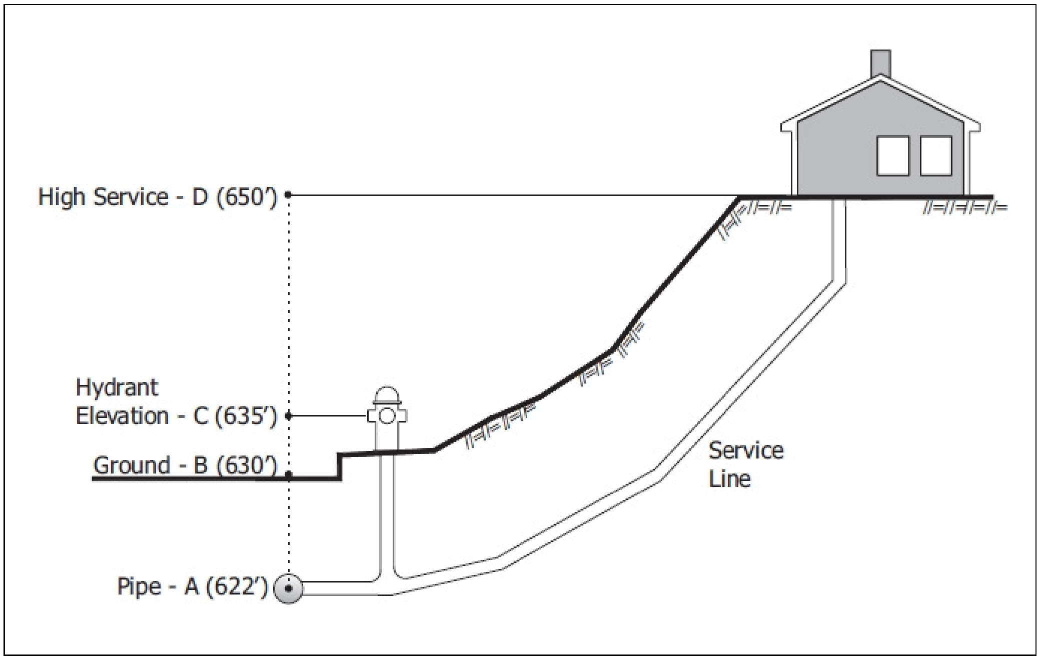


Figure 3.1: Different elevation choices for a hydrant (Walski et.al 2003)

Figure 3.1 shows different choices (A, B and C) for modelling a hydrant's elevation. Pipe depth (Point A) can be considered for modelling nodes but it may be a difficult job to determine the true depth of the pipe. Ground elevation (Point B) is the easiest measurable elevation for modelling node elevation; however, it will not represent the true elevation of the physical reality. Hydrant elevation (Point C) can be easily determined on the other hand it will not be so easy to gather elevations of points on other nodes like corporation cocks, or pipe branching points.

Ground elevations can be determined from classical geodetic methods, air photography or with GPS instruments. With the new established Cors-TR system, it became easy to determine elevations of any ground point very accurately by using a real time kinematic (RTK) compatible GPS device. At the end, collected elevations of the points are used to generate digital elevation models (DEM) to interpolate the elevation values of nodes. Most modelling and GIS software products are capable of assigning elevation values from the set of elevation data.

Topographic elevations of a water distribution network are important to determine the hydraulic grade at each node. Hydraulic analysis results will not be meaningful unless all nodes in the network are determined.

3.1.4. Modelling of Pumps, Tanks and Reservoirs

Pumps are usually essential elements in a water distribution network. They are modelled as point objects. Minimal needed data about pumps are their elevations, pump characteristics and inlet pressures. Without these data, pumps cannot be used in hydraulic analysis.

Tanks are point elements in the model. Base and water elevations should be known in order to include a tank into the model. Additionally, base area and shape of the base area are important issues for the investigation of oscillations in water levels in a dynamic analysis.

Reservoirs are modelled as point elements. Dams or water treatment plants providing water to a network can be modelled as reservoirs. Water elevation (and the oscillations in that level) in a reservoir should be known for modelling purposes. Groundwater sources can be considered as distribution reservoirs too.

3.2. Use of GIS in Modelling

3.2.1. Digital Elevation Models

Digital elevation models are the major sources of nodal elevations when a water distribution system is being modelled. Usually they are produced by various methods of interpolation. Geoid height data obtained by geodetic techniques or ellipsoidal heights obtained from GPS measurements are converted to geoid elevations with appropriate transformation parameters. After obtaining DEMs, contour maps are also produced. Contour maps and DEMs of the service area are important for a water administration for both planning and operating applications.

3.2.2. Digitized Network Maps

Most water distribution networks that are in use now are installed before accurate mapping applications were present. As a result, the as-built projects (if there are any) were mostly schematic drawings showing the routes pf pipes and schematically representing places of network fittings.

Geodetic measurements of pipe elevations are necessary if a transmission line between a pump and a storage tank is being constructed; however, in the distribution network elevation values are not collected in most old projects. Pipe elevations were assumed as a constant value below the ground elevations. However, due to changes in land use, some roads were filled and some of them were lowered. As a result, depths of network pipes became inconsistent with ground elevations.

As pipe elevations were not given enough importance in networks, only inaccurately coordinated or fully schematic x-y layout plans are the only data source while analyzing the network for modelling purposes. Digitizing these network maps becomes an important task at this stage. This task should be done either by scanning maps into computerized environment and coordinating by the help of softwares or by using digitizing tables. Regardless of the method preferred, pipelines should be digitized as polylines or lines, and fittings should be digitized as point features.

One last point to consider is very important for this task to be completely achieved. That is the updating the digitized network. An update is strictly needed because; the digitized network maps will be representing the networks first installment situations. Within time, various changes may have been applied on the network. These changes may be newly installed pipes and valves, cancelled out pipes and valves, displaced pipes and so on. Updating such changes on the digitized data will help the administration to have an up-to-date network data. As a result modelling an up-to-date network will represent more realistic values with the field observations.

3.2.3. Geodetic GPS Instruments

Nowadays, with the use of Cors-TR system, both x-y and z measurements having centimetre accuracies can be done with geodetic GPS devices. Most newly installed pipelines and are coordinated using geodetic GPS instruments. When coordinating pipelines, points on straight sections are not usually considered. Only points at nodes that an angle occurring between pipes are coordinated. Finally, when these points are combined with line or polylines, a linear feature representing the pipeline is obtained.

Coordinating pipe fittings is easier as only point data is collected from the field. The important thing is to collect point data always from the same place on every type of fittings (i.e. from the top point of the valve shaft) in order to calculate the elevation of pipe's internal elevation when necessary.

Coordinating pipelines and fittings is very helpful for exploring an old portion of networks. Pipelines are digitized as explained in Section 3.2.2, then by coordinating pipe fittings will help to transform the schematic drawings into better coordinated network layouts. Also, when pipe fittings are coordinated using geodetic GPS devices, they are easily found in case they are lost under asphalt some day. As geodetic GPS devices give centimetre accuracy, minimum excavation and searching will be done on the field, and fittings will be easily found.

As a result, a network having very realistic coordinates will be obtained. It will be very useful, when accurate network layouts are overlaid on a digital elevation model. Pipe elevations will then be available to the designer and analyzer with maximum accuracy. Therefore, modelling results will be more realistic and nearer to the field observations. High accuracies in x-y are useful in overlaying applications and high accuracies in z values may be very useful when calibrating the water distribution network, which considers head loss values as little as a few decimetres.

3.3. Use of SCADA System

Supervisory control and data acquisition (SCADA) systems are very useful tools for every kind of analysis in a water distribution network. In special, SCADA systems can be used to gather input parameters in a hydraulic analysis. SCADA systems in water distribution networks are used mainly in:

- Pump stations; measuring discharges, inlet and outlet pressures.
- Storage tanks measuring water levels.
- Any critical point defined by the authority measuring discharge and pressure.

Pump station and storage tank measurements can be used to determine daily demand curves of a region. Additionally, if measuring points are placed at the entrances of district-metered areas (DMA), instantaneous consumption in the area is measured directly. With the obtained consumption values of the region, demands at the nodes can be estimated.

Having a SCADA system has numerous advantages. One of them is having continuous measurements and recording them. Accessing the historical data enables the operator to see changes in the network and take actions according to them.

In addition, as measurements are continuously recorded, monthly (or yearly) water budgets can be derived. Combining SCADA data with the customer information system (CIS), opens the way of calculating revenue water, non-revenue water and water losses. These topics are studied with more detail in Chapter 4.

3.4. Use of Customer Information System

Customer Information Systems (CIS) can be a very useful data source in water distribution system modelling. The major data that will be obtained from CIS is the (generally monthly) consumptions of the customers. Besides keeping the record of consumptions, in CIS various information about the customers can be kept too. Some examples for these records can be address information, identification information about the customer (name, surname, telephone number, e-mail address, etc.), customer id number, pressure zone of the customer, information about the water meter, etc.

Monthly consumption values can be jointly used with SCADA measurement records to calculate water losses as stated above. The significant thing to consider for each customer in the CIS is to clearly determine which customer is connected to which pressure zone. If this knowledge is obtained exactly, water loss amounts in the interested region can be determined for sure. Chapter 4 gives detailed information about these topics.

CHAPTER 4

WATER LOSS CONCEPT BASICS

Water loss concept is a sophisticated concept and contains many components. These components should be clearly understood in order to take action on the major title. Before getting into the components, it is a necessity to see the full picture. International Water Association (IWA) prepared an international standard approach for standard water balance calculations. This standard approach can be seen in Table 4.1.

Table 4.1 explains the total input volume of water entering into the network and by dividing it into smaller components and placing the components into different categories. Each component and category has individual physical meanings. They are explained with examples in Section 4.1.

Usually in water administrations, different departments deal with the basic components of the water audit. For example, all consumption values (C_4 to C_8) can be collected by the customers department, while leakage terms (L_4 to L_6) are calculated by the water loss department. Unauthorized consumption issues can be solved with the help of a specialized department, while input volumes can be measured by the SCADA department. With such an administrative structure, it may be hard to collect the whole data together and complete the water audit table. Therefore, a shared database can be made available to all the departments in the administration to make the data transmission easier.

Table 4.1 IWA Standard Water Balance (Web 5)

System Input Volume (corrected for known errors) **[V]**	Authorized Consumption **[C_1]**	Billed Authorized Consumption **[C_2]**	Billed Metered Consumption **[C_4]**	Revenue Water **[RW]**
			Billed Unmetered Consumption **[C_5]**	
		Unbilled Authorized Consumption **[C_3]**	Unbilled Metered Consumption **[C_6]**	Non-Revenue Water **[NRW]**
			Unbilled Unmetered Consumption **[C_7]**	
	Water Losses **[L_1]**	Apparent Losses (Commercial Losses) **[L_2]**	Unauthorized Consumption **[C_8]**	
			Customer Metering Inaccuracies **[I]**	
		Real Losses **[L_3]**	Leakage on Transmission and/or Distribution Mains **[L_4]**	
			Leakage and Overflows at Utility's Storage Tanks **[L_5]**	
			Leakage on Service Connections up to Point of Customer Metering **[L_6]**	

4.1. Definitions

System Input Volume: This is the total volume of treated water introduced to the system. Here, system is part of the network, which the water balance in Table 4.1 is being calculated. Input volume should contain imported volume of water if there is any. The amount should be corrected for known errors. The volume at this stage is the sum of all components of the water audit. When calculated or measured precisely the components should add up to System Input Volume. It is denoted by “V” and is composed of the terms Authorized Consumption (C_1) and Water Losses (L_1).

$$V = C_1 + L_1 \tag{4.1}$$

Authorized Consumption: It is the total volume of billed and unbilled water taken by registered customers. Billed and unbilled water may be either metered or unmetered. If there is any water exported, it should be included in this term. In addition, leaks after the customer meters are added to this term. It is denoted by C_1 and composed of the terms Billed Authorized Consumption (C_2) and Unbilled Authorized Consumption (C_3).

$$C_1 = C_2 + C_3 \tag{4.2}$$

Water Losses: These are the total amount of Apparent (L_2) and Real Losses (L_3). They sum up a large part of Non Revenue Water volume.

$$L_1 = L_2 + L_3 \tag{4.3}$$

Billed Authorized Consumption: It is the sum of both metered (C_4) and unmetered (C_5) consumptions. These two components are the only terms included in revenue water. Therefore, Billed Authorized Consumption is the only term that the water administrations can generate income.

$$C_2 = C_4 + C_5 \tag{4.4}$$

Unbilled Authorized Consumption: It is the authorized consumption of customers, to whom a privilege is given by the water administration. They are included in Non Revenue Water amount as no billing is made for their consumptions. This type of consumption may be metered (C_6) or unmetered

(C_7).

$$C_3 = C_6 + C_7 \quad \textbf{(4.5)}$$

Apparent Losses: They consist of unauthorized consumptions (C_8) and water meter inaccuracies (I). They are referred as water losses but they are not actual water losses that leave out the system. They are also called as commercial losses, which indicate that the actual lost thing is money. Apparent losses are impossible to avoid completely, but with convenient methods, they can be minimized.

$$L_2 = C_8 + I \quad \textbf{(4.6)}$$

Real Losses: These are the major topics of interest in this study. They are the amount of water that somehow leaves out the system by leaks and overflows before the points of customer meters. This term can be separated into three terms of Leakage on Transmission and/or Distribution Mains (L_4), Leakage and Overflows at Utility's Storage Tanks (L_5) and Leakage on Service Connections up to Customer Meters (L_6). This term cannot be avoided completely but with appropriate methods, it can be decreased in high amounts.

$$L_3 = L_4 + L_5 + L_6 \quad \textbf{(4.7)}$$

Billed Metered Consumption (C_4): It is the major term in revenue water. It consists of mainly customers whose consumptions are being metered and billed. Residential users, commercial users, factories can be given as examples to this category.

Billed Unmetered Consumption (C_5): It is the term, in which a billing action is done to the consumers but that action is not done depending on metering values. It means customers are not billed by volume, instead an approximation is done to the consumptions they are making and billing is done according to that approximation. An example may be a billing to a customer, whose water meter is not functioning for a short time. Then an estimate can be done for this period's consumption.

Unbilled Metered Consumption (C_6): This type of consumption is metered but not billed. Examples may be given to the water usage of water administration itself or water supplied to some institutions without any billing (schools, religious facilities etc.). To be able to keep a record these amounts are metered.

Unbilled Unmetered Consumption (C_7): Neither metered nor billed consumptions are in this category. Examples are usually water drawn from fire hydrants by the fire authority, public garden watering, water used in street cleaning, water used in network flushing and discharging water from the network in a repair work. These sub terms can be transferred to unbilled metered consumption by using appropriate water meters while using water.

Unauthorized Consumption (C_8): It is the illegal usage of water in anywhere by any means from the distribution pipes or by deactivating the water meter by any methods to decrease the metered usages. As this action is illegal, water administrations apply fines to people doing unauthorized consumption. The amount of this consumption is naturally not metered. It is approximately determined.

Customer Metering Inaccuracies (I): They are defined as both meter reading errors and errors due to the type of the water meters. Water meter reading errors can be explained by rounding a decimal metered value to the nearest integer value in order to bill the customer (i.e. rounding 3.4 m^3 to 3 m^3). Water meters of type B are widely being used. However, this type (and its similar types) does not meter very low amounts of use. As a result, very little usages (like water dribbling from the taps) will not be metered with low accuracy meters. Type C and better accuracy water meters should be used to decrease the amount of water included in this term.

Leakage on Transmission and/or Distribution Mains (L_4): Any type of leakage that occurs on transmission mains or distribution mains is this kind. Either they are repaired, or they keep on leaking until they are discovered.

Leakage and Overflows at Utility's Storage Tanks (L_5): Leakage occurring at storage tanks can be avoided by water insulation methods used on structural elements. Overflows are possible outcomes of a bad management of storage tanks. They can be avoided using by automated systems like SCADA.

Leakage on Service Connections up to Point of Customer Metering (L_6): Leakages occurring on service connections are one of the major sources of water leaks. As they occur before the customer meter, water leaving the system is wasted without getting any revenue.

Revenue Water (RW): Revenue water is the total consumptions of water that produce revenue to the water administration. Naturally, administrations would be pleased to increase the revenue water amounts. It can be made possible by reducing the terms that are listed in non-revenue water in any amount. As the total supplied water amount is the sum of revenue and non-revenue water amounts, decreasing one term increases the other. To achieve an increase in revenue water:

- All types of unbilled consumptions should be billed
- Illegal usages should be prevented
- Precise water meters should be used
- Water losses should be prevented.

$$RW = C_2 = V - NRW \tag{4.8}$$

Non-Revenue Water (NRW): Non-revenue water is the sum of all terms except C_4 and C_5. This sum may constitute a large part of the total water supplied. Non-revenue water should be decreased as much as possible. It may be achieved by decreasing all the terms it includes one by one. Its main disadvantages are:

- Providing no revenue to the administration
- Wasting valuable amounts of water in some terms

$$NRW = C_3 + L_1 \tag{4.9}$$

Before beginning a study on the field, some measurements should be collected to have an idea about the properties of water usage of the interested region. Flow and pressure measurements are the basic parameters of the water loss studies. Measuring flows at the entrance of an isolated region provides daily demand curves of the region.

Daily demand curves are very basic and useful graphs that are drawn with the data obtained from isolated areas in field. Briefly, the daily demand curves are graphs showing the variations in flow with respect to time. Examining these graphs covering at least one day, reveals the water usage of the interested area. In Figure 4.1, a sample daily demand curve is given with its components. The components are described below. Apart from water usage characteristics, minimum nightly flows are observed in daily demand curves. This parameter is one of the basic parameters that indicate the amount of water leaks.

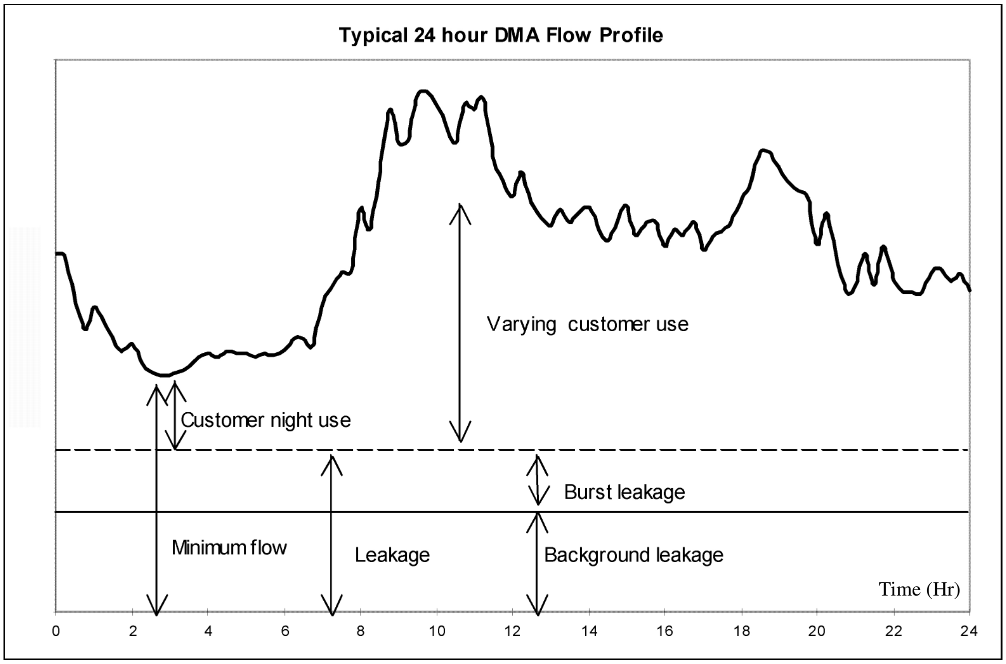


Figure 4.1 Typical Daily Demand Curve and Its Components (Web 7)

Minimum flow is the amount of discharge that enters to an isolated water distribution network (i.e. a DMA), at night hours (usually between 02:00 and 04:00). This value is an important value as it is the closest value to the physical loss amount of that network. As minimum night flow is the closest value to the physical water loss amount, usually these two values are assumed the same. When bursts or increases in background leakage occur in the network, minimum night flow level increases too. An ultimate minimum level should be reached at any region, and this level should be conserved by checking if there is an increase. If there is a big increment in the minimum night flow level, leak detection studies should be performed to reduce the level to its original value. In Figure 4.2 a sample for minimum night flows and burst effects are given.

Background Leakage: Background leakages can be defined as unavoidable small losses that are impossible to detect with today's technology of active leakage detection techniques. Today's technology mostly depends on acoustic detection, so flow rates of a very small leakage makes very little sound. Background leaks are very little seepages through any part of the network. They are discovered either by chance or after some time when they are big enough to be detected.

The amount of background leakages is directly proportional with the pressure. Therefore, to minimize the background leakages, pressure reduction techniques may be useful.

Bursts: Bursts are leakages that are bigger than background leakages, which can be detected with active leakage detection techniques. Bursts should be effectively detected and fixed as quickly as possible as the discharge that is lost through these events are greater than background leakages.

Bursts are usually reported by the customers if a harmful situation occurs, but bursts that is not harmful to any customer is not reported, as its existence is not known yet. Active leakage detection techniques are aimed to find and fix the bursts that nobody is aware of.

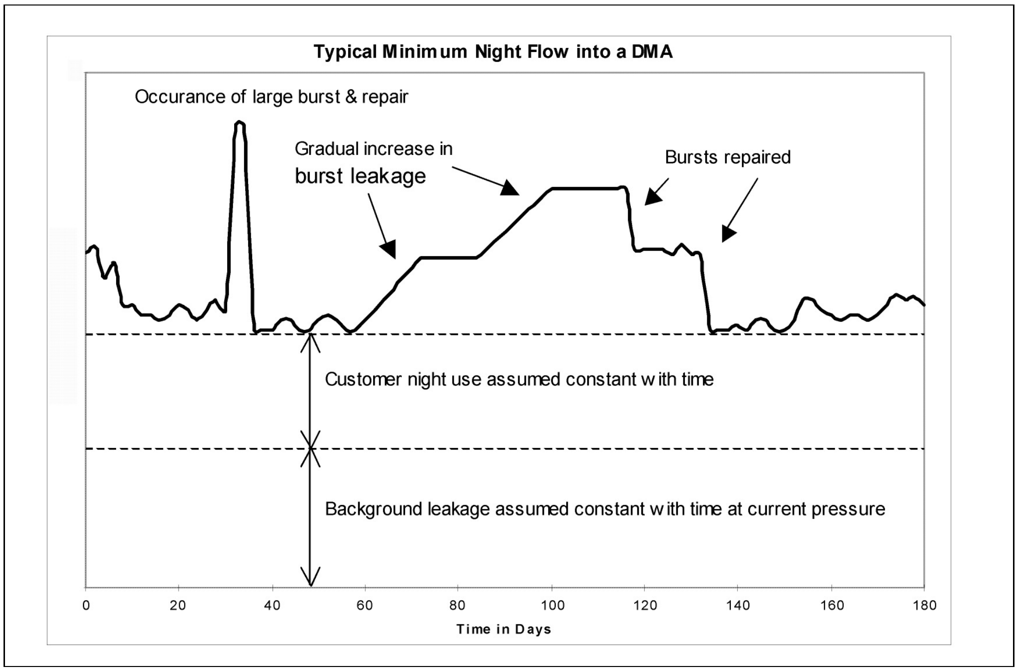


Figure 4.2 Typical Minimum Night Flow Changes with Time (Web 7)

Leak Duration: Leak duration is the time that passes between the occurrence of a leak and repairing of it. The duration can be divided into three components. They are; awareness duration, locating duration and repair duration. Any leak keeps on flowing throughout these three durations until it is fixed. These are awareness duration, locating duration and repair duration. To minimize the losses, minimum time should be spent on these three durations.

Awareness duration starts from the occurrence of the leak and lasts until the leak's existence is understood. If Active Leak Control (ALC) is being applied, this duration also includes locating duration. IF Passive Leak Control (PLC) is being applied, then awareness duration is the duration starting from leak occurrence and ending with the reporting of it to the water administration. Awareness duration may differ from a few hours to a few years. If the leak is big, visible above the ground and effects the customers directly, its existence will quickly be known. However, if the leak is small, hidden underground and does not affect any customers directly, its existence can be unknown for a long time.

Locating duration is the duration of pinpointing the leak spot using the leak detection tools. The duration is usually short in PLC type of approach. It does not exceed a few days usually. In ALC type of approach the locating duration is included in awareness duration as mentioned. This is because when a leak's existence is known with ALC, it is also located in the field.

Repair duration is the duration that passes while the leak is being fixed. With enough repair teams, this duration rarely exceeds one day.

4.2. Sources of Leakage

Leaks in a water distribution system can be categorized under many headings. At the end, every classification defines a part of the physically wasted water amount.

Here, leak sources are classified under two main headings. First one can be named as losses at the water sources, and second one can be named as losses at the distribution elements. All of the categorized elements have a different share on the total amount of leakage. Regardless of the share of leak amounts, every leakage should be investigated and minimized as quickly as possible. However, the shares of different leak sources should be known in order to determine which source has a bigger percentage and which source should be treated primarily.

4.2.1. Leaks Occurring at the Sources

Untreated water obtained from any kind of source is delivered to the treatment plant by means of trunk mains. These big diameter pipes carry water on long pipelines without branching. Trunk mains are usually made of prestressed concrete or steel pipes. Leaks occurring in these pipes constitute a small amount of the total leaks when compared to the total amount in the water distribution system. Whenever big leaks occur in the trunk mains, their effects may be observed in measuring points or SCADA stations as sudden decreases in discharge and pressure. Also big leaks can be observed as flooding of the pipeline route with the help of surveillance camera systems. Concrete pipes can be affected from aggressive water and aggressive soils, which cause internal and external corrosion resulting in cracks. Additionally cathodic protection for steel pipes is necessary to prevent corrosion.

Another type of water loss is the loss occurring at the water treatment plants. Some amount of water is inevitably lost during the treatment process however; it may be reduced by using more developed treatment actions. Butler (2000) states 2 – 3 % to 7 % water can be lost during the treatment process.

Water storage tanks in the water distribution system can be considered as sources. Losses that occur in storage tanks can be water leaks through the walls or spilling of water due to overflows. Leaks in the walls of storage tanks can be eliminated by constructing strong structures having water isolation. Also during regular cleaning studies, impermeability of the walls should be checked by standard tests. Spilling of water can be prevented by monitoring water levels from SCADA systems. Number of working pumps can be decreased or shut down completely according to the water levels in the storage tanks.

4.2.2. Leaks Occurring in the Network Elements

Leaks inside a water distribution system occurs more on different elements of the system. As there are many different types of materials and much longer pipes in total are connected to each other, a greater risk of making errors is valid inside the distribution system. Every singular pipe, every joint between pipes, every service lines connected to the network and every fitting in the network is a potential point for water leaks.

Pipes in the distribution network can be examined as transmission mains, distribution lines and service pipes. These pipes serving each a different purpose are connected to each other according to a predefined project. In general, in transmission lines prestressed concrete, ductile iron, steel or PE pipes are used. When distribution networks are considered, generally ductile iron, steel, asbestos cement, PE or PVC pipes are preferred. For service connections to the customers, usually galvanized iron or PE pipes are used. With such a variety of materials, high quality joint pieces should be used for making connections between them. Workmanship is another important issue. Good workmanship has to be combined with good quality of materials in order to obtain a leak-free water distribution system.

Rubber gaskets are inevitable pieces between every pipe and fittings. When installed properly, they guarantee a non-leaking connection between the pieces. Also during construction of any type of pipe, bedding and backfilling materials should meet the required standards in order not to harm the pipes as they are going to stay buried under heavy loads for many years.

Pipe joint elements such as tees and elbows are again elements similar to pipes. Only their job in the system is different. They should be installed with good quality material and good workmanship. Concrete thrust blocks are effective and cheap solutions for joint pieces to keep their positions with pressurized water in them.

Fittings in the water distribution networks are other sources for leaks. These fittings include mainly stop taps, fire hydrants and valves. Regular maintenance should be performed on every fitting, and they have to be renewed whenever they are found leaking.

Stop taps are pieces mounted at the end of dead end pipes. They should be installed tightly always using rubber gaskets. If a flanged pipe is considered, bolts and nuts have to be tightly installed, if a pipe with sockets (such as ductile iron pipes) is used, then concrete thrust blocks should be used to ensure the plugs are connected to the system and stay fluid-tight.

Fire hydrants can be a source for leaks as they are the most suitable pieces that are open to external interferences. They have to be protected from unauthorized people, traffic accidents etc. To prevent unauthorized use, hydrants should be kept tightly shut and a valve should be present on the pipe connecting the hydrant to the network. By this way, without opening two consecutive valves, fire hydrants will not work.

Valves are important fittings in a water distribution system, enabling control over the pipes. They have to be regularly checked and kept ready for usage at all times. Every installation standards mentioned above are valid for valves. Valves should not only be leaking water outside the system but also they should not be working against the operators actions. When a valve is completely closed, it should not let any water passing through itself. Similarly, when a valve is completely open, it should work as a section of regular pipe, without having any effect on the flow. Therefore, valve status has to be known for each valve (whether they are fully open, fully closed or partially open). Periodic valve operations (opening and closing) may be helpful on determining faulty valves, but it may not be an economic decision to replace every faulty valve. However, critical valves, such as valves at pressure zone borders and district metered area (DMA) borders, should be kept in perfectly working conditions.

4.3. Factors Affecting Leakage

Leaks occurring in a water distribution system may be caused by internal factors from the network itself or external factors from the environment. Under this section various factors will be studied such as pressure, hole size, leak duration, pipe material, aging of pipes, workmanship, network design, soil types and water quality.

4.3.1. Pressure

Pressure is one of the most important factors that affect leakage. It is the governing factor affecting rate of leaks with hole size. If pressure in the system is high, then leaks are flowing more. Therefore, to decrease leak rates, the first thing most water administrations think is to decrease system pressures. However, decreasing pressures heavily depend on the topography of the water supply area. Then, pressure reduction will be restricted up to a particular value. Critical points in the network such as points at the highest elevations or places that use high amount of water with some minimum inlet pressure will define the restriction of pressure decrease. However, in places that do not have steep topographic differences, big decreases in pressure can be made. By only that way amount of water lost through leaks will decrease significantly. Case studies in Chapter 6 gives detailed information and examples about effects of pressure reduction on water leaks.

Sudden increases in pressure can also be considered as a factor affecting leakage. Most sudden increases in pressures are caused from transient events. Sudden opening or closing of valves, quick filling of the empty network after repair works can be harmful to the system and can increase leaks in the network.

4.3.2. Hole Size

Naturally, bigger holes cause higher leak amounts. Big hole sizes combined with high pressure cause the most leaks. However, smaller hole sized leaks cause more frictional loss while water is flowing out, so they are better recognized by acoustic devices and located easier.

Hole sizes occurring in the pipes get bigger through time depending on parameters like pressure and pipe material. So when a very small hole is generated in the system, it gets bigger with time causing more amount of water to be wasted.

Another thing in the hole sizes is that they are not necessarily regular shaped holes. Discovering irregular shaped holes in the pipes makes estimation of loss amounts harder. Using approximate values for loss amount estimation can be made.

4.3.3. Leak Duration

Leak duration covering all the time that the leak is flowing is an important factor. Leaks discovered early causes small harms, but leaks discovered after many months or years from its occurrence cause water loss and increases whole size in time, which will cause more loss.

4.3.4. Pipe Material

Every pipe material has its own advantages and disadvantages. Their leak-effecting factor is also different from one material to another.

Asbestos cement pipes can be considered as old pipes and they have been or being replaced with modern materials nowadays. However, in some water distribution systems, they are still present in some networks. As asbestos cement is a very brittle material, pipes made from it are open to cracks. Cracks in asbestos cement can be repaired with collar repair clamps quickly. However, usage of such hardware fixes the problem temporarily. That fixed point remains as a weak spot on the network. For a permanent solution, the entire asbestos cement pipeline should be replaced with a better material.

Prestressed concrete pipes carry similar material properties; however, they are stronger to cracks than asbestos cement as they include reinforcement bars inside. These kinds of pipes may suffer from sulfate attack caused due to sulfate amount in the water. Within time, these pipes will be corroded from inside and outside it they are not protected enough from outer effects.

Steel pipes have a very wide range from the tiniest diameter to the largest diameter. Their main weak point for leaks is the absence of cathodic protection. If appropriate cathodic protection is not applied to the steel pipes, as they are being installed, they are going to be corroded quickly and formation of holes will be inevitable. Additionally welding workmanship can create weak spots and affect leaks in the future.

Galvanized iron pipes can also be considered as old pipes and they are very open to formation of holes. The galvanized protection does protect the pipe from external corrosion to some degree. Moreover, after the protection is over, any hole or crack formed on the pipe will quickly get worse with time.

PVC pipes are cheap pipes for water distribution and they are very easy to install. In addition, they are durable to corrosion. However, they are weak against any external force. So they are easily damaged with excavation machinery. Cracks are easily formed in PVC pipes causing leakage.

PE pipes are used in a very wide range of diameters for a very wide range of purposes. These pipes are again durable to corrosion but they may have weak spots on “push fit” connections to other pipes. With cheap material and workmanship, it is certain to have leaking spots in PE pipes.

Ductile iron pipes are very popular pipeline materials in varying diameters. When installed correctly, they are durable to internal corrosion with cement lining inside and external corrosion with the coating. They are easy to install but become expensive on very large diameters. Whenever they are not installed according to the standards defined, they become weak and can leak from pipe connections or fitting spots. Therefore, as valid for every type of pipe, high quality workmanship and material should be essential.

4.3.5. Aging of Pipes

As water distribution systems are designed according to projected population’s usages for tens of years from the construction date, installed pipes are going to get older and deteriorate. Therefore, it can be generalized that older pipes may cause more leaks than new pipes.

Stronger pipe materials can be preferred for durability against time. PE pipes and ductile iron pipes are being preferred for high durability to time effects as long as they are installed with proper workmanship.

To decrease the effects of aging, renewing of the old pipes, broken valves and other elements should be scheduled. Every year a percentage of network renewal should be programmed.

4.3.6. Workmanship

As stated before, workmanship and material quality play complementary roles when leaks are considered. Good workmanship and high quality materials should be combined to prevent leakages. At the absence of any of the two, weak spots in the network are probably generated. For good workmanship, skilled workers and apprentices should be employed. Apart from skills, workers should have a good technical knowledge about the repair works.

Workmanship is also crucial when new pipes are being installed. If good workmanship is applied, problems at the beginning of the installment are minimized, leaving less problems to future. Additionally, pipe transporting to site, stacking, laying the pipes, bedding with appropriate material and backfilling all depend on good workers. As a result, water administrations should not employ cheap and inexperienced workers at any stage of water works.

4.3.7. Network Design

Water distribution networks are designed before construction and construction drawings are generated generally in 1/1000 scale. During construction, these drawings usually cannot be applied on the field completely. According to construction difficulties faced in the field, some changes in the original drawings are made and as built drawings are drawn which represents the actual constructions made. During this process, original network design is changed, and in the constructed system, there might be critical points in terms of leakage, which are not present in the original design. For example, if looping network is changed into branching network, some high pressure points can be generated resulting in more leaks.

Another thing concerning the network design is that during construction stage, all different infrastructure elements (telecommunication, electricity, natural gas, fiber optics, drinking water, wastewater, rainwater, etc.) should be installed leaving a distance (in both horizontal and vertical) between them. By this way when excavating for any purpose water pipes are less damaged. However, if different infrastructure elements are installed at very close distances to each other, it will be inevitable to harm the lines during excavation. Unfortunately, it is a fact that relatively new infrastructure elements can be laid just on top of the previously laid infrastructure systems. For example, natural gas pipelines can be just on top of wastewater lines or drinking water lines. This is because, during very first installments in such an area, ground is excavated and backfilled with soft material. Other firms working at the same route prefer to excavate the exact same location with the previous pipeline in order not to excavate hard soil and lay down the pipes quicker. This can be considered as a cheap workmanship example as well.

Plastic marker tapes laid along the pipe are widely used in the field that warns the excavator before reaching to the pipe. Additionally Butler (2000) suggests using metallic strips inside these markers for locating plastic pipes using utility locators. When water pipes are located with good accuracy (both position and depth), less leaks will occur during excavation for pipelines.

4.3.8. Soil Types

Soil types are also important factors when leaks in pipes are considered. Aggressive soil types can cause external corrosion to pipes. As a result, holes, cracks and various other types of damages can occur. During planning phase, detailed soil surveys should be conducted to have the knowledge about the soil types in the region. Then appropriate pipe materials and backfill materials can be defined to satisfy a strong water distribution system having minimum amount of leaks caused by soil effects.

4.3.9. Water Quality

Quality of water inside the distribution network can be a pipe-weakening factor. Various materials in the water can cause internal corrosion to metallic pipes. In addition, on dead end pipelines water can remain still due to low consumption. In such cases, water quality drops considerably, and rusting of metallic pipes can be accelerated. To prevent these kinds of water quality issues, periodic flushing activities should be performed in the network.

4.4. Controlling Water Leakages

Leak management is considered as a long-term study worldwide. It is not a process done a few times throughout the lifetime of a water distribution network. Leak management is a process that has to be run simultaneously with the operating of network from the beginning without waiting the network to weaken.

Forming and evaluating manageable district metered areas and measuring inflow water is crucial for leak management studies. While DMA is being formed, missing fittings are discovered, unknown connections are found, missing projects are found and an up to date overall project is generated. During these operations already, possibly water losses will be found at a certain extent (such as leaks, missing and unknown connections between DMAs and pressure zones, etc.).

Water leaks can be controlled by means of separate or combined strategies that use two approaches. These two approaches are named as “Passive Leak Control” and “Active Leak Control”. Either of the two can be applied according to the water administration’s needs; however, for an effective leak control strategy, the two approaches should be applied to the field in different ratios, which meet the administration’s demands.

4.4.1. Passive Leak Control (PLC)

Leaks occurring in the network not visible and their effects are not easily recognized as long as they do not reach to the surface and harm people in some way. As soon as a leak grows big enough to show itself on the ground, or flood somebody’s property, the necessity of locating and fixing the burst comes up. Leaks do not necessarily harm some place by flooding. They might show their effect as low-pressure problems or having no water above some floors in an apartment. These “big enough” bursts are reported either by the customers, or by the administrative staff to the leak detection crew.

Passive leak control comes into picture at this stage. It can be defined as detecting leakages depending on the reported burst events. Action taken contains only repair of observed bursts and elimination of low-pressure problems of related customers. Only customer reports of house flooding events, inadequate pressure problems and similar reports are focused on.

Smaller leaks that do not harm any customer remain below the ground until they are big enough to start giving damage. Small leaks can remain hidden for months or even years. As undetected leaks, water lost through them constitutes a huge amount when awareness time is extended to years.

In simple words, PLC is chasing big leaks after they have given enough harm and made themselves visible. Its main disadvantage is, leaks are detected after big amounts of water are lost. However, it may be a cheap solution if there is a plenty of water sources that are enough for customer demands and water losses. Apart from water sources, if water production cost is very cheap, if bursts are found out easily and quickly, searching for leaks in an active manner may not be feasible. However, it should be noted that, by applying passive leak control, it would be a difficult task to decrease the overall water loss amounts. Conversely, overall water loss amounts will possibly tend to increase with the growing city, increasing population and water demands.

4.4.2. Active Leak Control (ALC)

Unlike PLC, active leak control is a collection of methods applied on a formed and evaluated DMA. In general, flows in the DMAs are monitored and sudden, unexpected increases in flow are searched for. Whenever these kinds of changes occur, leak detection surveys are done inside the borders of the DMA. This activity of continual searching for water leakages (mostly bursts) is done using acoustic and electronic devices. These devices are listening rods, ground microphones, digital correlators, leak noise loggers and so on.

With the help of active leak control methods, big bursts that do not reach above the ground surface can be easily detected depending on the instrumentation. Additionally, even small background leaks are detected and pinpointed with this method. As a result, all the "detectable leaks" are found and fixed in the DMA. However, there are limits that a leak could be found with these methods. Butler (2000) states; in the UK, 55 l/property/day is the acceptable level of leakage. Trying to find leaks beyond this point is not considered as economic solutions. He also defines an undetectable leakage level as 30 l/property/day. It is the ultimate level that leaks can be decreased in a water distribution network using today's technical equipment (unavoidable night flow).

ALC is effective up to some extent when applied alone. When bursts are found and fixed in a system, pressures will increase in the system. This increase will generate new bursts or background leaks at various parts of the network. Therefore, ALC should not be applied only once to the network. It should be applied to the network within a schedule. Weekly, monthly or yearly repetitions of ALC studies may be a good idea depending on the properties of the network.

To decrease the happening of new background leaks, pressure management studies should be run with ALC cooperatively. With pressure management (mostly reducing excess pressure in the system where possible), generation of background leaks can be slowed down or totally avoided. Pressure reduction in a network decreases the volume of wasted water as well as the rate of leak growth. With lower pressure, fewer leaks will be generated with time in the network.

ALC requires the administration to spend money on possible constructions for DMA formation, leak detection instruments and to make effort to locate and fix the leaks. The effort includes training staff and giving the staff up to date information of new technology. As the process is an expensive investment at the beginning, some DMAs should have higher priority than the others should. For instance, DMAs that are fed by pumping should be investigated before DMAs that are fed by gravity pipelines. That means water lost at higher elevations are more valuable than lower elevations considering electricity costs.

After applying ALC, less water is supplied to the DMA so resources and energy costs are saved. Applying ALC is reasonable when resources are limited, water production costs are high and bursts cannot be detected by visual inspection only.

For both PLC and ALC, a water administration should form a specially trained team. This team should have the knowledge of using various equipments like water meters, data loggers and ground microphones. However forming a leak detection team would be insufficient, as the job requires different sources of data from different departments of the administration. Various departments therefore should work cooperatively letting their data to be used by anyone. These departments in a typical water administration are GIS, SCADA, project developing, IT, customer relations and operations' departments.

CHAPTER 5

DEVELOPING THE METHODOLOGY

Before applying the methodology for locating water losses in a water distribution network, some minimal requirements should be satisfied. These requirements involve detailed studies on projects, investigations on field, construction works, training staff and many more subjects.

Formation of a water distribution system goes through some essential phases like master planning, feasibility studies, rehabilitation studies, final design and construction. The resulting system is usually handed on to operations department. The work from now on is to operate the existing system, dealing with new consumers, repairing the failures and performing any kind of maintenance work including leak detection.

In these general phases of events, a perfect system in every aspect is impossible to create. In any phase, due to any reason a change in the ideal system can be made. However, for an effective study against water leakages, all kinds of uncertainties have to be minimized. In simpler words, every detail in the water distribution system should be known precisely from master planning phase to operating phase. The ultimate objective is to trace any water drop from the source at the very beginning of the system to the taps of customers where it is consumed. It is possible only by having a water distribution system that is totally under control. To achieve this goal, simple but important steps should be followed. These steps are briefly discussed below.

- Pressure zone borders have to be defined clearly (Figure 5.1). If any change in the pressure zone borders is to be made, it should not be made by combining zones having two different pressures but extending one zone up to the needed point. Defining pressure zone borders is crucial because they are the most suitable parts of the water distribution system that are open to exploits. In any case of low pressure problems, constructing new connections from an upper pressure zone is used as the most practical solution. Changing pressure zone borders is one of the most harmful actions against a controlled water distribution network.

- The modern requirement of having SCADA, GIS and CIS is essential for a controlled water distribution system. SCADA is a must for measuring pressures and discharges at various points, GIS is necessary for having an up to date knowledge of the system elements (pipes, fittings, pumps, tanks, etc.) and CIS is needed for keeping the customer records regularly. With these three elements integrated together, a totally controlled water distribution system can be easily achieved.

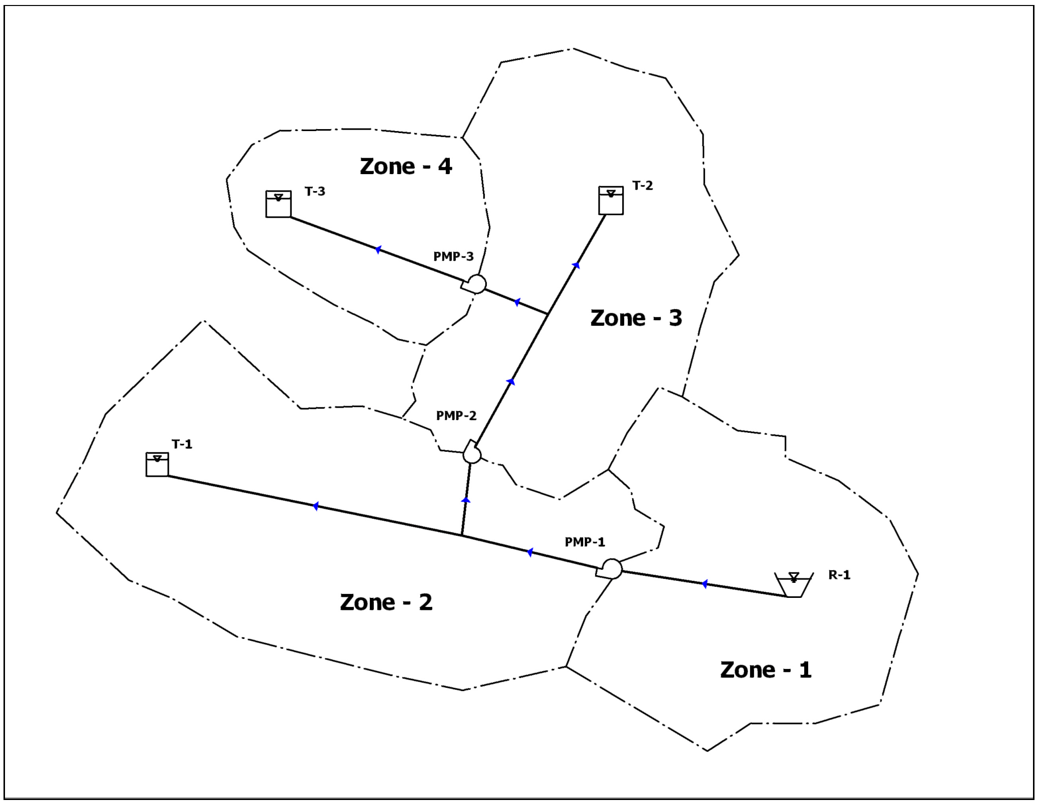


Figure 5.1 Defining Pressure Zone Boundaries

- To have a controlled water distribution system, it is necessary to know every element in detail. By analogy, this goal is similar to a tree, from the roots and the body, then to the branches and lastly the leaves of the tree. For the water distribution system elements, firstly pumps, main transmission lines (with every fitting on them) and water storage tanks should be precisely known. As a second step, distribution network should be known in detail with every fitting on them (Figure 5.2). Lastly, service pipes and customer locations should be known. These records are preferably kept in GIS environment. Keeping these data up to date is crucial for a controlled network. Every change in the field has to be quickly reflected to the related GIS layers with enough accuracy.

- Unknown connections (connections physically existing in the network, but not drawn on as-built projects) should never exist in the system. Unknown connections between networks (whether in the same zone or not) should be discovered and recorded. Having unknown connections at any point in the network means studying a theoretical network depending on official records, which behaves completely different from the actual state on the streets. As a result, observations and measurements obtained from field would not meet theoretical studies done at the office.

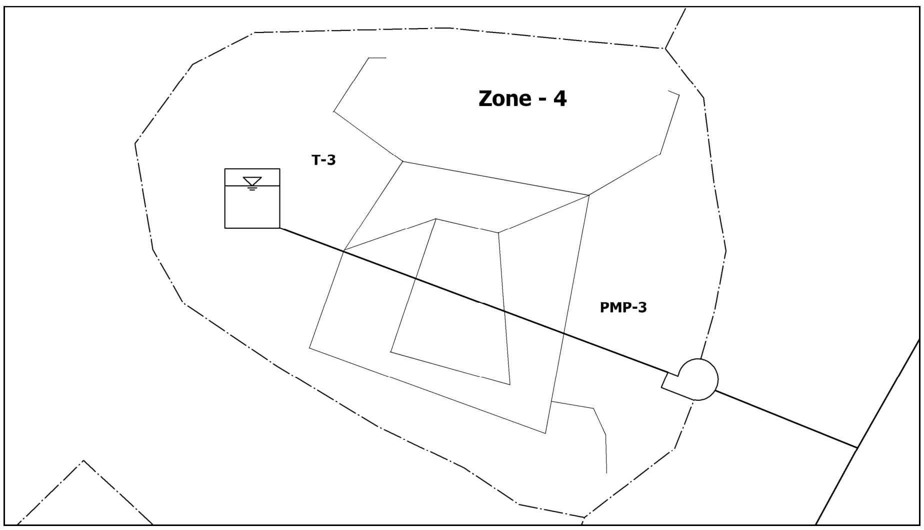


Figure 5.2 Controlling Pumps, Tanks, Transmission and Distribution Pipes

- After detecting the routes of transmission lines, distribution network pipes with their fittings and service connection pipes, pressure zone borders should be defined with precision. The required precision is at building level (Figure 5.3). Every building (covering the customers inside) must be known with their pressure zones. Customers inside the borders of a pressure zone may be easy to determine but customers near the borders of the zone is harder to investigate. With this step, every building is assigned a pressure zone, therefore the reflection of any action done on the pressure zones is known in building level.

Figure 5.3 Assigning Each Customer a Pressure Zone

- Upon completing the most necessary actions stated above, district metered areas can be formed for the purpose of water leak detection. The procedure is explained in Section 5.1.

The major purpose of completing the tasks for a controlled water distribution network is to clarify the mysteries that lie under the ground. When the infrastructure is known well enough, the working system is known in detail. Knowing the system in detail lets the water administration act consciously. Only conscious actions done on a working system leads the administration to its goals.

If the administration does not make its choices consciously, in any stage of water leak detection studies surprises may occur. These surprises usually slow down the studies, make all planned actions invalid and force them to be planned from scratch. The surprise events can be exemplified by unknown pipes in use, unknown cancelled pipes, old pipes that are not known either they are in use, unknown valves that are left closed, incomplete or wrong customer databases, measuring devices working improperly and so on.

5.1. Formation and Evaluation of District Metered Areas (DMA)

Every leak occurring in a water distribution network can be defined as a unique case. Type of the network, material of the pipes, workmanship, soil type of the region and operating pressures are just some of the uncertainties that can make the case unique. In order to take action against these kinds of unique cases, proper, standardized, methodological steps must be followed. When designed and applied properly, these steps will certainly be helpful for preventing water losses.

As a simple fact, precise and routine metering at predefined points (preferably at the entrances of isolated regions) should be the first step for water utilities to start dealing with water loss. Flows must be accurately measured in the distribution network for the grand purpose of tracing the input water from the source to the consumer. Most of the time, metering is only done in two stages of the water distribution cycle. First metering is done at the water treatment plant, where the treated water is supplied to the system and last metering is done at the consumers at the billing stage. It seems that there are no middle stages, but there should be. Without having any middle metering stages, any calculated lost water will be the representative amount for the whole distribution network area. To decide where to focus on the network, considering the losses, middle metering points should be established between the source and the consumers.

Forming district-metered areas (DMA) will guide the water utilities to decide to focus on smaller segments of their distribution networks. By these establishments, water utilities will have the opportunity to watch over their networks not just as a big one-piece mechanism but also as a big mechanism that consists of several smaller living parts. Metering of the DMAs, continuously with SCADA systems or by routine metering with portable equipment helps the water utility to take control over the metered area.

DMA realizations should have some limitations in size. DMAs that are small in size but large in quantity may have a high initial cost to the water utility, but controlling smaller DMAs may be easier. On the other hand, large sized DMAs will have low initial cost. However, as the area gets larger in size to take control over the area will be harder. There is not a single valid limitation for DMAs. The necessary DMA formation rules should define lower and upper boundaries. These boundaries may be in terms of area, pipe length or number of consumers. In some cases, natural topographic limitations may force the utility for a DMA design.

Butler (2000) gives typical DMA sizes in UK in terms of property counts. The given limitation is areas having properties between 1000 and 5000. This can be used as a guideline for limiting the size of the DMAs. Assuming every property having 5 people living, the limits become 5000 to 25000 people. DMAs containing properties less than 1000 mean too small areas. When the area gets smaller, it will be easier to manage the water losses, and every detail in the network could be better investigated. On the other hand possibly too many dead ends will be created in the network. Water quality will be adversely affected due to still water in the dead ends. Also the initial investment cost will increase if permanent measuring stations are established for each DMA. When DMAs contain more than 5000 properties, the area becomes too big to manage. It will take too much time to scan the area for water losses. In addition, it will be easy to miss the unknowns in the network (unknown connections, forgotten valves left closed, etc.). However, less dead end points will be created and less initial investments will be done. The basic thing is, when the DMA gets larger, it will be harder to find and locate singular, small water leak spots.

At the absence of population and building number data, DMA sizes can be defined considering the lengths of distribution network pipes. However, if the region is a developing region where settlements are still taking place, considering lengths of pipes for the definition of the size of the DMA can mislead the designer. If an example in terms of pipe lengths is to be given; DMA's total pipe lengths should not be less than 5000 meters and should not exceed 25000 meters.

DMA formation can be studied in two points of view. One is forming the DMA before the construction of the water distribution network. The other is to divide and isolate the divisions in an existing water distribution network to form DMA.

The first one includes classical design procedures of a distribution network. In the design process of a water distribution network, a branching type of network is suitable for DMA formation purposes. However, due to quality aspects in dead end pipes, branching type of networks are disadvantageous choices. Grid types of networks are better choices instead of branching type of networks. Circulating water in this type of networks removes the drawbacks of the water quality, but as the network is designed in a loop type, DMA formation has to be done with valve closing operations in order to divide the area into smaller areas. This may have some disadvantages while the operations are applied to the field like, not properly working isolation valves or unknown connections (pipes and/or valves) within the network.

Second point of view deals with DMA formation in existing networks. As stated above the existing network will be either in the form of a branching system, a grid system or a combination of these two.

The solution for purely branching systems may be to make each and every branch a DMA (measuring at points A and B), which may be an expensive solution, or place metering points at some predefined points on the water distribution mains and use differences between these metered values for the branches between metering points (at points C, D and E). An example for this case can be seen in Figure 5.4. As a rule of thumb, forming a DMA can be stated as drawing a closed border around the network without crossing any of the pipes; except the pipe that is both the starting and ending point.

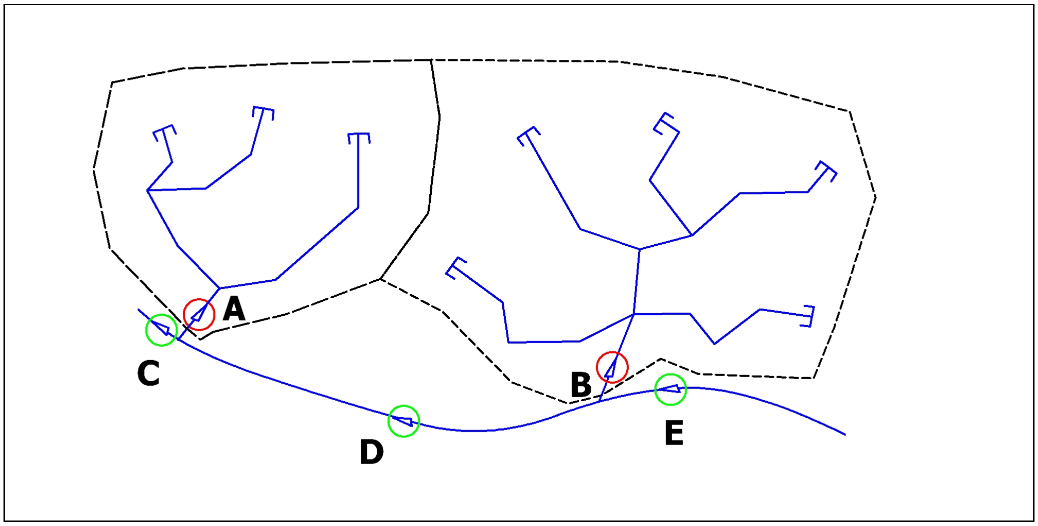


Figure 5.4 Forming DMA in a Branching Network

When it comes to form DMA regions in a grid or a grid and branch combined system, valves and their locations on the network becomes extra important. In this case valve places are important because they are used (by closing or opening) to isolate smaller pieces from the big area. In this case, the rule of thumb stated above is still valid with the inclusion of rule to allow crossing the network only at valve points meaning that the crossed valves will stay closed to form the DMA. A sample DMA formation for grid systems can be seen in Figure 5.5. Measuring points are located at A and B. The advantage is ability to define different DMA areas by a few valve operations. The disadvantage may rise in a hydraulics problem in which the defined and applied DMA may suffer from low water pressures in peak consumption hours. The main reason for this is that while applying the DMA, the designer chooses a one-pipe-fed system, so that the metering location would be on that only pipe that feeds the DMA. If the diameter of the main feeding pipe is not large enough to feed the DMA after itself or if water is forced to follow a path with a high-energy loss; some customers will face low-pressure issues. The solution to this problem can be found in defining the DMAs only for short terms. Here, short term is defined as applying the DMA and necessary valve operations only for the hours of minimum usage (mainly night hours until early morning) while actively working on the field for leak detection. DMAs that are not suffering this kind of problems can be left as permanent areas, so need for valve operations becomes unnecessary.

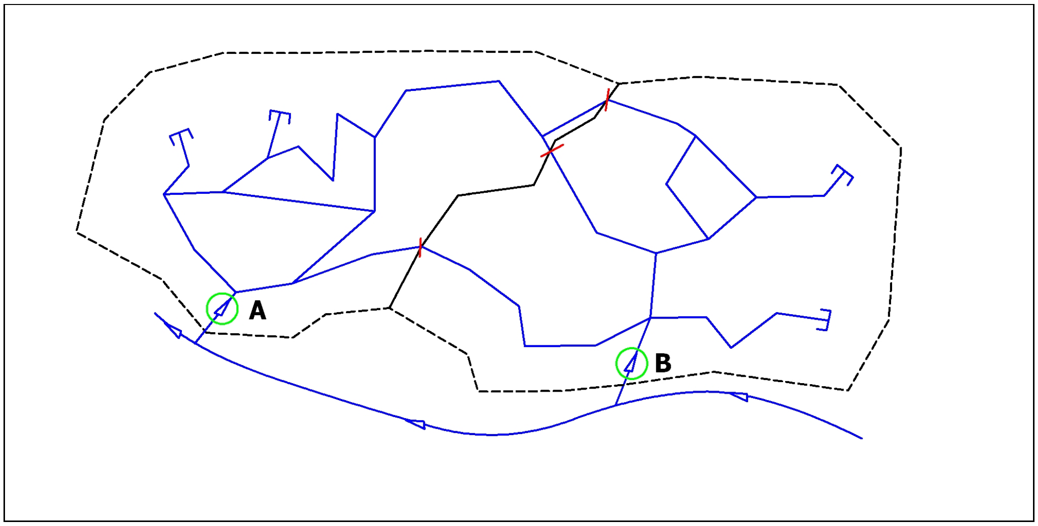


Figure 5.5 Forming DMA in a Branching Network in a Grid Network

A procedure to be followed for DMA formation can be given like this:

- Clearly identify the transmission mains and their branching points to the secondary pipes.
- Obtain maximum knowledge about paths of the secondary pipes and the valves placed on them.
- Keep all valves in operating condition.
- Define the desired limits for DMA size.
- Use the largest diameter branching pipe as the entrance for the aimed DMA.
- Draw the borders of the DMA around the area within the desired size by crossing pipes only on the points of isolation valves.
- Place the discharge-metering device (water meter) on the entrance branch pipe.
- Keep the isolation valves closed whenever DMA is in use.

A valve at the entrance of the area can be useful for testing the validity of the DMA. After isolating the area from the rest of the network, the entrance valve can be closed and the area can be observed if there is an unknown source entering the system. Normally with this operation all the consumers should have a shortage of water within some time. This means that the border drawn in office is valid on the field too. If there are some consumers still not affected from closing of the entrance valve, it shows either an isolation problem or an unknown connection from neighbouring zones.

Another useful method for testing isolated DMAs can be taking pressure readings along the borders of two neighbouring areas. To see a difference between neighbouring zones, they have to be in different pressure zones. At the end, it will be seen that at one side of the border a set of similar pressure readings are read (maybe high values), on the other side of the border another set of similar pressure readings are read (conversely low values).

5.2. Measuring Daily Demand Curves of the DMA

The major aim to form district-metered areas in water distribution networks is to measure the flow entering to that area. Only measuring night flows can be useful for leak detection but at least measurement of a whole day gives a daily consumption data about the isolated area. From the daily consumption data, graph of the consumption, commonly referred as a daily demand curve can be drawn. This curve clearly indicates the amount of water that is given to the DMA with respect to time. From the shape of the graph, consumption pattern of the region can be seen. By analyzing the pattern, water usage characteristics of the area can be seen. These characteristics differ from one DMA to other, as the people living in different DMAs have different habits of water usage. Many different aspects can be listed for different usage habits, like socioeconomic status of residents, whether the area is a residential area, a commercial area, or a hospital region etc.

For a typical residential DMA, it may expected to have a two peaked daily demand curve, one peak in the morning when the residents wake up and go to work and one peak in the afternoon when the residents return to their houses from work. Of course, these patterns do not have to be exact copies of one another for different days, but for a correct measurement of a daily demand curve, the pattern of the graph is not expected to show a big change unless an event affecting the water usage habits occurs.

In water loss studies daily demand curves are used extensively but especially late night measurements of the curve is searched for. For a typical residential district, night flow values entering to the district decreases to a minimal level, between mostly 02:00 and 04:00 a.m. In Figure 5.6 a conceptual drawing for a minimum night flow is given. This conceptual minimum level is usually taken into consideration to have an idea about the water leaks (Area B).

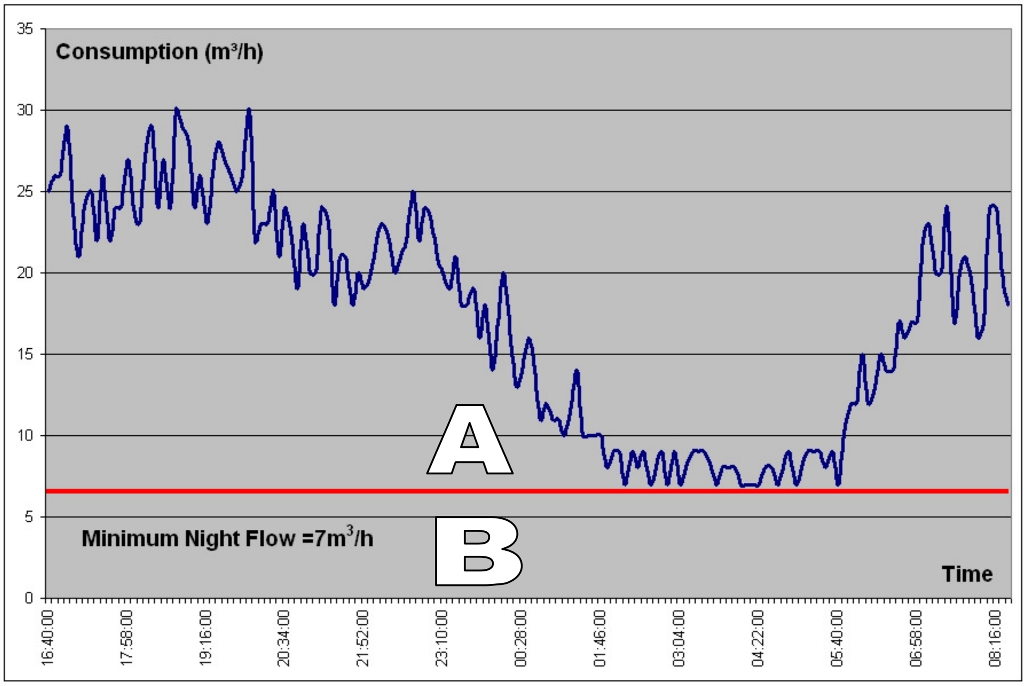


Figure 5.6 Sample Daily Demand Curve Showing Minimum Night Flow in a Residential Area

Above explained minimal level can be called as minimum night flow and in an ideal, leak free zone it is zero (Figure 5.7). This ideal situation is believed to be reached when nobody consumes any drop of water for a time period at night. An ideal situation told above is never reached in reality. Water flowing into the isolated and metered area does not drop below a level. Mostly this minimum night flow is considered as the sum of leaks in the area if there are not any significant night users.

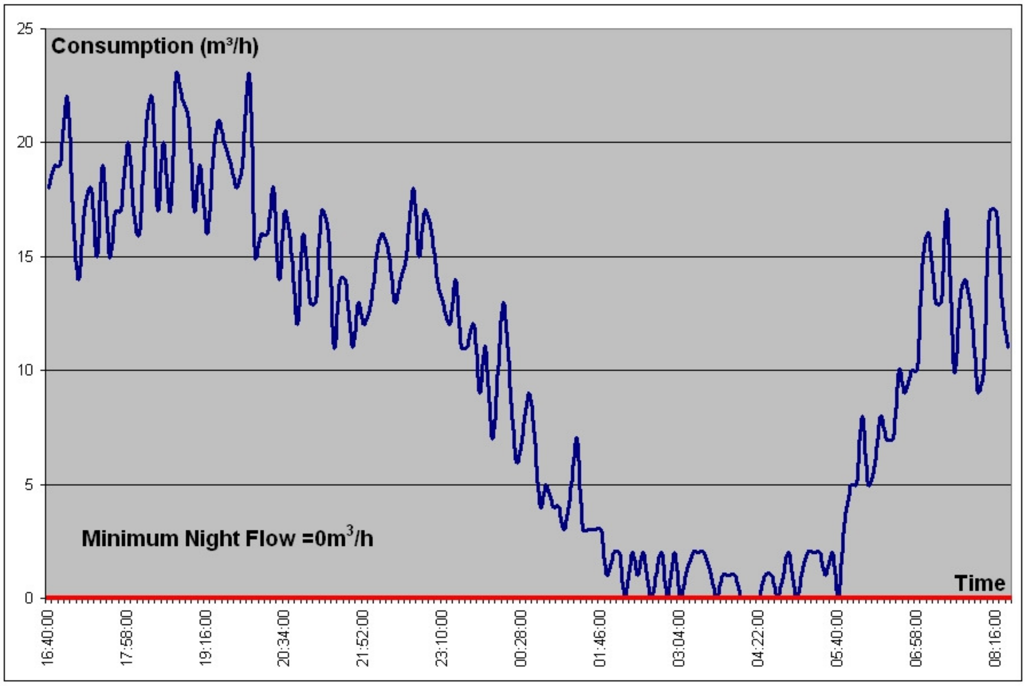


Figure 5.7 Sample Daily Demand Curve Showing Zero Minimum Night Flow

By obtaining the daily demand curves of different DMAs, their minimum night flow amount can be divided to the average daily consumption value to define a leakage percentage. Among these values, greater ones should have higher priorities for leak detection studies compared to DMAs having small leakage percentages.

Different approaches for defining a leakage percentage may be normalizing the minimum night flow with number of people living in the DMA or sum of lengths of the pipe network of the interested area.

After fixing the leaks in a DMA, a decrease in the daily demand curve will be observed. Normally minimum night flow values will be decreased. These decreased values should be observed routinely to see when there will be new leaks occurring in the area. Every DMA should have its own characteristic minimum night flow value to be observed carefully.

As stated above, the minimum night flow values are decreased to zero only in theoretical ideal conditions. In reality very little leaks (i.e. dripping water within the system) will be in the system all of the time. These very little leaks will be too hard and costly to find and fix so they are left to flow freely out from the system. Their cumulative amount will form the minimum unavoidable night flow (See Section 4.4.2).

Another fact is that the minimum night flow line is not a constant line throughout the day. Theoretically, it must rise a bit at night hours due to decreasing consumption and increasing overall system pressure. Similarly, it must decrease a little at peak consumption hours as the overall system pressure decreases. Therefore, this parameter is directly related with network's pressure (Figure 5.8). The curve shown as "Real Water Loss Curve" indicates the representative curve of water losses changing due to pressure variation during the day. "Idealized Water Loss Level" is on the other hand, is the simplified level of water losses. Pressure changes effecting losses during the day is not taken into account for this line. However, by taking 24-hour pressure measurement samples in the network, it may be possible to generate a model for real water loss changes during the day. Among this study, the variation of leaks will not be taken into account and assumed constant during the day.

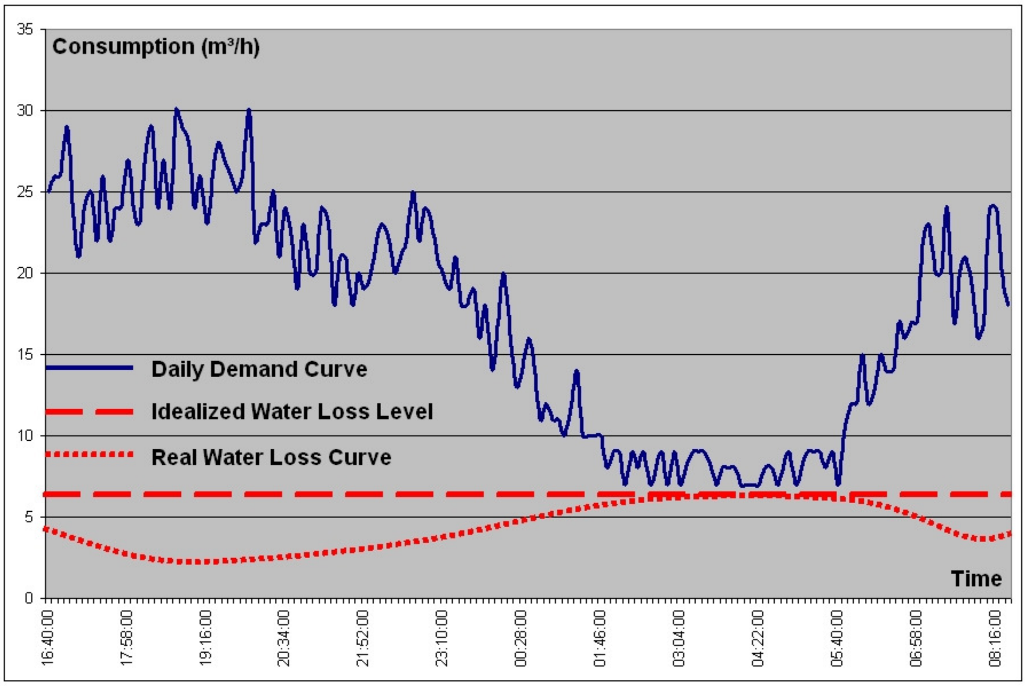


Figure 5.8 Conceptual Curves Showing Real and Idealized Water Loss Amounts

5.3. Sub-DMA Formation

Dividing DMAs into smaller regions using valves can be used to determine the starting point for water leak detection. In practice, the DMA is divided into smaller sub-DMAs, which consist of only a few streets. Therefore, with operations like step testing, it might be possible to choose the weakest places of the DMA. This step can be preferred for quick analysis of large DMA areas where maximum benefit is aimed within limited time.

Sub-DMAs are formed just like forming DMAs. In an arbitrary DMA, a looping pipe with preferably a larger diameter from the rest of the pipes can be seen as a transmission line. Next, the necessary areas are defined by drawing the border over the isolation valves that are going to stay closed at least on metering times. It should be carefully checked that unknown connections should not exist between isolated sub-DMAs. In such a case, it is not possible to form the needed isolated area. An example for a sub-DMA can be seen in Figure 5.9. Sub-DMA borders, isolation valves to be closed in order to isolate A07 from A02, A03, A08 and controlling valve at the entrance of sub-DMA are seen in the Figure 5.9.

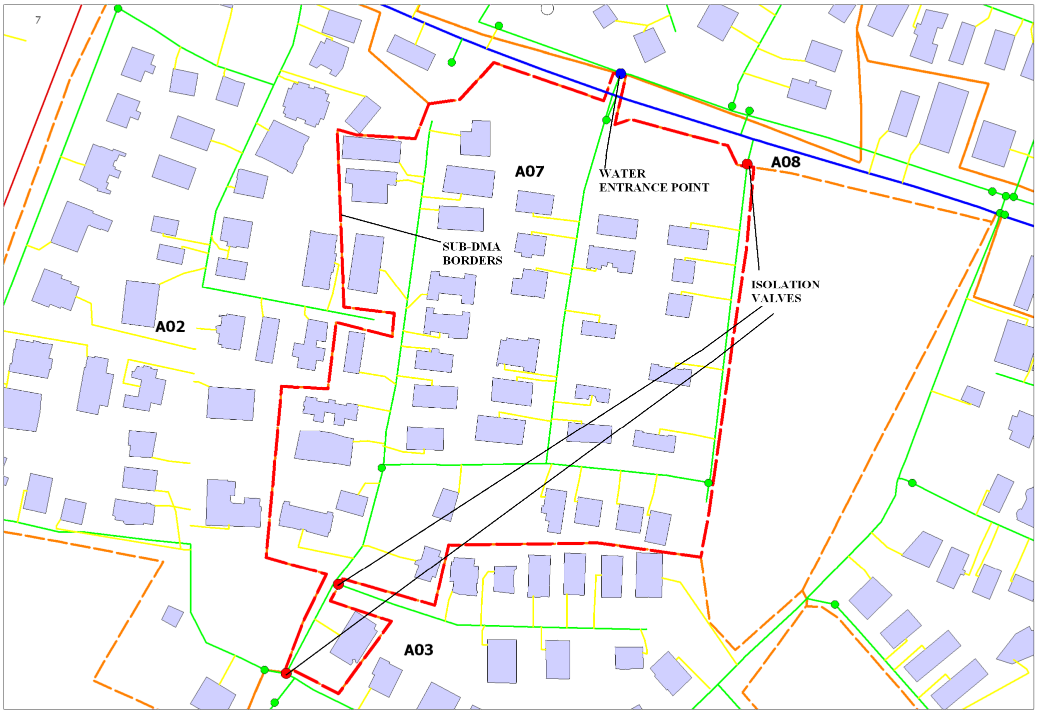


Figure 5.9 Example Formation of a sub-DMA

Purpose of forming sub-DMAs is to perform some tests to define which part of the DMA is weaker in terms of water loss. This method can be useful when the metered area is too large and equipment and workforce is limited. So instead of losing precious time examining parts of the network that the operator is not sure whether there is leakage or not, certainly leaking parts of the network is focused on.

Forming sub-DMAs inside a DMA may have advantages in terms of taking control over the network. Keeping a valve just behind the sub-DMA entrance enables the field operator to control a few street pipes by using only one valve.

To use one valve to control a whole DMA requires little investment and maintenance as there is only one valve to keep an eye on. This provides a superficial control over the network of the DMA. This means that only rough experimental actions can be applied to the network (shutting the whole DMA). When sub-DMAs are formed, all the necessary valves behind sub-DMA entrances should be kept usable. This step requires more investment and maintenance. However, a better level of control over the network is provided. As a result, much more flexible operations over the network may become available (shutting any combinations of sub areas inside the DMA). If an ultimate degree of control is required over the network, all of the valves at each street intersection should be kept usable. It requires much more time, money and human resources to keep the valves ready for action. As a result, an in depth control over the network is guaranteed, meaning very precise operational actions over the network can be made (shutting any street level pipe combinations). The three different situations can be explained with fictitious valve numbers.

Low Control (*1/50 valve*): If a DMA is known to have 50 valves installed, but only the main valve at the entrance is kept ready for usage it is an example for the first situation. In this case only shutting the whole DMA can be performed. Step tests and sub-DMA formation is impossible.

Medium Control (*20/50 valve*): This is the situation when only the boundary valves between sub-DMAs are kept working. It may be any number between 1 and 50 but to be similar with the case study it is given as 20 of the 50 valves are being used. In this case, a few sub-DMA regions can be defined, and step tests can be performed. Sub-DMAs can be shut down without disturbing other parts of the DMA.

High Control (*50/50 valve*): Each water distribution network should reach this ideal situation. In this case, all of the installed valves are being used. It enables the operator to generate numerous different sub-DMA combinations. Step tests are still valid. Moreover, one of the most useful aspects is to shut down only pipes at street level even without disturbing the neighboring street.

Sub-DMA formation concept can be ignored by some water loss operators that do not prefer to prioritize the area instead prefer to search for leaks covering the whole area.

5.4. Calculating Water Loss Percentages

Water loss percentages can be calculated from two different points of view. One of them is to integrate SCADA and CIS data to calculate the monthly revenue amounts. It is a monthly based calculation considering several assumptions. The second point of view is to calculate the water loss percentage by using only daily demand curves obtained from SCADA systems or other devices. This second method can be applied daily. Theoretically, the percentages that are going to be explained in Sections 5.4.1 and 5.4.2 have to be equal. However due to errors in the data and assumptions made in calculations, these two values show a variation. Table 4.1 formed by International Water Association (IWA) can provide the schema for organization of the consumption records and water loss percentage calculations.

Considering Figure 5.10, the parallelism between the two approaches may be clearly explained. In the figure, Q represents the monthly volume of water flowing into the DMA, q1, q2 and q3 represent the monthly volumes of consumptions of the customers in the DMA and q4 represents the monthly total volume of water loss due to leakages. For simplicity, water meter errors and reading inaccuracies can be ignored; therefore, those errors are all added to q4. If they are not ignored then, all errors should be considered in the meter readings of the customers. Considering the given figure, following equation can be written:

$$Q = q1 + q2 + q3 + q4 \tag{5.1}$$

The above equation is based on monthly revenue aspect explained in Section 5.4.1.

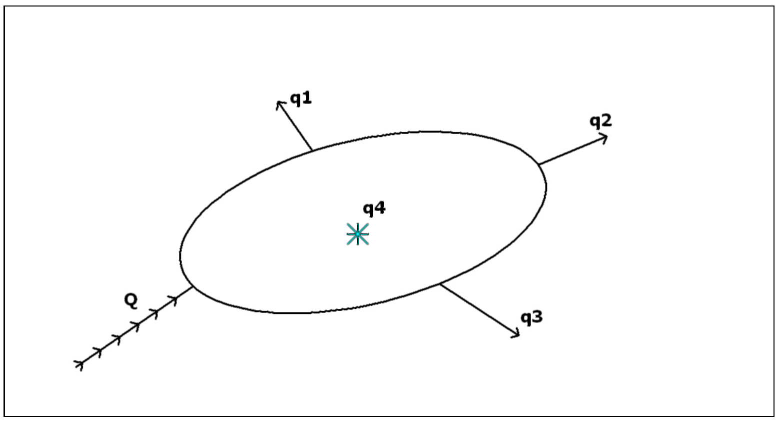


Figure 5.10 Conceptual Drawing of a DMA with Water Movements

From the other approach, minimum night flow aspect, again Figure 5.10 is considered but for simplicity, this time not in a monthly manner but in a daily manner. Of course, same procedure can be applied in monthly manner. This time Q will represent the total volume of inflow through the day, q1, q2 and q3 will represent the volumes of consumptions and q4 will represent the total volume of water loss due to leakages. To show these values on the daily demand curve Figure 5.11 is given below. In the figure, "q1+q2+q3" summation is the area between minimum night flow and the daily demand curve. Due to changes in the usage through the day, different values are reached at different hours. However, a constant level of water leakage keeps on flowing in the day. This leakage volume is represented by "q4" and it can be investigated as the area under the minimum night flow. To sum up, the addition of q1+q2+q3+q4 gives the total inflow into the DMA and still equation 5.1 is valid. The value q4 represents the same physical quantity as a result.

In the next two sections calculation of water loss amounts from two different perspectives is given.

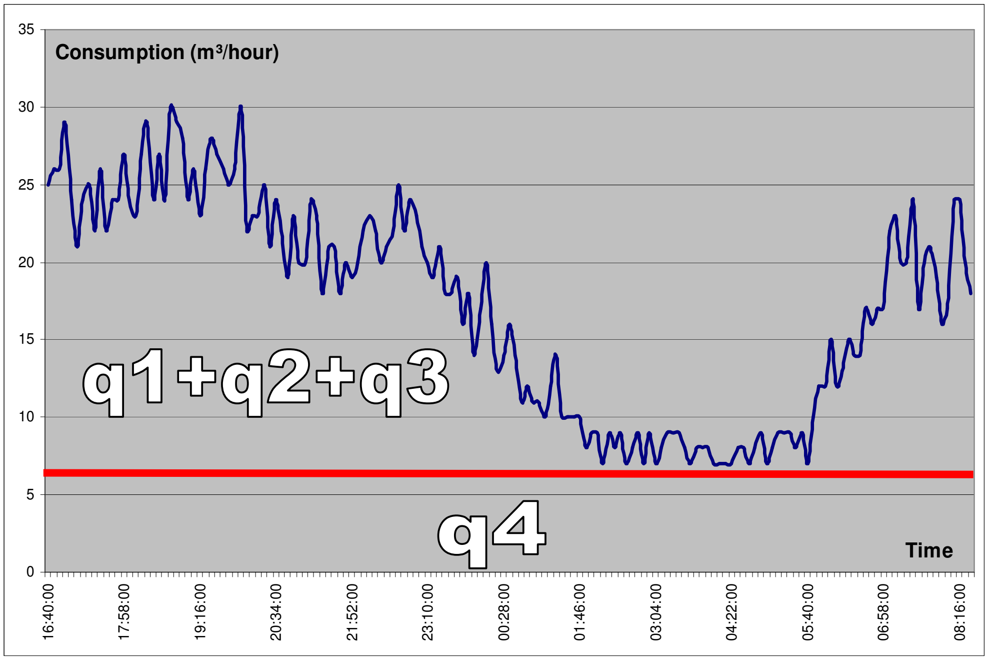


Figure 5.11 Conceptual Daily Demand Curve with Its Components

5.4.1. Monthly Revenue Aspect

While calculating water loss amounts considering monthly revenues, two sources of data should be present. One of them is monthly consumption values for each customer in the DMA, the other one is monthly continuous discharge measurements obtained usually from SCADA measurements. It is the best to have a continuous SCADA discharge measurements for the month, to see detailed changes in the consumption. However, to make the calculations, only cumulative discharge values at the beginning and end of the month is sufficient. So, at the absence of SCADA measurements, needed data (discharge index) can be collected with other types of devices such as a turbine water meter (usually referred as Woltman type meters). With the turbine meter installed at the entrance of the DMA, two readings must be taken from the indexes of the meter; one reading at the beginning of the month and one at the end.

In order to make the calculations, data obtained from SCADA (or manual measurements) and CIS have to be integrated. This integration is needed due to the limitation of CIS data. As consumption readings are collected in monthly basis, continuous SCADA data has to be divided into monthly slices.

In Figure 5.12 all possible irregularities that may occur during superimposing of SCADA measurements and CIS readings. If monthly regular readings are taken from the customer meter, that is the case that will generate minimum amount of error. For irregular monthly readings type I and II, some amount of error will be introduced, as only one end does not overlap with SCADA measurement period. In types III to VI, more amount of error is introduced because, two ends of the meter reading period do not coincide with SCADA measurement periods.

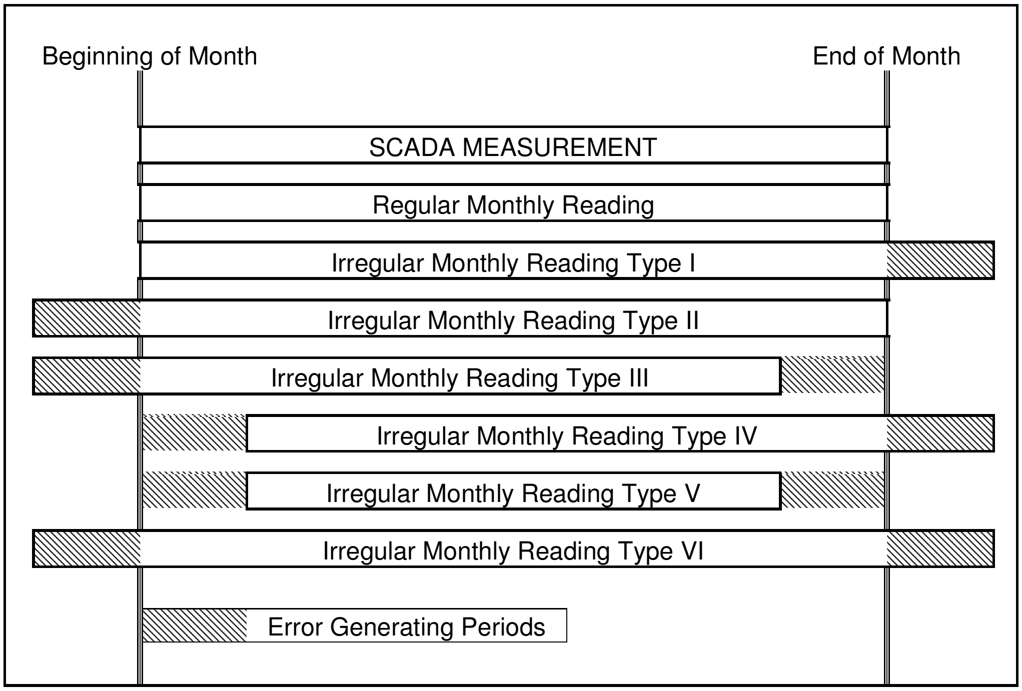


Figure 5.12 All Possible Irregularities in Monthly Meter Readings

In the below formulations, q_{S1} and q_{S2} are denoted for cumulative SCADA measurement indexes at beginning and ending points of the month (i.e. 5000 m^3 and 10000 m^3), t_{S1} and t_{S2} are denoted for the beginning and ending points of the month determined from SCADA settings (i.e. 1 March 2010 at 00:00 a.m. and 31 March 2010 at 23:59p.m.). Q_S is then the difference between the indexes, indicating the total inflow and T_S is the duration of the month in terms of days.

$$Q_S = q_{S2} - q_{S1} \tag{5.2}$$

$$T_S = t_{S2} - t_{S1} \tag{5.3}$$

According to the given example values, Q_S becomes 5000 m^3 and T_S becomes 31 days. That indicates that a total inflow of 5000 m^3 has occurred in 31 days into the DMA.

Additionally, an I_T parameter is defined to calculate daily average inflow to the DMA, assuming that the inflow entering the DMA is same everyday throughout the month. Unit of I_T is m^3/day.

$$I_T = Q_S / T_S \tag{5.4}$$

In Table 5.1 a sample for a CIS database is given. In the sample table, minimal required fields are given as "Building ID", "Customer ID" to identify the consumers, "DMA ID" to identify the customers in a DMA from other DMAs, the beginning and ending days of the interested meter reading periods and the consumption value of the interested period in meter cubes. As optional fields, any kind of information for the customers can be added to the database. These fields are simply given as "Various Information" in the table. These fields can include any kind of contact information of the customer (address, telephone, etc.), water meter related data (ID, type, installation date, etc.), type of the consumer (residential, school, hospital, public garden, etc.). After each reading period, new-collected consumption data is added to the database under three new columns. These columns will be next periods first meter reading date (which will be the same date with previous periods last reading date), last reading date and the consumption value.

Table 5.1 Typical Structure of a Customer Information System Database

Building ID	Customer ID	DMA ID	Various Information	March Period First Date [$t_{C11} \dots t_{Cn1}$]	March Period Last Date [$t_{C12} \dots t_{Cn2}$]	March Consumption (m^3) [$q_{C1} \dots q_{Cn}$]	…
500010	800001	5	…	27.02.2010	28.03.2010	30	…
500010	800015	5	…	27.02.2010	28.03.2010	12	…
500010	800020	5	…	27.02.2010	28.03.2010	23	…
500011	800002	5	…	05.03.2010	03.04.2010	40	…
500011	800255	5	…	05.03.2010	03.04.2010	8	…
500012	800003	5	…	01.03.2010	31.03.2010	50	…
500012	800365	5	…	01.03.2010	31.03.2010	19	…
…	…	…	…	…	…	…	…

To explain the consumers, q_{C1}, q_{C2}, q_{C3} … q_{Cn} are defined as the monthly meter readings for each customer indicating their consumption in terms of m^3 (i.e. 30 m^3, 40 m^3, 50 m^3 …). Total number of metered customers is denoted by n. t_{C11}, t_{C12}, t_{C21}, t_{C22}, t_{C31}, t_{C32} … t_{Cn1}, t_{Cn2} are the dates that customer meters are being read by the administration staff. First index defines the customer and second index defines whether the reading is done at the beginning of the month (corresponding to previous month's measurement) or at the end of the month. If the second index is 1 then it is the meter reading date of previous month. If the index is 2 then the value is the meter reading date of the related month (i.e. for 1st customer 27 February 2010 – 28 March 2010, for 2nd customer 5 March 2010 – 3 April 2010, for 3rd customer 1 March 2010 – 31 March 2010 …).

To calculate the monthly periods of each customer the below equations are used:

$$T_{C1} = t_{C12} - t_{C11} \tag{5.5}$$

$$T_{C2} = t_{C22} - t_{C21} \tag{5.6}$$

$$T_{C3} = t_{C32} - t_{C31} \tag{5.7}$$

$$\vdots$$

$$T_{Cn} = t_{Cn2} - t_{Cn1} \tag{5.8}$$

Then, the values given in the example lead to the results of; T_{C1} = 33 days, T_{C1} = 30 days and T_{C1} = 31 days. Then parameters D_{C1}, D_{C2}, D_{C3} … D_{Cn} are defined. These D parameters will define the daily average consumption of each customer depending on the assumption that everyday same volume of water is consumed.

$$D_{C1} = q_{C1} / T_{C1} \tag{5.9}$$

$$D_{C2} = q_{C2} / T_{C2} \tag{5.10}$$

$$D_{C3} = q_{C3} / T_{C3} \tag{5.11}$$

$$\vdots$$

$$D_{Cn} = q_{Cn} / T_{Cn} \tag{5.12}$$

As a last step, the D parameters are added up to find the total average daily consumption of the DMA. The resulting parameter is defined as D_T. Similarly, the units of D_C and D_T parameters are m^3/day.

$$D_T = \sum_{i=1}^{n} D_{Ci} = D_{C1} + D_{C2} + D_{C3} + \ldots + D_{Cn} \tag{5.13}$$

At the final stage, the D_T value is subtracted from I_T to find the rate of water loss in terms of m3/day.

$$WL = I_T - D_T \tag{5.14}$$

A percentage can be derived from the calculated value by:

$$WL(\%) = \frac{WL}{I_T} \times 100 \tag{5.15}$$

5.4.2. Minimum Night Flow Aspect

Considering Figure 5.11 as a sample daily demand curve, a water loss percentage for the DMA can be calculated. On the graph minimum night flow line can be drawn horizontally ignoring the effects of pressure changes. Another important thing to consider is to detect the DMA's minimum night flow hours. This is a period of time in which none of the consumers are using water. When that time is reached the measured inflow value to the DMA will be the minimum night flow. The area below minimum night flow line (q_4) is the water loss amount during the day. To make a comparison with the total water entering to the DMA ($q_1+q_2+q_3+q_4$), following formula is used:

$$WL(\%) = \frac{q_4}{q_1 + q_2 + q_3 + q_4} \times 100 \tag{5.16}$$

With this percentage, a realistic idea about the amount of water loss can be obtained. The needed data can be obtained from SCADA records or manual daily flow measurements (with mobile flowmeters, etc.). After obtaining water loss percentages for different DMAs, it is possible to see the weakest DMA in terms of leaks.

The values found in 5.15 and 5.16 should be the same. However, due to various errors and assumptions made before calculations, "WL" values differ from each other.

5.5. Prioritizing the Sub-DMAs

After forming sub-DMAs, the number of areas to be controlled against water leaks increase. The increased number of areas can make things complicated if an order of some kind is not given to the areas. An order can be given to the sub-DMAs by a method called step test.

In step testing method, it is required to have an isolated DMA with its measuring point ready to use at the entrance. In addition, DMA should be split into smaller sub-DMAs in order to prioritize them. The test is applied usually at night hours (or whenever minimum daily usage occurs in that particular DMA) while measuring the flow entering to the DMA. At the time when it is believed that no water usage is occurring (that is when minimum night flow occurs), one of the sub-DMAs is shut down with the help of its valve at the entrance pipe. By doing so, the water loss occurring in that sub-

DMA is precluded from the minimum night flow. By checking the measurement that is being recorded at the DMA entrance, it is possible to determine the water loss amount in the area that has just shut down. The discharge amount measured at the entrance will decrease to some level and that decrease will be the amount of water that is being lost at the closed down sub-DMA. Keeping the first sub-DMA closed, another sub-DMA is shut down and its effect will be seen in the measuring point immediately. Without opening any of the previously closed valves, all the sub-DMAs are shut down and their effects are recorded by checking the flowmeter at the DMA entrance. After closing all the sub-DMAs, the flowmeter should read zero flow and this result will be compatible to the result that is applied to the field. This result is; by closing all the necessary valves, all the users and the leaking points are restrained from the source. At the end of the closing steps, a flow versus time data is generated and it should look like Figure 5.13. The graph explains the amount of water loss occurring in each of the sub-DMA like steps of a stair. In the sample graph, minimum night flow is 50 m³/hr. It can be considered as the total loss of the DMA. By closing the first sub-DMAs, loss of the remaining sections reduces to 40m³/hr. It indicates that water loss occurring in the first sub-DMA is 10m³/hr. Each reduction in the graph will reflect the loss occurring in the related sub-DMA. A prioritization among the sub-DMAs can be done by the data obtained in the closing steps. Highest water loss detected sub-DMAs should have a higher priority when searching for leaks.

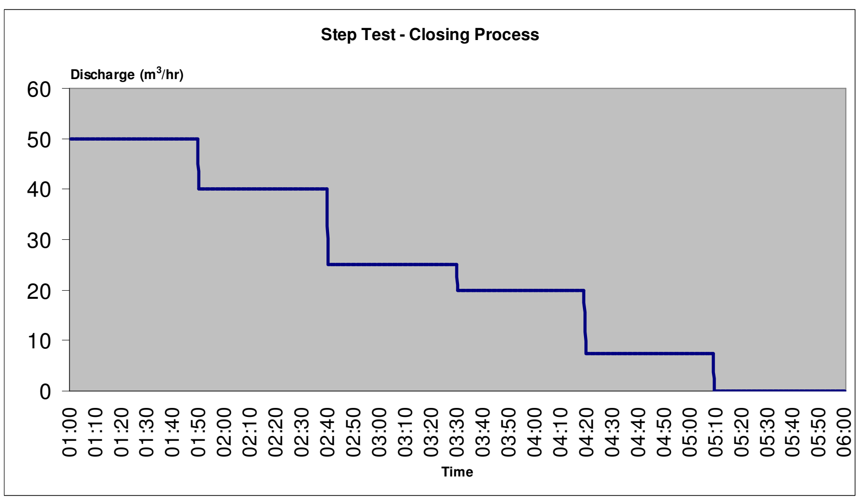


Figure 5.13 Sample Valve Closing Data in a Step Test

After reaching zero flow at the end of closing steps, the reverse procedure should be done in order to check if same prioritization could be done or not. In a similar manner, it is performed by opening the valves of the sub-DMAs one by one and getting a step-by-step increasing flow versus time data indicating the water losses of the sub regions (Figure 5.14).

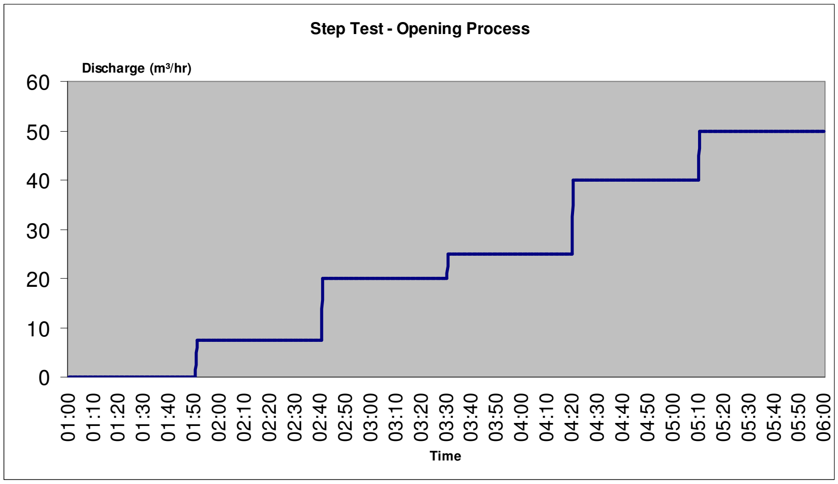


Figure 5.14 Sample Valve Opening Data in a Step Test

There are some important points to be considered while doing step tests. First, step tests should be done at minimum night flow hours. This is usually some time between 02:00 a.m. and 04:00 a.m. (which may extend to 01:00 – 05:00 depending on the water usage characteristics of the region). Opening or closing a valve should be done very slowly to prevent transient effects that might occur in the network. Next, after shutting an area, the effect should be seen at the flowmeter clearly and if an inconsistency occurs in the discharge values (i.e. an increase instead of a decrease when a valve is closed), a waiting period should be left before shutting another area. Within this waiting period, the transient effects minimize and the network comes to equilibrium.

5.6. Search for Leaks with Leak Noise Loggers

Leak noise logging devices are being used in water leak detection for more than 20 years (Thornton, 2002). Simply they are mobile microphones with recording capability. They are usually placed on the fittings of the network such as valves, fire hydrants etc. Their job is to record the noises of the pipeline it is placed on for leak sounds. Testing is preferably conducted between 02:00 a.m. – 04:00 a.m. to make sure environmental noises are minimal. A potential leak is found by getting a noise amplitude data that never drops to zero indicating that a constant noise is present in the network (Figure 5.15). That constant noise should be checked whether it is a constant leak sound or another noise such as a machine, working non-stop. This check can be done by looking at the dominant frequency value of the recording, or from frequency histograms of the recording if supported by the device. A non-leak noise is determined from a data logger result that hits zero noise level at night (Figure 5.16). It states that ultimate silence is reached at the measurement location indicating no leak on the nearby water distribution network. The success is greatly dependent on the technical specifications on the device as well as the material of the pipe. The spatial location of the location in the network is also important as the farther the leak point to the logger, the lower chance it is to be detected. Units in sample figures (Figure 5.15 and Figure 5.16) may differ from one brand to another. However, the general approach is to provide unitless sound levels, which gives rough information about the leaking spot.

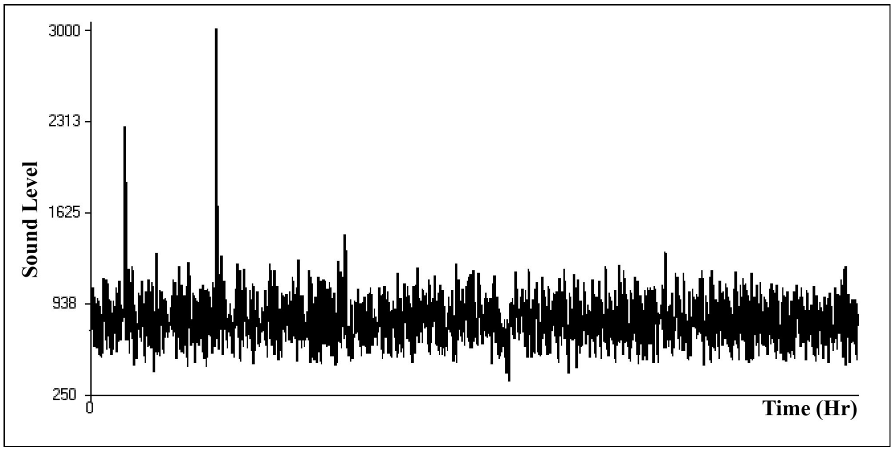


Figure 5.15 Data Logger Result Graph Showing a Possible Leak Noise Recording

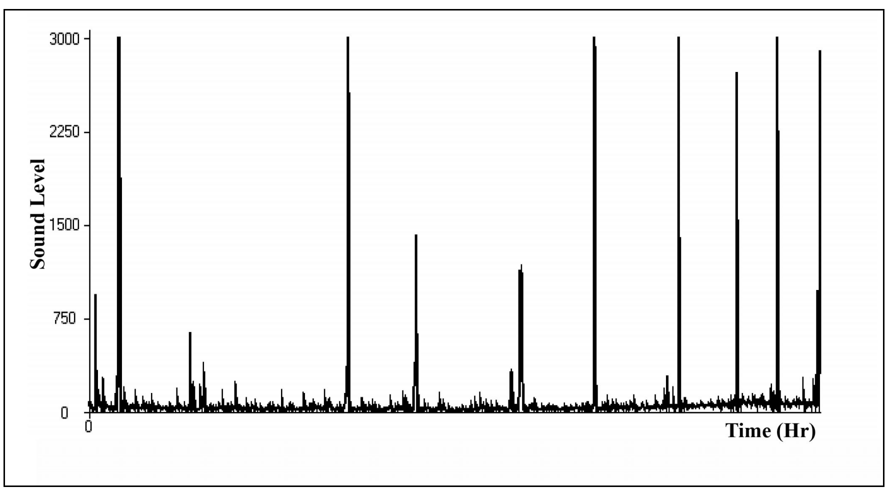


Figure 5.16 Data Logger Result Graph showing a non-Leak Noise Recording

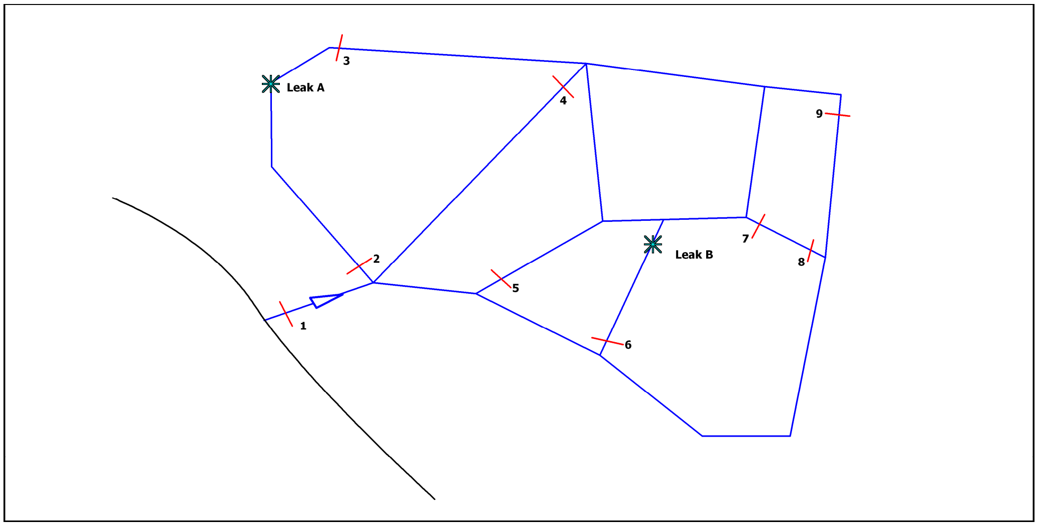


Figure 5.17 Sample DMA Showing Leaks and Possible Detection Points

For a sample network shown in Figure 5.17, it is assumed there are two leak spots A and B. If leak noise loggers are to be placed on every valve from 1 to 9 in this network, most probably leak A's noise will be generated on valves 2 and 3. Similarly leak B's noise will be heard by the loggers on valves 6 and 7. Of course, loggers placed on other nearby valves may be affected from leak noises depending on the intensity of leak noise and depth of the leak. However, the above named valves are expected to have higher noise levels, as they are the nearest valves to the leaks. In addition, logger on valve 3 will gather more noise from logger placed on valve 2. Valves 6 and 7 will give similar results which will provide the important knowledge of which valve is nearer to leak B. Intensity of the logger measurements will determine the nearness amount.

Noise loggers can be used in "measure and move on" manner or as permanent devices. Many brands develop different models for these two purposes. In the first manner, devices are used to measure for leak noises on a set of fittings for one or two days, then collected to be placed elsewhere. By this way with a limited number of loggers, a large number of DMAs can be searched for leaks. In the second manner, suitable loggers are placed on fittings for long time use. They are programmed in such a way that, measurements are taken every day, or every week, or every month. Then on predefined dates and times, the operator sweeps the area to collect the data to check whether a leak exists or not. As the water distribution network can be considered like a living organism, there may be no leak signal on a fitting one day, but an opposite signal can be received the other day. Therefore, the network should be kept under investigation all the times.

It is a well-known fact that sound is transmitted better in particular materials. Materials such as cast iron or steel have a better transmission of sound than plastic materials like high-density polyethylene (HDPE) or polyvinylchloride (PVC). Loggers placed on metallic pipes receive leak noises from a greater distance compared to loggers placed on plastic pipes.

In the last few years, these devices are improved greatly. Primitive versions of noise loggers only recorded environment noises wherever they are placed. Nowadays loggers can be programmed to stand by on daytime and start recording noises on night hours to eliminate ambient noises. Also a considerable amount of energy saving is insured. In addition, they are capable of detecting the frequency of the recorded noises and with the help of preinstalled frequency libraries; loggers are able to compare the recorded noises with real leak noises. By this comparison, leaks can be detected with a better accuracy. Another useful property is provided with the help of GIS tools. Sound amplitude data collected with two consecutive loggers can be correlated with the distance calculated from the water distribution network layer to point a leak point if it is between these loggers. With this property, leak noise correlating devices, which are used to perform this same correlation work, can be eliminated from leak detection studies.

5.7. Pinpointing the Leak with Ground Microphones

Pinpointing leak spots with ground microphones is one of the most preferred techniques in water leak detection. With the improved technology, numerous brands produce numerous models of acoustic leak detectors. Generally called ground microphones, are the devices that are used outdoors for listening possible leak noises on asphalt, concrete or earth surfaces. Their working mechanism depends on amplifying the noise that the device detects from ground and delivers that noise to the operator. With some improvements on the device, they are able to filter unnecessary noises and interferences making the operator easily focus on the leak noise.

Preferably, after making necessary detections with noise data loggers, operator starts searching the most probable areas (near valves that generate the highest leak signals on loggers) moving back and forth. Operators with enough experience usually pinpoint the leak within one hour's time.

Similar to leak noise loggers, sound generated by the water leak first vibrates the faulty pipe. Then the pipe spreads the noise and vibration to nearby locations. At this step pipe material parameter becomes more of an issue. Noises will be spread to a wide area or to a narrow area depending on the material. As a general fact, metallic pipes spread the noise to much wider areas than plastic pipes. This fact effects ground microphoning study deeply. Listening on plastic pipes require more attention in order not to miss the leak spot whereas on metallic pipes less attention may be paid. The importance of this aspect can be explained by assuming two similar networks, one composed of metallic pipes whereas the other one composed of plastic pipes. For example, in the first case a water leak will be detected by ground microphoning the pipeline with 100-meter intervals, whereas same leak spot will be detected by ground microphoning with 10-meter intervals. This will yield the fact that sound spreads more on metallic pipes.

Usually, pinpointing is done by spotting the point that most noise is gathered. After excavating the pointed spot, whether the correct position of the leak is spotted is understood.

Errors of a few meters are acceptable as in some cases leaking water sprays and hit a hard surface away (like a rock) and most of the noise is taken at the water hitting point. However to be able to find even that spot without being able to see what is going on underground can be stated as a success.

5.8. Measuring Daily Demand Curves of the DMA to See the Effects of Leaks

After locating and fixing the water leakages, daily demand curves and consumption data should be obtained again for the new period to see the effects of leaks. Water loss percentages should be calculated for the new conditions and those percentages should be investigated closely while on the other hand leak detection studies should go on. Probably for every DMA, a level will be reached where the leaks cannot be decreased anymore. That level should be recorded as in future investigations if that ultimate value is exceeded, then it means that new leaks are generated in the network and as soon as possible some action should be taken.

A continuous discharge measuring system like SCADA may have great advantages when located at the DMA entrance. With the help of such kind of a system discharges, pressures and daily consumptions of the DMA can be investigated continuously. A summary table like Table 5.2 can be a useful tool for examining daily water loss values. The values from SCADA records can be manually picked for this table or some kind of software can be developed to scan SCADA records every night and pick the minimum values recording them on a separate environment.

Table 5.2 Sample Summary Table for Examining Daily Minimum Night Flow and Water Loss Percentages

Date [A]	Days [B]	Water Entering (m^3) [C]	Minimum Night Flow (m^3/h) [D]	Minimum Flow Time [E]	Total Lost Water (m^3) [F] = 24 x [D]	Water Loss / Total Flow (%) [G] = 100 x [F] / [C]
01.03.10	Mon	1160	30.2	01:50	724.13	62.425
02.03.10	Tue	1130	28,7	04:10	688,88	60,962
03.03.10	Wed	1096	31,0	02:00	744,38	67,917
04.03.10	Thu	1156	36,1	04:30	866,25	74,935
05.03.10	Fri	1167	29,2	04:35	701,63	60,122
06.03.10	Sat	1247	29,3	04:30	702,00	56,295
			. . .			

It should be noted that, having a leak free network is not realistic. Then, instead of dealing with little leakages after fixing the big ones in a DMA, some other unstudied DMA should be investigated for leaks that are bigger (leaking more) and easier to find. By this way, in a shorter time, larger quantity of leaks can be detected and their cumulative effect would be greater in every aspect.

With the help of a table similar to Table 5.2 used during the case studies, the effects of repairs on the network and possible occurrence of new leaks are observed. In Section 6.2.5 and in Table 6.10, effects of repairs are seen as the decreasing values of "Total Lost Water" column. The repairs are done beginning from 6th of April and the "F" column of Table 6.10, decreased from 834.75 m^3 down to 500-m^3 level when the repairs are completed. In this aspect, tables similar to Table 5.2 prepared by the administration are very useful for leak monitoring purposes.

5.9. Equipments Used In the Field Studies

The history of leak detection devices goes back more than 150 years (Figure 5.18). According to the historical records, leaks are tried to be localized by using wooden sticks. Those sticks were used to listen and pinpoint the leak spot in a very primitive manner (Web6). However, today's high-end technological devices use the same principle of leak sounds to pinpoint them. Throughout this study, acoustic loggers and advanced ground microphones are used for leak detection. According to the timeline in Figure 5.18, these devices are all developed after 1990s, so the technology they are being used is a new technology.

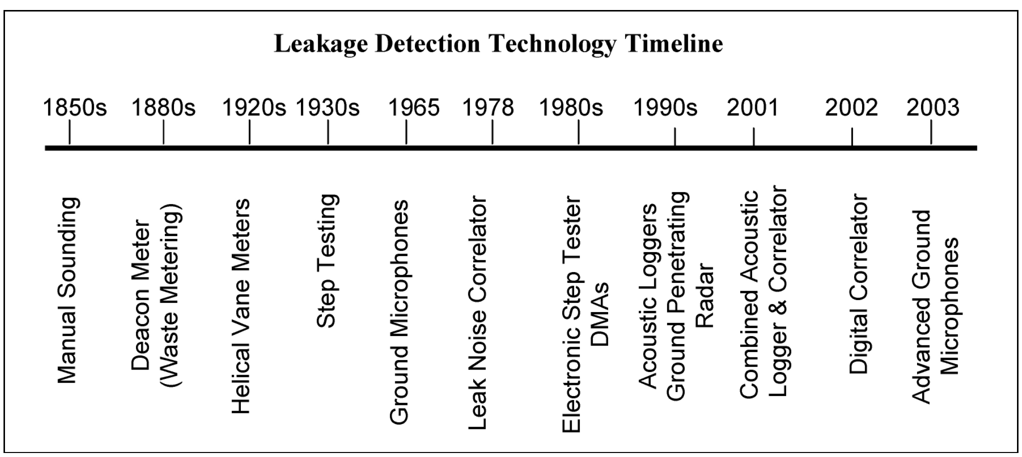


Figure 5.18 Timeline Showing Leakage Detection Technology Developments (Web 6)

The two major equipments (noise data loggers and ground microphones) used during field studies are products of Hermann Sewerin GmbH. Sewerin is a German company dealing with water losses for many years. In general these two devices are easy to learn and practical to use in the field.

There are more complicated and more functional devices on the market, but used Sewerin products satisfy minimum requirements for a basic scanning of a distribution network.

The two devices work with similar principles. Acoustic leak detection is the basis of these devices. A leaking pipe generates a sound with some characteristics. Noise data loggers are capable of detecting these characteristics and give alerts indicating water leakage nearby. In addition, their output results can be manually examined for detailed analysis and detecting leaks that could not be automatically alerted. Ground microphones work with simpler principles. They raise the sound level where the listening stick is touching. With the raised sound level, operators can trace and pinpoint the leak spot very efficiently. Interfering noises can be filtered by these devices, to have a clearer sound of the leak spot.

5.9.1. Noise Data Loggers

Sewerin's SePem® 01 is used as data loggers in the field. A pack of 20 loggers was available during the study. Loggers were distributed over the water distribution network during daytime, and collected from the field the next day. Before distributing, programming of the loggers was performed. They were programmed to take listening measurements at night between 02:00 and 05:00. Having a total of 20 loggers had a limitation in terms of working time. Total working time in the field could be shorter if more loggers were equipped.

SePem® 01 devices are actually meant to be permanent loggers that will stay in the field for years. With the help of their radio connection property, they can be programmed and their results can be transferred easily and quickly within a distance. This distance is usually enough to make remote connection from a slowly moving car. As a result, loggers can be permanently recording measurements. From time to time, operators can drive through the area to check whether any leak is detected by the loggers. However, in this study these devices were distributed and collected within two days not to face the risk of getting the devices stolen.

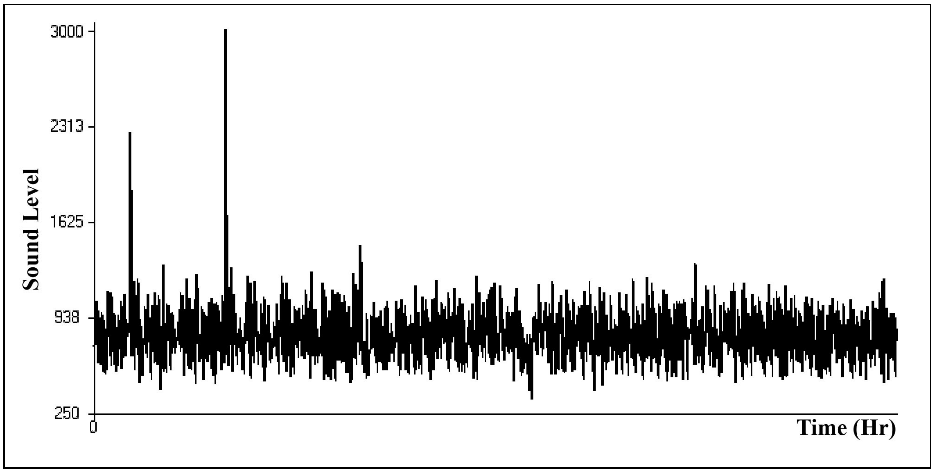


Figure 5.19 Sample SePem® 01 Result Graph

Figure 5.19 shows a sample result graphic obtained from a SePem® 01 recording. In this graph, x-axis shows the time in hours, which covers the duration of measurement. Y-axis is a unitless axis showing the intensity of the sound level. According to the information obtained from the manufacturer, the intensity values in y-axis can be converted to values in terms of decibel (dB) by using Formula 6.1. In this formula, "I_L" represents the intensity value obtained from the graph (sound level); "*dB*" represents the sound level in decibel.

$$dB = 20x\log_{10}(I) \qquad \textbf{(5.17)}$$

The intensity value I_L is a unitless quantity, which is the proportion of the field-measured amplitude A_1 over a reference amplitude A_0. This reference amplitude could not be obtained from the manufacturer, so throughout this study the output graphs are given with unitless sound levels.

5.9.2. Ground Microphones

During the field studies, Sewerin's Aquaphon® A 100 was the most used equipment. It is an electronic ground microphone having the ability to recognize noises of frequency between 1 Hz and 10 KHz. With such a wide range, it is also equipped with the frequency-filtering feature. It can filter out the selected frequencies, helping the operator to focus on the leak noise only. The device can be used with two major hardware. One ground microphone headpiece for listening ground noises (on asphalt, pavement or earth surfaces) (Figure 5.20) and one listening stick for listening noises from fittings (valves, hydrants or customer water meters) (Figure 5.21). One from the two hardware is selected depending on the listening spot. The units of the values read in the device's screen are again unitless values as described in Section 5.9.1.

Working mechanism of Aquaphon A100 is easy. Volume of the noise that is being listened is elevated at the device and transferred to the operator from the headphones. When the leak spot is near, operator hears a higher volume of the leak sound also observing the amplitude of the noise from the device's screen. Search for leakage is done near the suspected spots, trying to detect the highest leak sound. Leak spot is often located where the maximum leak noise is obtained.

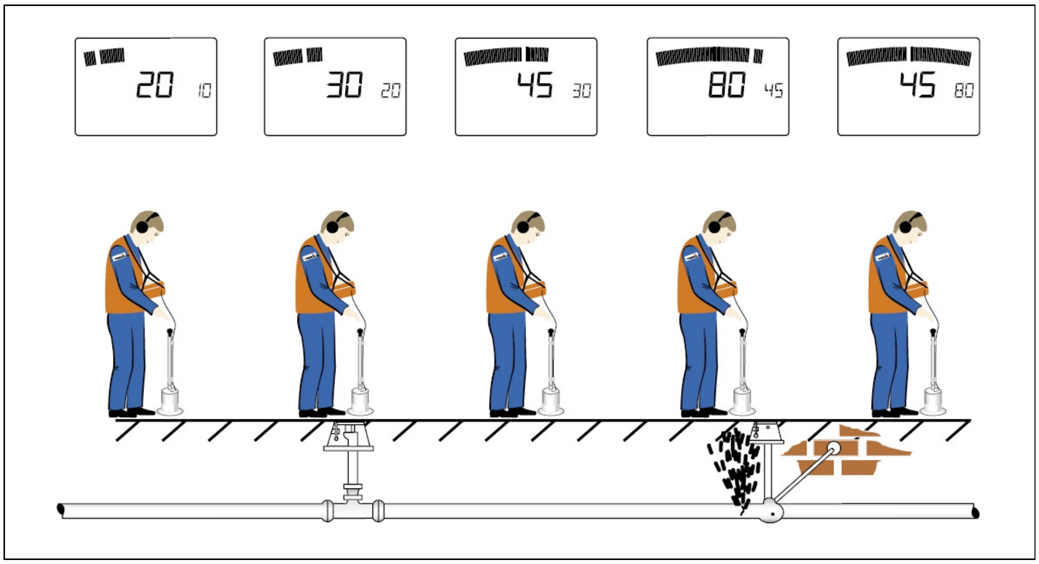


Figure 5.20: Pinpointing Leak Spot with Ground Microphone from Surface (Web10)

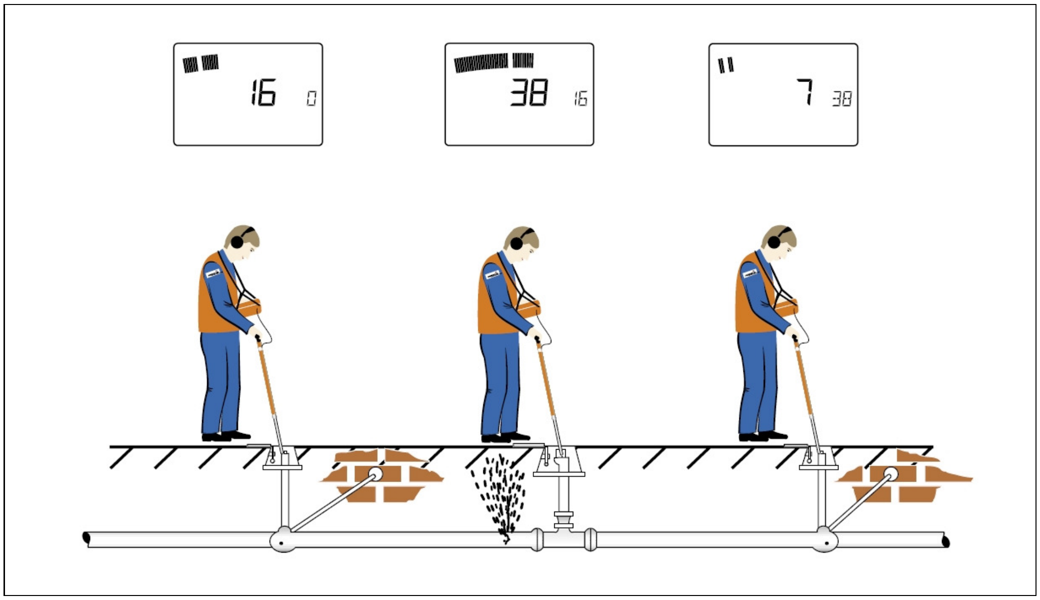


Figure 5.21: Pinpointing Leak Spot with Listening Stick from Fittings (Web10)

As seen from Figure 5.20 and Figure 5.21, the device's screen shows higher values when listening point is nearer to the leak spot. As another helper, the real, amplified sound of the leak heard from the headphones are considered. In Figure 5.21, conceptually two corporation cocks and one underground hydrant is shown. Corporation cocks are usually buried and not kept ready for regular usage in Turkey. Valves in the network are used more than corporation cocks.

CHAPTER 6

CASE STUDIES IN ANTALYA WATER DISTRIBUTION NETWORK

As applications of the methodology explained in Section 5, two district metering areas, namely “Zone 6” and “Zone 2” are selected in Antalya’s Konyaaltı County. The procedure is clearly applied on field. At the end, a decrease in minimum night flow and an increase in monthly revenue ratios are achieved in both zones.

6.1. General Information about Antalya Water Distribution Network

Antalya is Turkey’s seventh biggest city in terms of population. The total population of the city is nearly 2 million and about half of them are living in central counties (Aksu, Döşemealtı, Kepez, Konyaaltı, and Muratpaşa) (Web1). As the city is one of the major tourism cities of Turkey, its population increases considerably in summer.

Antalya’s major water sources are deep-wells distributed over city’s different places. As a treatment process, only chlorine is injected to the water and it is pumped to the city. Distribution concept is drawing the water out of the wells, and then pumping it to storage tanks located at the far end of the network mains. While pumping water to the tanks; distribution to the secondary network is done.

Water consumption of Antalya’s central counties stated above, is around 180000 m^3 per day according to the records at the SCADA centre. Moreover, according to the previous records, consumption becomes slightly more than 200000 m^3 per day during the tourism season.

The city has nearly 3000 km of water distribution mains and secondary pipes. Pipe materials show a great variation throughout the city network. Major materials can be stated as; PVC, HDPE, asbestos cement, steel, ductile iron and cast iron (Table 6.1). The whole city network goes through a rehabilitation process in which the old pipes (mainly steel and asbestos cement) are being replaced by PVC pipes. Most of the house connections are HDPE pipes, while there are still some primary and secondary distribution pipes, which are HDPE too.

Table 6.1 Percentages of pipe materials in Antalya WDN

Pipe Material	Percentage (%)
PVC	58.18
HDPE	24.90
Asbestos Cement	7.29
Steel	3.78
Ductile Iron	2.37
Cast Iron	2.30
Galvanized	0.56
Glass Reinforced Plastic	0.36
Unknown	0.25
Total	**100**

Topography of the city varies considerably as the city lies between Western Taurus Mountains (Bey Dağları) and Mediterranean Sea. Neighbourhoods in Konyaaltı have a very flat elevation distribution, whereas neighbourhoods near the sea cliffs and the Castle may have very steep sloped streets.

Antalya Water and Wastewater Administration (Antalya Su ve Atıksu İdaresi, ASAT) is the organization, which is responsible for all of the water and wastewater issues in the central counties. For more than a year, the administration runs a pilot project aiming to deal with water losses, controlling the network, forming a SCADA system with district metering areas (DMA), obtaining reliable GIS layers of the city, forming an up to date database of the customers.

As a starting location Konyaaltı county is chosen. The whole network in the county is investigated carefully with the administration's office and field personnel and as a result, the network is divided into 18 DMAs (Figure 6.1). To achieve a big success almost all of the valves on the network were located in the field, excavated and made ready for use. This makes thousands of valves that have been treated all around Konyaaltı. To overcome the risk of these valves to be covered by asphalt, all of them have been coordinated precisely with Cors-TR compatible GPS receivers. Forming the DMAs in the field was achieved by determining the borders and closing the valves that intersect with the borders. Similarly, detection of valves under asphalt surface and making them ready for use is done in the rest of the city.

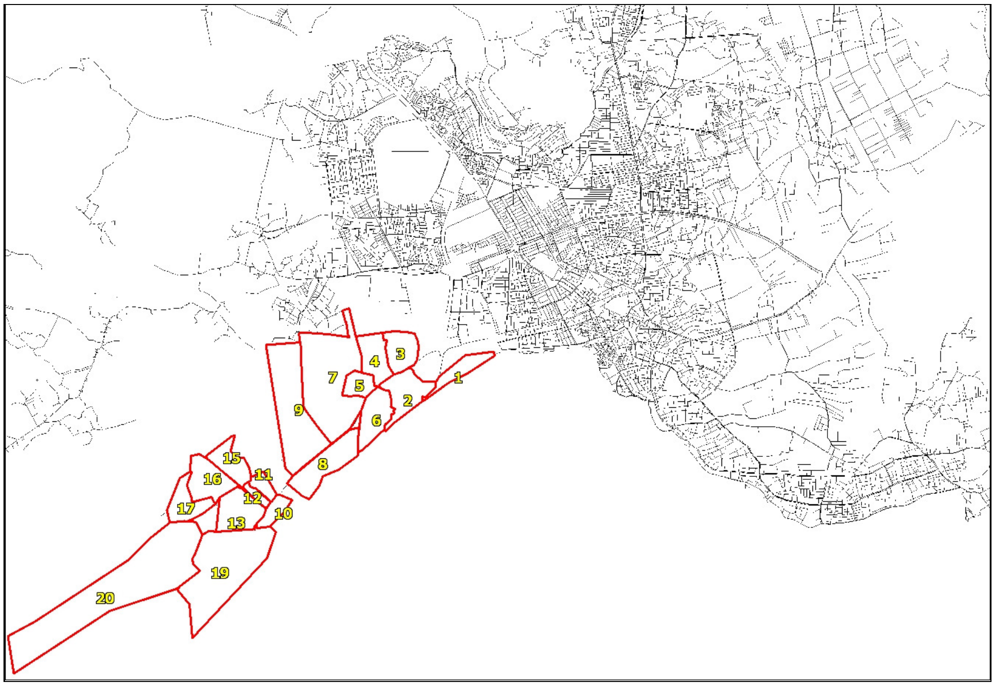


Figure 6.1 18 District Metered Areas formed in Antalya Water Distribution Network

At the entrance pipes of each DMA, electromagnetic flowmeters were placed and connected to the SCADA system. By the help of this system, administrative staff can see the flow, pressure and water quality values of the interested DMA instantaneously. In addition, all of these data are stored in the SCADA's database for future access to the historical values.

To obtain reliable GIS layers of the city GPS surveys have been done. Field collected data is entered to a system built on ArcGIS. As stated above, all of the isolation valves are coordinated using GPS. Additionally all of the fire hydrants, air valves and related fittings of the network are coordinated. Also, all of the pipes and dead end points in the network are coordinated some by just tracking the pipes between valves on the asphalt surface, and some by excavating and taking the real coordinates (Figure 6.2). Another GIS layer is formed from the house connections. Again, some of them are coordinated by excavating the asphalt and touching the connection, some of them were coordinated either by the help of utility locator devices (pipe and cable detectors) or by knowledge of highly experienced field personnel.

Figure 6.2 Coordinating the pipeline (Web 4)

As another task, all of the buildings in the county are given a unique id and they are connected to the customer database (see section 6.1.3). With this step, a customer information system that can be integrated to GIS is almost established. By the help of this study, it became easy to calculate the total consumption in a DMA in a monthly basis. On the other hand, it is possible to measure the flow entering to the DMA in any time period. So the water loss amount and non-revenue water percentage of each DMA in Konyaaltı can be calculated to a certain extent. These topics are discussed in detail in sections 6.2.2 and 6.3.2. Other useful layers like cadastral layers and street centreline layers are obtained from Greater Municipality of Antalya and Municipality of Konyaaltı.

Konyaaltı has approximately 310 km of water distribution network mains and secondaries. Just like the other parts of Antalya water distribution network, pipe materials in Konyaaltı is mainly PVC with small amounts of HDPE, steel, ductile iron and asbestos cement.

Konyaaltı lies along the Mediterranean Sea and has very little elevation changes. Mainly all of the elevations near the seaside can be assumed as a constant value. So this makes very little pressure changes at the entrance of the consumers due to topography. This is not valid in other regions of the city. For example, neighbourhoods near the mountainous regions or old city centre located in the Castle (Kaleiçi) show great elevation changes. Assuming constant elevation values can only be accepted in some parts of Konyaaltı.

The county has 42104 consumers according to the records of ASAT. The 2009 population for the county is given as 106748 by TÜİK (Web2).

6.1.1. GIS Layers

6.1.1.1.Pipes

Pipe layer is drawn in polyline and contains the following attribute fields: Unique ID for each pipe segment, diameter of the pipe in millimetres, material of the pipe, depth of the pipe (if known), calculated length of the pipe, pressure zone of the pipe, address information and information about the installation of the pipe. These attribute fields are filled from project values and field staff's knowledge but they may contain important mistakes (mostly wrong diameter and wrong material) that conflict with the reality on the field.

6.1.1.2.Fittings

Fittings layer is composed of point objects. These objects' coordinates are collected using GPS. However, this realistic drawings of the fittings are not suitable for a map layout especially fittings that are located within centimetres to each other. To overcome this problem, the GIS department places new point objects that represent the position of the object schematically. In Figure 6.3 below, "Kvana" represents the real coordinated valve; on the other hand, "Vana" represents the schematic drawing of the corresponding valve. These schematic points are identified in their attribute tables. They are not placed for each valve. Placement is within operator's responsibility. If operator thinks that too much overlapping of the objects will occur when a layout is plotted, he or she places a schematic twin of the fitting.

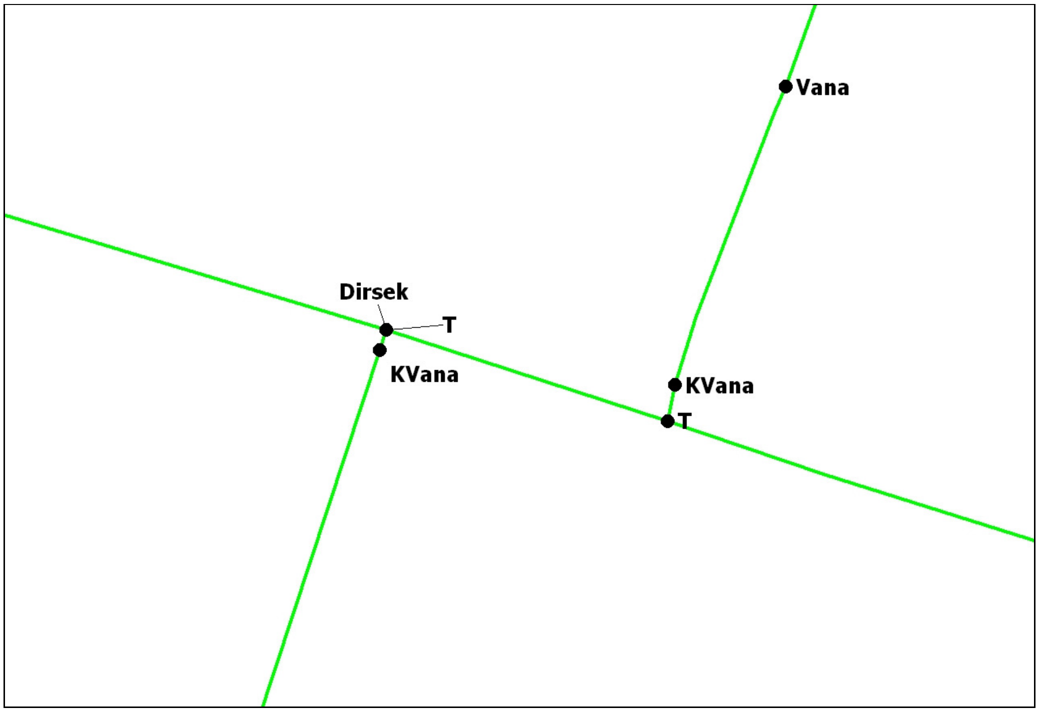


Figure 6.3 Explanation of Coordinated and Schematic Valve Drawings

Fittings layer contains the following attribute fields: Unique ID for each fitting, diameter of the fitting in millimetres, material of the fitting, type of the fitting, address information and information about the installation of the pipe. Whether the fitting is coordinated or schematic is identified in "type of the fitting" column.

6.1.1.3.House Connections

House connections layer contain exactly the same attributes with the pipe layer, but they represent the service connection pipes not the distribution network pipes. Therefore, they have smaller diameters and shorter lengths. This useful layer determines which building is connected to which pipe. In addition, it becomes more important on the borders of different pressure zones. If the buildings seem to be connected to a different pressure zone's pipe, the leakage computations of the zones are deeply affected.

6.1.1.4.Buildings

Buildings layer is the layer that represents every building in the city. They are drawn in polygon shapes. They are digitized using satellite images by using the corners of the roofs mostly. The attributes can be listed as: Unique ID for each building, name and number of the building, type of the building (residential, office etc.), number of floors, subscription ID of one of the consumers in the building, number of customers in the building, number of the zone that the building is in and address information. Subscription ID of one of the consumers is aimed to build a connection with the customer information system in order to assign monthly consumptions to the buildings. By this way, very precise hydraulic modelling works can be done. Also this knowledge can be used to make a connection with the SCADA records to calculate the amount of physical water loss. This topic is studied in sections 6.2.2 and 6.3.2.

6.1.1.5.Roads

Road layer is a polyline layer that represents the centreline of the roads. They are given a unique id and the road name as the most important attribute values. This layer is a layer obtained from Municipality of Konyaaltı.

6.1.1.6.Cadastral Layers

Cadastral layer is obtained again from Municipality of Konyaaltı and drawn in polygons. Usually these layers are produced in NetCAD environment and transformed into GIS layers through a series of operations. They represent the cadastre areas and have the following attributes: Unique ID, Area of Usage (residential, green field, hotels etc) and cadastre number. This layer is useful in field studies as the street spaces are clearly seen between cadastre areas helping to determine the addresses. In addition, it is useful to check whether a pipeline falls inside a cadastre area or not indicating a possible cancelled out pipe that is not removed from the pipe layer.

6.1.2. SCADA Data

Data obtained from SCADA is very useful for the determination of water losses. From SCADA measurements, the total water flow entering to the DMA can be obtained for a particular time period. This is obtained by subtracting the first index from the second index. With ideal conditions where there is no water loss in the system in any type, the same amount of water should be obtained by summing up all the index changes at the customer meters within the same time period. Unlike ideal conditions, there are water losses all around the network, water meters are not perfectly measuring the flow that is used and meter readings are being read by people that can make rounding errors.

The metering data is explained in section 6.1.3 in some aspects. Strict monthly readings are not done so, each user's water usage is metered for a different time period. With the data available, it is impossible to superpose the SCADA data and the customer readings because of different time periods (Figure 6.4). To overcome this difficulty, customer readings can be normalized by the time period they have used water, so monthly usages can be converted to daily usages assuming a 24 hour constant flow everyday throughout the metering period. By summing all of the average daily consumptions of all users, average daily consumption of zone 6 is obtained. Average daily consumption of the total zone can be compared to the monthly water flow entering to the DMA divided by the time period. In Section 5.4.2 extensive information is provided for water loss percentages and SCADA – CIS integration.

6.1.3. Customer Information System (CIS)

Having examined the structure of the customer information system, it is difficult to say an organized connection between the consumptions and the GIS data is present. The integration is made by the interested staff's effort. This is because the customer relations department and GIS department were not designed to work cooperatively at the stage of establishment of ASAT. GIS department has done most of the work by digitizing the all of buildings in the pilot study area, giving a unique ID to each building, and collecting all of the customer information in the buildings (pressure zone name, customer IDs, address related data, telephone numbers, e-mail addresses, water meter IDs, water meter types and brands). In the meantime, customer relations department keeps on collecting monthly consumption data from water meters with a different crew. As the water meter reading crew works directly on field, GIS crew also worked on field to check if the buildings still exist, or if new buildings are being built. Data collected from these two sources are integrated manually. On the other hand, a study for the automation of this integration was going on when this thesis study has been done. The integration is made simply by bringing together the unique customer IDs and unique building IDs with the consumption data of each customer.

As explained theoretically in Section 5.4.1, consumption records being kept in terms of periods. Each period roughly defines 30 days consumption. As the record collecting crew is working independently from the GIS crew, the data collected in the same period represents different days' consumptions for different users. With the help of Figure 6.4 below an example can be given for this situation. For example; a user's (Customer 2) consumption data is collected between 02.03.2010 and 07.04.2010 (37 days) on the other hand another user's (Customer 1) consumption data is collected between 11.02.2010 and 23.03.2010 (41 days) and these two consumption data have been recorded under 2010 – 3rd period consumptions column. Almost every customer has different monthly reading periods. This is done probably because of people in the meter reading crew is collecting data considering different borders (probably neighbourhood borders) but not pressure zone borders. It is best to collect the data within the pressure zone completely in one day to detect monthly water loss amounts. However, due to administrative reasons this stated action seems very difficult to apply with meter reading crew. It may be possible if data logging water meters were used throughout the zone.

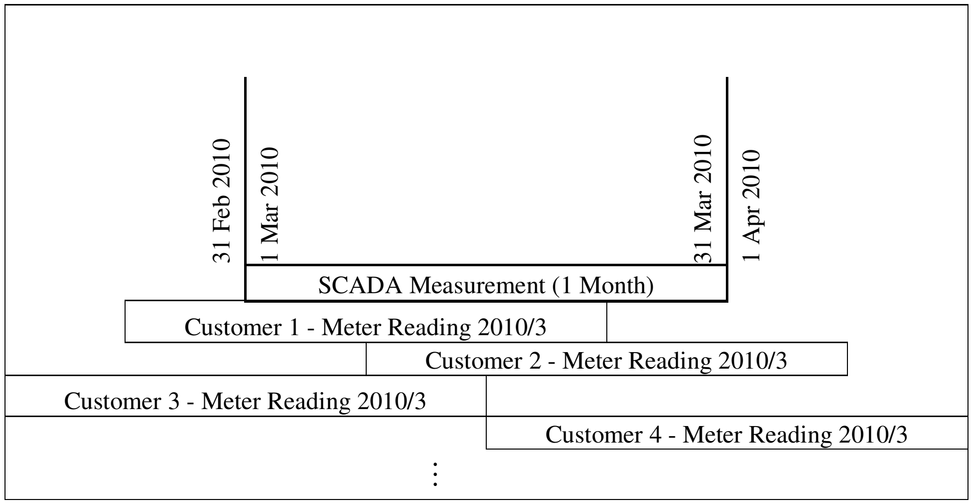


Figure 6.4 SCADA Measurements and Corresponding Customer Readings for one Month

As stated, the errors are introduced from beginning and ending of the monthly periods. To reduce this effect, a long period of time can be considered. By this way there still will be errors coming from the edge of months, but their share in the total will decrease. When considered monthly, every customer's reading will be out of SCADA bounds. When a longer period is considered, only January and December readings will be out of yearly SCADA measurement's bounds. All the other consumption readings from February to November will be reflected in SCADA measurements (Figure 6.5). This helps to determine the revenue percentage in a better way with the available data.

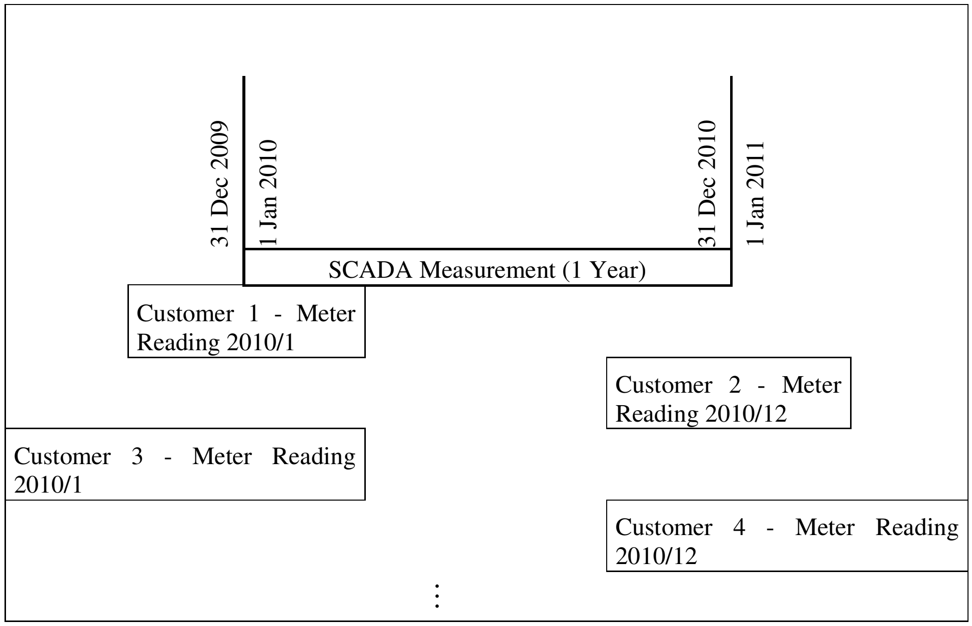


Figure 6.5 SCADA Measurements and Corresponding Customer Readings for one Year

The records for consumptions have been integrated (as stated above) beginning from 1st period of 2008. The consumptions for each customer are kept under three columns for each period. Two of these columns are the beginning and ending days of reading periods, and the third column is reserved for the collected metering data in terms of meter cubes. The precision of the readings are in meter cube level. Unfortunately, an inevitable piece of error is introduced to the collected data at this stage, by rounding up or down the water meter reading.

The data obtained shows that a proper record keeping has been done from 2009 until now. The improper records in the first 12 months are due to some absences in beginning and ending dates for periods. After 2009 1^{st} period, there are not any missing data in the beginning and ending date columns. In Table 6.2 a sample record from the CIS of Antalya Water and Wastewater Administration is given. The original database is reordered and grouped into five categories defined by the author for visual simplicity (PART A to PART E).

In PART A, key values about the identity of the customer is given. ABONE NO defines the unique ID for the customer and it never changes with consumers moving in or out to the address. In other words, this unique ID is tied to the address where the consumption is being done. Typical address and contact information are being recorded in the related fields. Type of the customer is given in two fields, one in ABONE TURU (as predefined codes for quick fetching from the database) and the other one in ABONE TURU ACIKLAMASI (for print out purposes). Lastly DURUM field defines the status of the customer whether water is actively being used or account is suspended due to some reason.

PART B contains fields about the water meter. Its identification number, brand and type of the meter and the meter's installation dates are being recorded in these fields.

PART C is the only part that is being updated regularly in monthly intervals due to consumptions. Every month three new columns are added to the database, which keeps the record of the consumption period's beginning date, ending date and consumed water volume. Additionally, in a separate field, the average of all consumptions are being calculated and updated every month.

PART D contains all the GIS related data. Most of the address data recorded in this part is also kept in predefined codes for possible GIS integrations. The most valuable field in PART D is CBS ABONE NO. In this field, unique IDs for the buildings are being kept. By using these unique IDs, a quick integration between the monthly consumption values and the building layer in GIS (or node layer in the water distribution models) is possible to make. Also pressure zone's (or DMA's) IDs are being recorded in this part.

Lastly, in PART E, necessary administrative data for each customer is recorded. These data contain tax information, sewerage details and data required by customer relations department's water meter reading crew.

Table 6.2 A Sample Record from the CIS of ASAT

PART A – IDENTIFICATION	
ABONE NO	195755
ABONE ALT NO	1
ABONE ISMI	SEVKET YARIMBAS
ABONE TURU	1
ABONE TURU ACIKLAMASI	EV ABONESI
ADRESI	ARAPSUYU MAH 646 SOK NO:37 D:7
EV TELEFONU	2299999
IS TELEFONU	
CEP TELEFONU	5324777777
E-MAIL ADRESI	
KOMSU ABONE NO	20020354
DURUM	A
PART B – WATER METER DATA	
SAYAC NO	16532
SAYAC MARKA	CBAY-B
BINA IC SIRA	1
İLK ABONELİK VERİLİŞ TARİHİ	01.03.2005
ABONE BAŞLANGIÇ TARİHİ	01.03.2005
KAPANIŞ TARİHİ	
PART C – CONSUMPTION DATA	
ABONE TUKETIM ORTALAMASI	10,42
2010-4 ILK TRH	10.03.2010
2010-4 SON TRH.	12.04.2010
2010-4 M3	11
2010-5 ILK TRH	12.04.2010
2010-5 SON TRH.	12.05.2010
2010-5 M3	9

Table 6.2 Continued

PART D – GIS DATA	
CBS ABONE NO	195755
CBS ZON NO	2
ADA	3747
PARSEL	7
ILCE KODU	3
ILCE ADI	KONYAALTI BELEDIYESI
BELDE NO	1
BELDE ACIKLAMASI	MERKEZ
MAHALLE KODU	7
MAHALLE ADI	ARAPSUYU MAH.
SOKAK KODU	38
SOKAK ADI	646 SOK.
SITE	
BLOK	
APARTMAN	MANOLYA APT.
DIS KAPI	37
DAIRE NO	7
EV SAYISI	1
ISYERI SAYISI	0
PART E – OTHER ADMINISTRATIVE ISSUES	
DEFTER	368
DEFTER ACIKLAMASI	ARAPSUYU-3
SAYFA	104
SIRA	102
CTV VAR MI? 1-Var 0-Yok	1
KANAL VAR MI? 0-Yok 1-2-3-4 Var	1
KANAL ORANI	0,30
KANAL TARIHI	01.05.2006
ZON NO	368
BINA TAKIP NO	119

6.2. Zone 6 Studies

Zone 6 of Konyaaltı network is one of the 18 district metering areas explained above. Zone 6 has 344 buildings registered in the customer information system (CIS) at the time of this study. The total number of customers is given as 1800 in the CIS.

The DMA is fed by a pump station located in Boğaçayı and a storage tank located in Hurma (Figure 6.6).

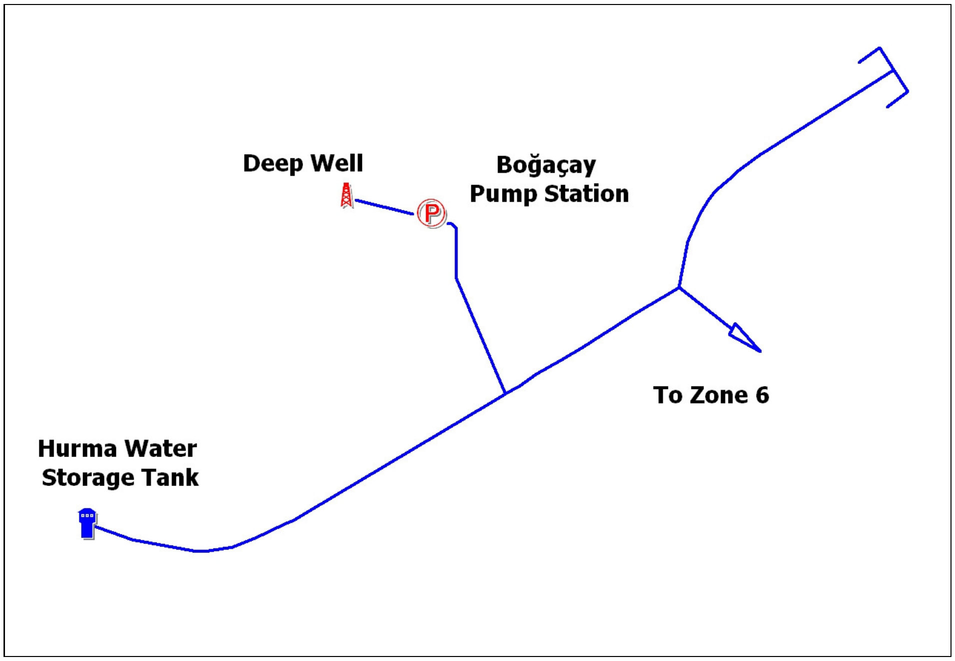


Figure 6.6 Simplified Schematic Drawing of Konyaaltı Water Transmission System and Zone 6 Entrance

The diameter of the transmission line between this pump station and storage tank varies from Ø400mm to Ø800mm. Zone 6 and most of the other 18 DMA's take one branching pipe from this transmission line and serves to a district area (Figure 6.7).

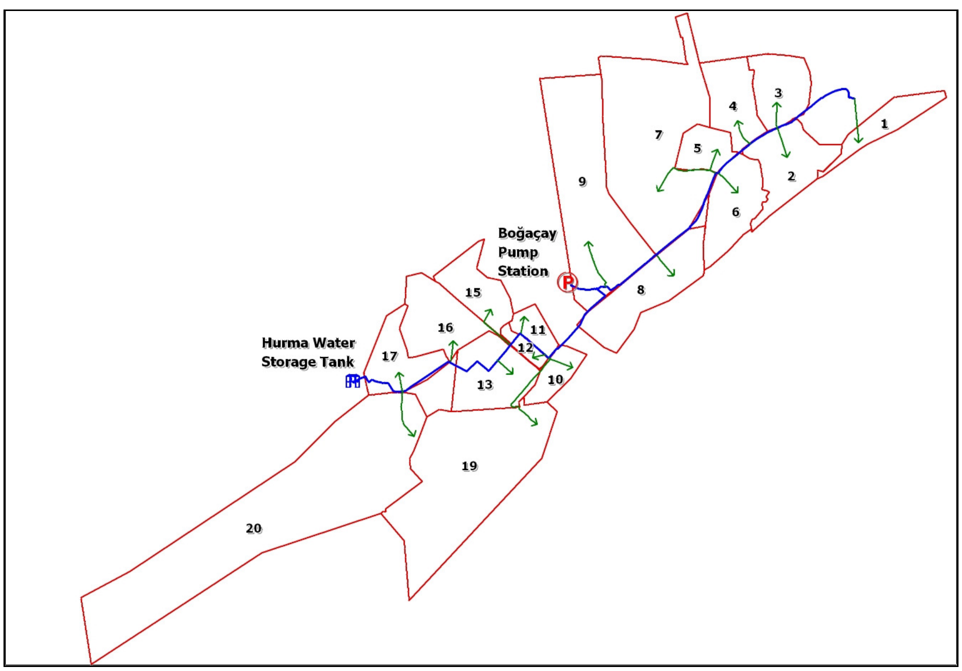


Figure 6.7 Distribution Main of Konyaaltı and Branching Pipes of 18 DMAs

6.2.1. Data Sources

6.2.1.1.Geographic Information Systems

6.2.1.1.1. Pipes

The name of DMA has two alternatives that are being used by the ASAT staff. It is named as zone 6 by the GIS crew, as metering point 70 by the SCADA crew.

The main transmission line within the DMA is an Ø200mm HDPE pipe, and it serves to an approximately 8800m of secondary pipes. The distribution of lengths of the pipes is given in the table below (Table 6.3). It can be seen from the table that transmission mains are mainly Ø200mm and a small amount of Ø225mm pipes. In addition, a majority of the street network consists of pipes between Ø90mm and Ø150mm pipes.

Table 6.3 Pipe Diameters and Pipe Lengths in Zone 6

Pipe Diameter (mm)	Pipe Length (m)
50	156.0
63	233.7
75	361.3
90	1842.9
100	907.6
110	4380.3
150	962.6
200	1851.1
225	39.3
Total	**10734.8**

It is stated previously that pipe materials in Antalya water distribution network consist of various types. Similar situation is present in this DMA, namely zone 6. The material distribution is given in the table below (Table 6.4). It is seen that because of the rehabilitation studies done in the study area, most of the old pipes are renewed with PVC pipes. A relatively small amount of asbestos cement pipes (AÇB) are planned to be cancelled out due to low durability to pressure and due to water quality risks.

Table 6.4 Pipe Materials and Pipe Lengths in Zone 6.

Pipe Material	Pipe Length (m)
Steel	27.9
Galvanized	46.9
Unknown	149.0
PE	161.7
Asbestos Cement	385.8
HDPE	1884.2
PVC	8079.4
Total	**10734.8**

The result of a more detailed tabular analysis is given below indicating the diameters, materials and their lengths in this network (Table 6.5).

Table 6.5 Pipe Diameters, Pipe Materials and Pipe Lengths in Zone 6

Diameter (mm)	Pipe Material	Pipe Length (m)
50	PE	156.0
63	Galvanized	46.9
63	PVC	186.8
75	PVC	361.3
90	PVC	1692.6
90	Asbestos Cement	150.3
100	PVC	758.6
100	Unknown	149.0
110	PVC	4374.6
110	PE	5.7
150	PVC	705.3
150	Asbestos Cement	235.5
150	Steel	21.8
200	HDPE	1851.1
225	HDPE	33.2
225	Steel	6.1
Total		**10734.8**

6.2.1.1.2. Fittings

On the fittings layer there are 58 valves and 5 fire hydrants all of which are suitable to use. These isolation valves are examined one by one on the field. Some old valves were seen to bleed very little amounts of water out of the system. In long-term studies, these leaks can sum up to big amounts. However, as these valves are working properly, meaning they can be completely closed or opened without affecting the flow; the Administration is not willing to spend money and time to renew them. After all, these small leaks remained unrepaired.

Another important aspect for the isolation valves was the existence of three isolation valves that were isolating zone 6 from two neighbouring zones, Zone 2 and Zone 8. It is necessary to keep these three isolation valves closed at all times because the neighbouring zones are under different pressure values. If any of these isolation valves remain partially or fully open, then unaccounted water may enter to or exit from the system. In more complex and rough topographies, borders of pressure zones are mostly determined by elevation, but in Konyaaltı, the topography is very flat. Consequently, pressure zone borders are determined by isolation valves that remain closed at all times.

Before the study, it was noted that the DMA had some deficiency in terms of valve numbers and placements. In the technical brochures of the equipment used on the field, Sepem 01 leak noise loggers, it is given under the "recommended distance between loggers" title as 300 – 500 meters for metallic pipe material, and 50 – 100 meters for plastic pipe material (Web 3). To be on the safe side, and by considering the major pipe material, which is PVC, it is assumed that the devices will work within a limit of 50-meter range on the field. By making a buffer analysis to draw 50-meter diameter circles around valves, it was seen that most of the network remained outside of the effective range of the noise loggers. In conclusion, at ten different places of the network the administration was advised to place valves and connect some of the dead end pipes to the nearest pipe available to ensure the sound of the leaks will travel to a wider distance. Administration was convinced and constructed eight of the ten connections in a short time period. Two of the advised connections were not made because of the complexity of the electricity and telecommunication network at the construction points.

The administration was also advised to place 35 valves at different places of the network. 11 of them were placed while constructing the nine connections stated above. However, the other 24 valves were not placed because they were mostly not at street intersections but in the mid point of street lines. These kinds of valves remain ineffective in terms of isolation of pipes at street level. The ineffectiveness is due to the existence of valves at street intersections. The situation is explained better in Figure 6.8. In the figure, dots indicating present valve locations and possible recommended valve places are seen. The buffer circles around valves are 50 meter in diameter. Valve at the street intersection controls the whole street. New valves will remain ineffective as their job of isolating the street is done better with the present valve. In addition, placing valves at regular distances on the network may be an expensive job.

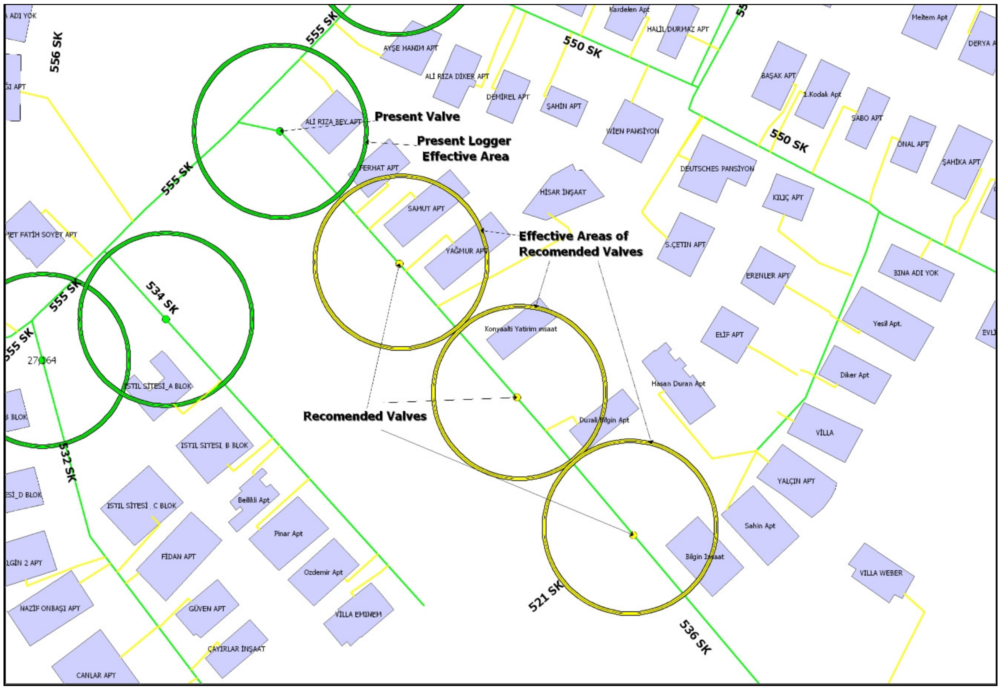


Figure 6.8 Recommended Valve Places and Their Effective Areas

The figures below show the situation of the network before and after the maintenance works (Figure 6.9). Before the maintenance, network had 47 valves, after the suggested construction works number of valves increased to 58.

Figure 6.9 Valves and Their Effective Areas Before and After Constructions

6.2.1.2.Customer Information Systems

Upon investigating the CIS database, it is found out that there are totally 1782 customers in zone 6 of Konyaaltı. These customers are being residents in 344 buildings according to the customer relations department's data. However, in the building layer generated by GIS department, there are 392 buildings. Remaining 48 buildings are either buildings that use water mutually with some neighbouring building (commonly seen in shacks), or using wells instead of city's water distribution network. Therefore, these kinds of customers do not have a separate customer IDs. Consumptions generated by mutual users are reflected to the owner's meter, and consumptions of private well users are out of interest for this study.

6.2.2. Calculating Water Loss Percentages

Water loss percentage calculation is studied in two aspects throughout this study. First aspect is calculating monthly revenue ratios with the help of SCADA and CIS data. Second aspect is comparing minimum night flow of the region to the total consumption. Extensive explanations are given in Section 5.4 theoretically. During field studies, the procedures given in Section 5.4 are applied in both aspects. They are explained in Sections 6.2.2.1 and 6.2.2.2. Results obtained after the field studies are also summarized in Section 6.2.5.

6.2.2.1.Monthly Revenue Aspect

This calculation can be done in monthly periods if water meters are being read in monthly periods, which is the usual situation. In addition, as explained in previous sections, it contains some amount of error if the SCADA system and CIS are not meant to work cooperatively. In addition, this calculation cannot determine whether the lost water is revenue loss (illegal water usage) or a physical water loss. Resulting calculation gives the result as the sum of all losses.

Procedure explained in Section 5.4.1 is applied to Zone 6 and for 2010 3rd period (before the field works). The water flow index on 1 March 2010 00:00 is 23560 m³ and on 31 March, 23:59 is 59970 m³. The difference is 36410 m³, which is the volume of water entering to zone 6 during the dates mentioned. The time period is 31 days. Averaged daily supplied flow is 1174,52 m³/day. The sum of all 1782 customers' averaged daily usage is 436,87 m³/day. This means that with all the errors considered, about 63% of the supplied water is lost, only 37% of the supplied water can reach to end users. This percentage is called as monthly revenue.

After the field works applied in zone 6, the same calculation is done. This time the volume of water entering to the zone is 30980 m^3 between 1 April and 30 April. Its daily averaged value is 1032,67 m³/day. On the other hand, during 2010 4th period, the sum of customers' averaged daily usage is 457,84 m³/day. Applying the same procedure, the monthly revenue is found out to be 44%, increasing by an amount of 7%. As explained, this procedure involves a considerable amount of error. Therefore with the help of previous consumption and SCADA records, monthly revenue ratios are calculated from 2009 6th period (roughly between 1 June 2009 – 31 May 2010). The tabulated results and their graph are discussed in Results section.

6.2.2.2.Minimum Night Flow Aspect

As explained in detail in Section 5.4.2, minimum night flow value theoretically represents the amount of physical water loss of the network. Comparing the minimum night flow value to the daily usage of the region gives a water loss ratio. As the only data source is SCADA, this percentage can be calculated for any time period. However, daily loss calculations should be considered for consistent results.

SCADA records are investigated day by day and for each day, total water volume entering to zone 6 is determined. It is then compared to total lost water volume that is the minimum night flow occurring at that day, which is leaking for 24 hours. Graphical meaning of this is the ratio of the area below minimum night flow level over the daily demand curve area.

As an example, the daily demand curve in Figure 6.10 can be considered. It is the actual daily demand curve of zone 6 on 23 March 2010. The area under the minimum night flow line is the amount of water lost throughout the day and can be denoted by letter "B". On the other hand, the total area is the total volume of water entering to a DMA for a day, denoted by "A+B". Water loss percentage (L%) is formulated in Equation 6.1 below. In this example, minimum level is at 32.5 m³/h but this is a value changing from day to day in small amounts. As the study area is a tourist area, theoretical minimum night flow may not be observed at all. There is a consistent night usage everyday by some consumers. Consumptions occurring at late night hours tend to decrease towards morning hours but most probably, their usage hours overlap with those who wake up early and generate usage at early morning hours.

As mentioned in Chapter 5, minimum night flow shows little variations during the day due to changes in pressure. However, in the case studies, this variation is ignored and minimum night flow is assumed as constant.

$$L(\%) = \frac{B}{A+B} \times 100 \tag{6.1}$$

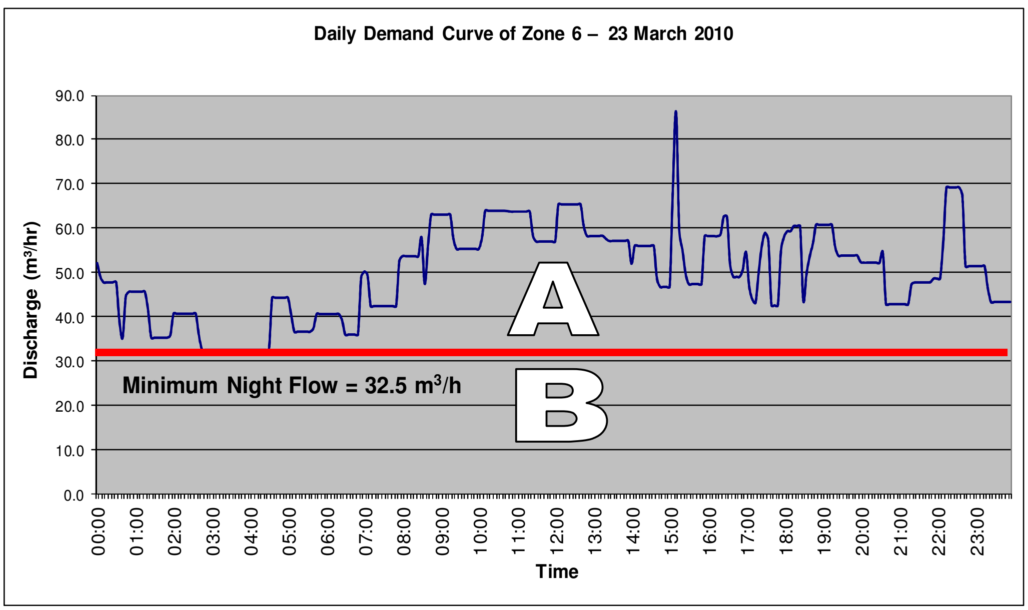


Figure 6.10 Sample Daily Demand Curve of Zone 6 Showing Minimum Night Flow before the Study

Calculations for zone 6 are done before and after the field works. Before the field works, minimum night flow in the system was at 30 m^3/h level. Corresponding water loss ratio was around 65%. After detecting the leaks and repairing them, the minimum night flow decreased to 20 m^3/h level and water loss ratio decreased down to an average of 55%. However, a short time after the repairs, both minimum night flow and water loss percentage showed an increase. This is an indication of new leaks at either new repaired points or other weak points in the water distribution network. This topic is discussed in detail in Results section.

6.2.3. Forming Sub-DMAs

In zone 6 network of Konyaaltı, with the help of new connections and new placed valves, the DMA was divided into 8 sub-DMAs (Figure 6.11) on the plans first. Then the theoretical borders were verified by closing boundary valves on the field. As a transmission line, the Ø200mm PE pipe is used. Seven out of 8 sub-DMAs consisted of branches of pipes, which are fed by this main pipe. The eighth sub-DMA covered an area of houses that are directly connected to the main transmission line. First seven sub-DMAs are controlled with their entrance valves. Whenever one of the valves is closed, the associated sub-DMA is left without water. The valve controlling last sub-DMA is on the main transmission line. Therefore, if it is closed, the whole DMA is shut down.

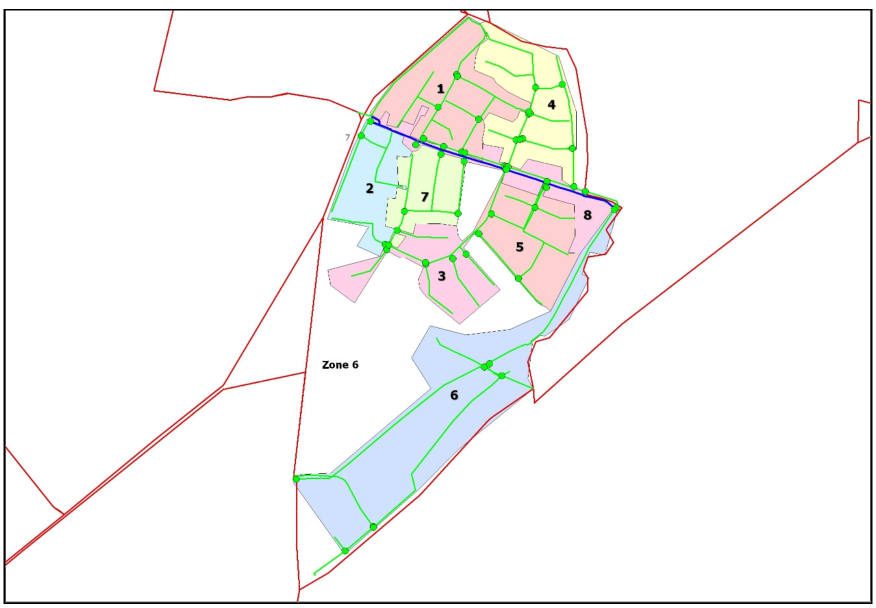


Figure 6.11 Sub-DMAs in Zone 6 of Konyaaltı Network

6.2.3.1.Prioritizing sub-DMAs by Step Tests

Although the flow data is recorded by the SCADA system, the measurements were recorded manually by checking the flowmeter instrument's panel located at the DMA entrance (Figure 6.12). At this panel, real time flow, pressure and water quality values can be observed. The SCADA system in Antalya is configured in such a way that, changes in flow or pressure at measuring points are not transmitted to the central SCADA unit up to some tolerance limits. If flow or pressure values change more than that limit, then the new value is transmitted to centre. By this limitation, it is aimed to minimize the transmission traffic and therefore minimizing the possible scrambles that may occur in the transmitted data. However, setting such a limit prevents the operator to see small changes occurring in the system. Therefore, the only way was to use flowmeter's panel to see and record the changes occurring for a reliable study.

Figure 6.12 Manually Recording Discharge Values from Flowmeter's Panel during Step Test

The step test is performed on 1 April 2010 between 02:00 – 05:00. The main reason for testing between these hours is that the neighbourhoods Arapsuyu and Kuşkavağı are mainly residential areas. There are some touristic facilities but as the date of measurements were in April, very limited tourist activity was present in the region. As a result, minimum nightly usage occurs between these hours. Sub-DMAs are shut down in the order 2 – 7 – 3 – 4 – 1 – 5 – 6. Valve at the main entrance that controls the eighth sub-DMA is not shut down because after shutting seventh sub-DMA, zero flow value is reached at the flowmeter. According to the valve closing steps following tabulated results are obtained (Table 6.6). In addition, the corresponding graph is given in Figure 6.13. As seen from the graphical results, most of the water leakage is measured at sub-DMAs 4, 5 and 6 with leakage amounts 8m³/hr, 14m³/hr and 12m³/hr respectively. Therefore, they are the weakest regions of zone 6 according to the closing step results.

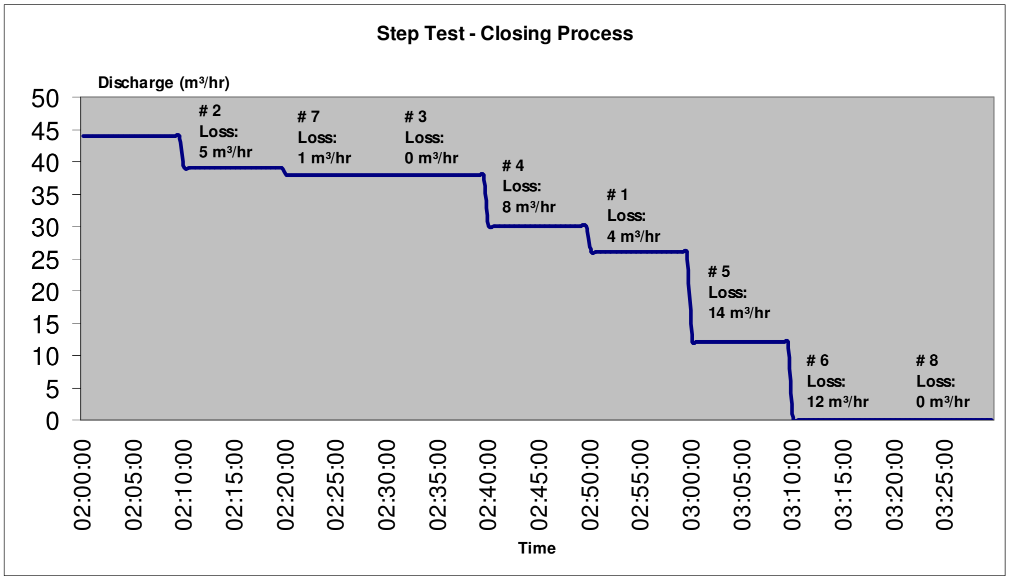


Figure 6.13 Water Losses in sub-DMAs Determined by Closing Valves

Table 6.6 Tabular Results of Flowmeter Values during Valve Closing Steps

Closed Sub-DMA	Discharge Read From Flowmeter (m³/hr)
All Open	44
2	39
7	38
3	38
4	30
1	26
5	12
6	0

Valve-closing actions ended around 03:30 and zero flow values are reached as expected. To check the results, valve-opening actions started. Valves were opened slowly to minimize possible transient effects. Opening order of the valves was 6 – 5 – 1 – 4 – 3 – 7 – 2. At around 05:00 all the sub-DMA entrance valves were opened, and the network was returned to the state before the step test. Obtained results are given in Table 6.7 and Figure 6.14 below. If the results are examined, it would be seen that the priorities of the sub-DMAs are in accordance with the results of valve closing actions. The weakest zones are 5 and 6 as they are in the both test results. Sub-DMA 4 seems one of the weak sub-DMA in valve-opening test but the opposite in the valve-closing test. Rest of the sub-DMAs are relatively stronger sub-zones when compared to 5 and 6.

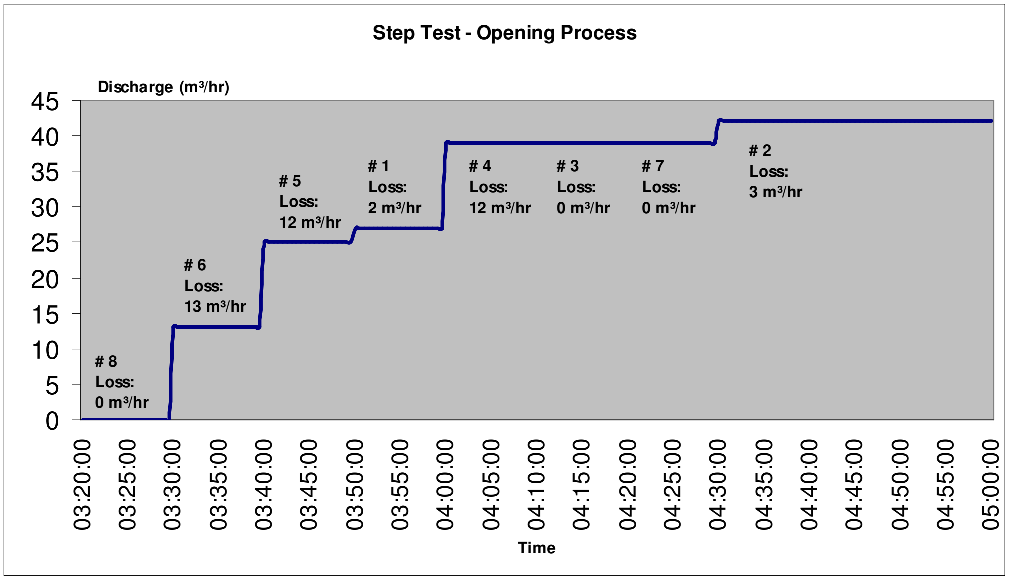


Figure 6.14 Water Losses in sub-DMAs Determined by Closing Valves

Table 6.7 Tabular Results of Flowmeter Values during Valve Closing Steps

Opened Sub-DMA	Discharge Read From Flowmeter (m^3/hr)
All Closed	0
6	13
5	25
1	27
4	39
3	39
7	39
2	42

As a result, sub-DMAs 4, 5 and 6 are grouped as weak, and the other sub-DMAs are grouped as relatively strong DMAs. Looking at the number of valves at each sub-DMA it was concluded that in two days, it would be possible to sweep the whole zone 6 by using leak noise loggers. As there were a limited number of loggers first day should be spent on scanning sub-DMAs 4, 5 and 6. Rest of the sub-DMAs can be scanned the other day.

6.2.4. Locating Physical Water Losses

6.2.4.1.Forming Buffer Areas for Leak Noise Loggers

After prioritizing the sub-DMAs, zone 6 is divided into two regions that are going to be swept one after other with leak noise loggers. Sub-DMAs 4, 5 and 6 are given first priority for leak detection study, sub-DMAs 1, 2, 3, 4, 7 and 8 are given second priority. Number of valves in each sub-DMA are given in Table 6.8 below.

Table 6.8 Number of Valves in Sub-DMAs

Sub-DMA	Number of Valves
1	9
2	2
3	6
4	10
5	8
6	7
7	4
8	8

With the equipped 20 loggers, sweeping study was first done in sub-DMAs 4, 5 and 6 on 01.04.2010. The loggers were programmed to record possible leak noises between 02:00 and 05:00 in 10-second intervals. They are programmed to send the recorded data to the master unit, the day after between 10:00 and 12:00. While collecting the data from the loggers one by one, master unit gave warnings at valves where possible water leakage is detected. According to the technical details of the data loggers, minimum sound level must be much greater than zero. Additionally, frequencies between 50 Hz and 100 Hz are treated as possible background noises and it is said that they do not come out to be leaks usually. The Operation Instructions booklet also states that low frequency values indicate leaks far away, high frequency levels indicate nearer leaks. Lastly, third parameter, width of the measurements should be low to indicate a good measurement with a low interference noise. Noises that satisfy these three conditions are reported as possible leakage and a warning is transmitted to the operator. At the same manual, it is written in bold that "A leak alert is not a guarantee that a leak is actually present" (Web 3). Therefore, other studies should be done in order to pinpoint the leak spot.

Forming buffer areas around logger placed valves, depends on the idea of determining effective leak detection areas of loggers. According to the technical details of the equipped loggers, their effective leak detection distance is between 50 and 100 meters as diameter, on plastic pipes. This is stated as "recommended distance between loggers". According to Thornton (2002), this distance can be as low as 10 – 15 meters for plastic pipes. For metallic pipes, he states effective distances can be as high as 1000 meters, but recommends a conservative value of 250 meters for an upper limit. Additionally, he recommends a value for asbestos cement and cement pipes between plastic pipes and metallic pipes. These values recommended by Thornton are direct distances from leak to listening point so they should not be treated as a diameter distance. Taking into account these recommendations given by Sewerin and Thornton, two buffer layers are built around logger placed valves, with diameters 20 meters and 50 meters taking into consideration the worst cases. With these buffer layers, logger effective pipes and logger ineffective pipes in the network are easily determined. The results can be seen in Figure 6.15, Figure 6.17, Figure 6.19, Figure 6.21, Figure 6.24 and Figure 6.26.

Considering 20-meter buffer areas, it is hard to say leak noise loggers are useful for the network of zone 6. That is because; loggers can scan a very little portion of the network. As expected, in sub-DMA 6 loggers do not scan for leaks at all, due to very long distanced pipes without any valves on them. In rest of the sub-DMAs, the picture is not much different. Only little portions of the network on street intersections are believed to be scanned. The total length of pipes that are logger ineffective is 7847 meters. It corresponds to 73% of total pipe length in the network. According to these data, suggested study is to sweep the logger ineffective areas with ground microphones. However, it seems better to use only ground microphones and sweep the entire network without spending money and time on leak noise loggers.

According to 50-meter buffer areas, a larger portion of the network is believed to be scanned. However, sub-DMA 6 is still suffering from lack of valves. Sub-DMAs excluding 6 are in better condition when compared to 20-meter buffer areas, as logger ineffective areas are much less. Total length of logger ineffective pipes is 7229 meters. It corresponds to 67% of the total network length. When these percentages are compared, it seems sensible to use leak noise loggers with ground microphones together.

As a result first day at 2 points water leak noise were detected at valves 27066, and 27169 with the logger serial numbers 3603 and 3605 (alert #1 and alert #2). Same study done on 01.04.2010 is repeated on 05.04.2010 with the remaining valves. Second day results were 5 leak noise alerts with logger serial numbers 3596, 3606, 3612, 3622, and 3641 (alert #3 to alert #7). Detected points are shown in figures below. As a next step for leak pinpointing, ground microphoning is applied.

<u>Alert #1:</u> Noise Data logger with serial number 3603 is placed to the valve at the intersection of 6th Avenue and 551st street. According to the GIS layer pipes are steel and PVC with diameters

Ø150mm and Ø90mm. The valve that is used during the data logging process is given a unique ID number of 27066 (Figure 6.15). In the figure, the position of the valve is seen with the 10m radius and 25m radius buffer areas. Pipes inside the buffer circles show the maximum possible effective distance of the logger according to the criteria discussed above.

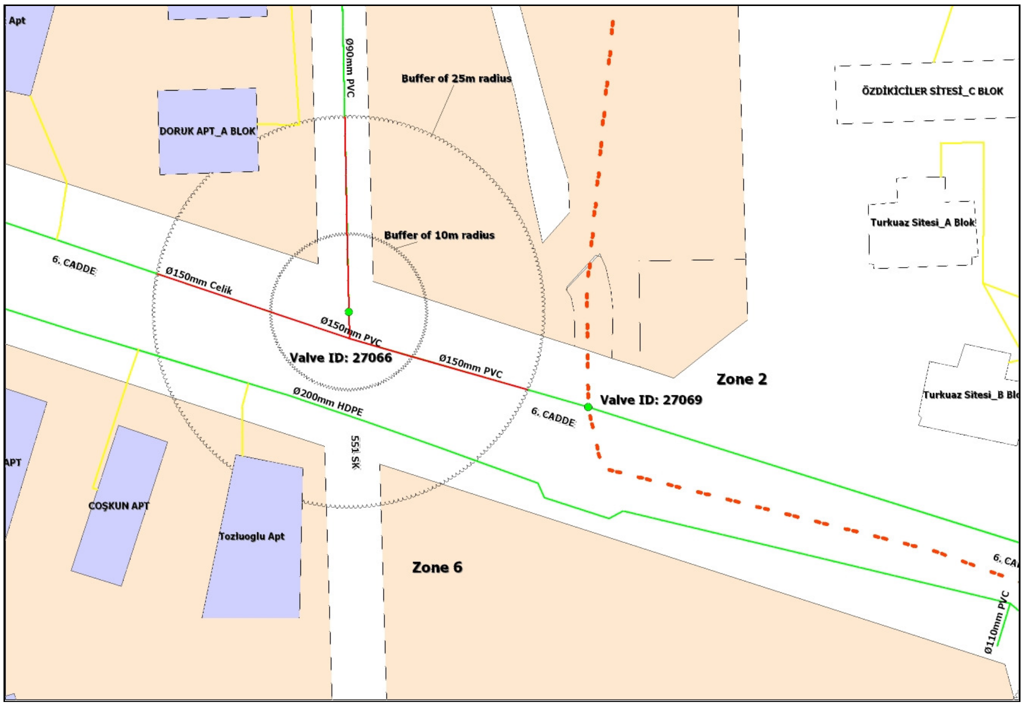


Figure 6.15 Noise Data Logger with Serial Number 3603 Placed On Valve #27066 and Its Corresponding Effective Areas

As it can be seen from the Figure 6.16, there is a constant noise on this logger between 02:00 and 05:00 that never drops below 163. This noise is generated with a frequency value 634. The value for width indicates the quality of the measurement, and it is relatively small compared to the other loggers distributed the same day. It indicates a good measurement with a small margin for errors. The only drawback in this measurement is that the "Minimum level" value is rather small. It may indicate a leak that is not very close to the valve. For a detailed investigation, scanning with the ground microphone along east and west in 6th Avenue and towards north in 551st street was scheduled.

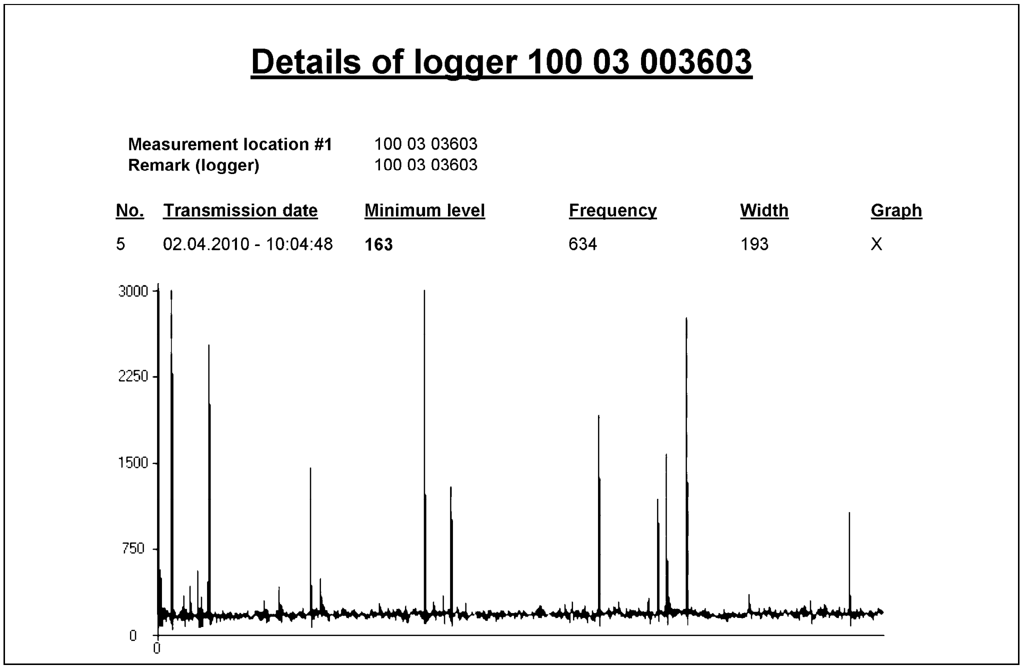


Figure 6.16 Details of Logger with Serial Number 3603 Placed On Valve #27066

Alert #2: The logger having a serial number of 3605 is placed on the valve with ID 27169 on the intersection of 555th and 553rd streets. Below in Figure 6.17 the position of the valve is seen. In addition, the corresponding buffer areas with 10 meter and 25 meter radius can be seen too. Pipes at this corner are coded as Ø110mm PVC pipes.

Figure 6.17 Noise Data Logger with Serial Number 3605 Placed On Valve #27169 and Its Corresponding Effective Areas

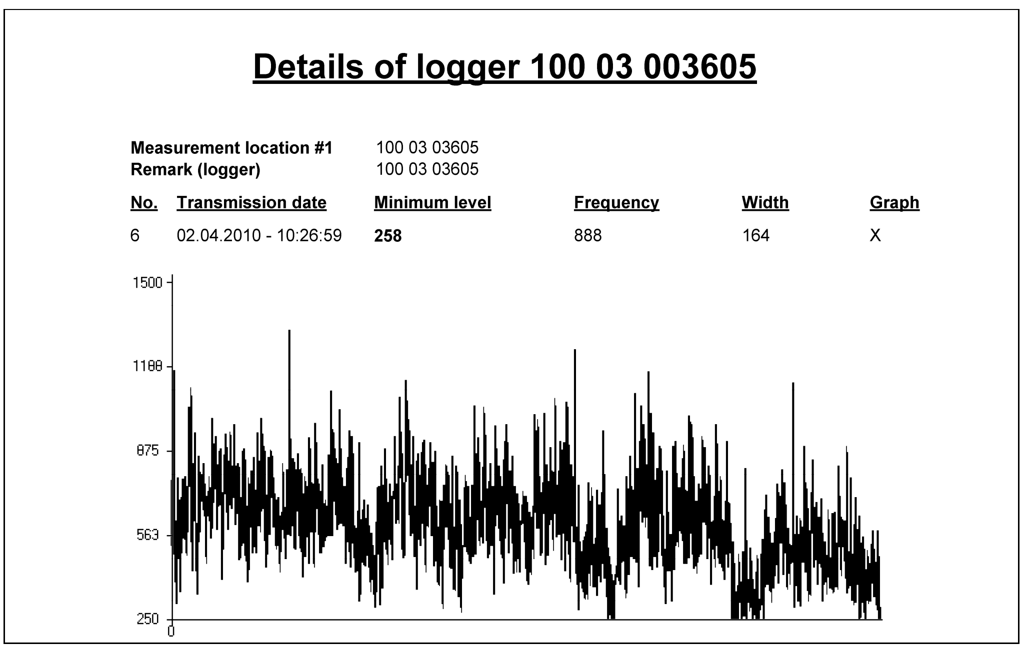


Figure 6.18 Details of Logger with Serial Number 3605 Placed On Valve #27169

Above, it is given the output figure for the logger with serial number 3605 (Figure 6.18). It gives the minimum level as 258, which is a little higher than the previous logger but still a low noise.

Frequency is reported as 888 Hz. Width is given as 164, which is a low value indeed. It indicates that the measurement is done with low interference. To find probable leaks, a ground microphoning study was scheduled on these two streets.

Alert #3: Leak noise logger with serial number 3605 was placed on the valve with ID 39681 at the intersection of 6th avenue and 659th street. The pipes are PVC and HDPE with diameters differing from Ø110 mm to Ø200mm. In Figure 6.19, three logger placed valves are seen. Only logger on valve #39681 reported probable leak alert (Figure 6.20). At the same time, that valve is the one, which is used while making one of the advised connections.

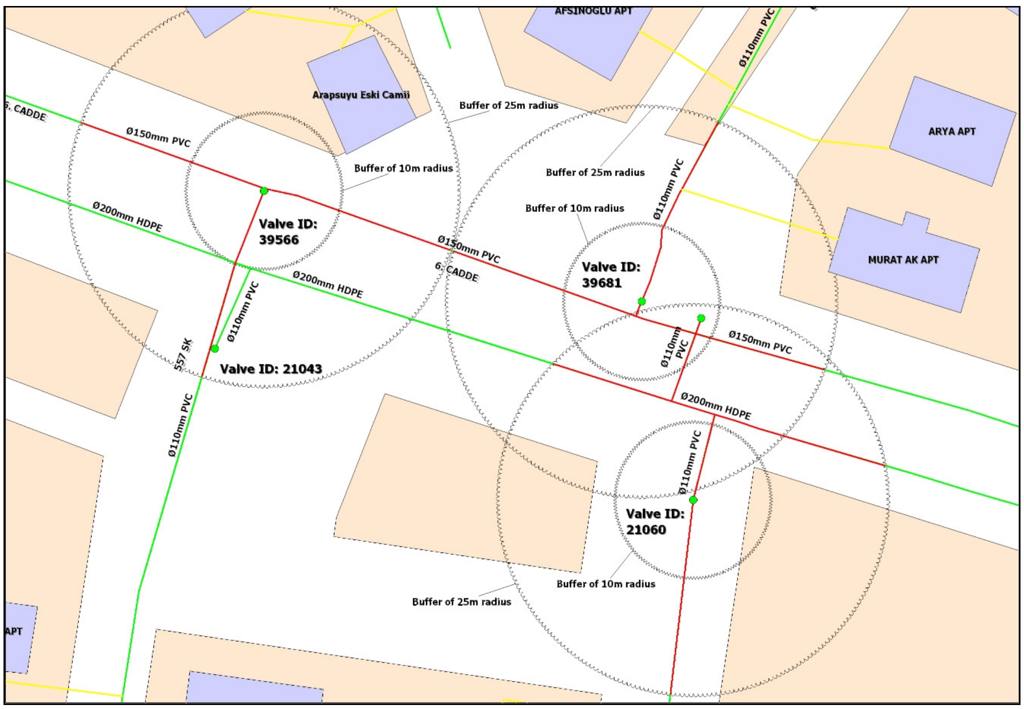


Figure 6.19 Noise Data Logger with Serial Number 3605 Placed On Valve #39681 and Its Corresponding Effective Areas

Details of logger 100 03 003596

Measurement location #1 100 03 03596
Remark (logger) 100 03 03596

No.	Transmission date	Minimum level	Frequency	Width	Graph
7	06.04.2010 - 10:48:28	**226**	349	111	X

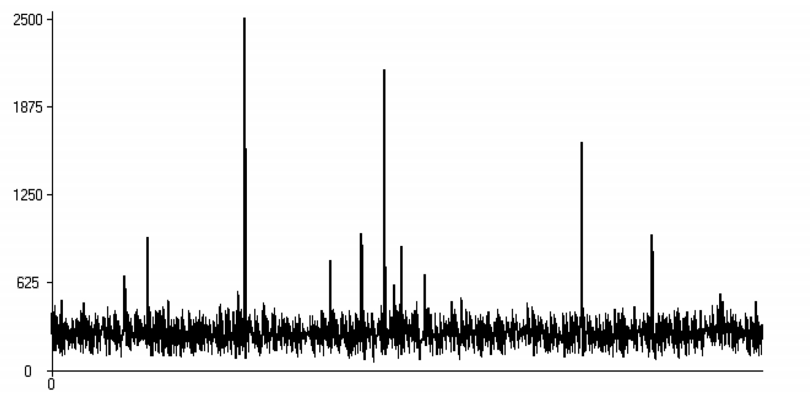


Figure 6.20 Details of Logger with Serial Number 3596 Placed On Valve #39681

<u>Alert #4 and Alert #6:</u> At the intersection of 526th and 555th street there are three valves given in Figure 6.21. Around each valve corresponding buffer areas are seen. Three loggers were placed at these valves. Two of them reported a leak alert. These two loggers (3606 and 3622) were placed on valves #27102 and #27104. Logger resulting graphs are given below in Figure 6.22 and Figure 6.23. Logger 3606 resulted with a minimum level 697 whereas logger 3622 resulted with 423. With a quick judgement, if the signal is coming from the same source it has to be nearer to logger 3606 than 423 as its minimum noise level is higher. The frequency values are 269 and 333 respectively so this result strengthens the conclusion that is reached by assuming the source is same for these loggers. The measurements are done with little interference if width values 146 and 104 are considered.

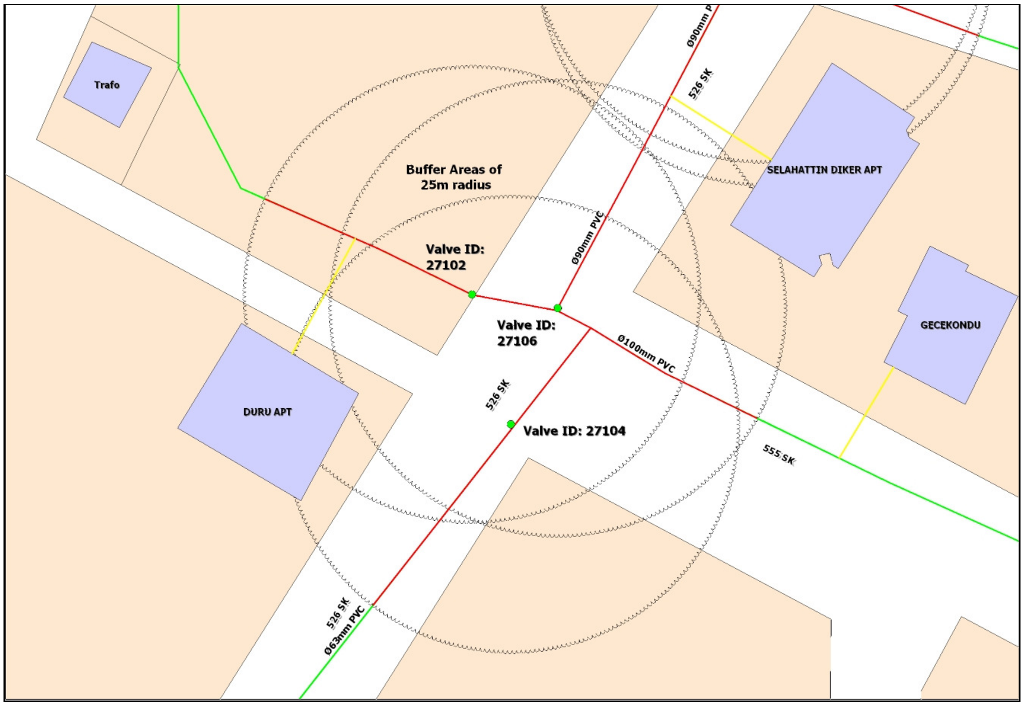


Figure 6.21 Noise Data Loggers with Serial Numbers 3606 and 3622 Placed On Valves #27102 and #27104 and Their Corresponding Effective Areas

Details of logger 100 03 003606

Measurement location #1 100 03 03606
Remark (logger) 100 03 03606

No.	Transmission date	Minimum level	Frequency	Width	Graph
5	06.04.2010 - 10:34:09	**697**	269	146	X

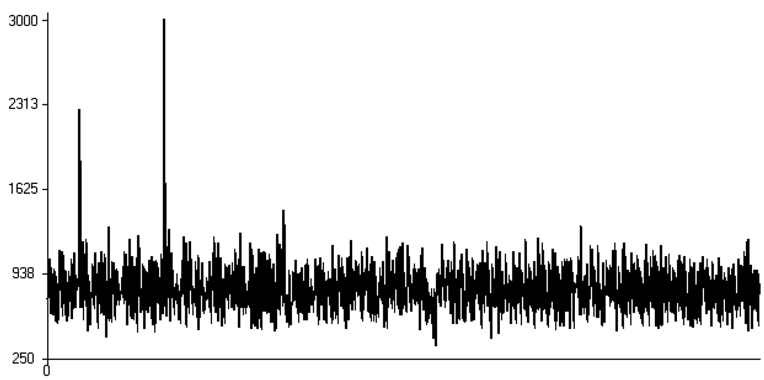


Figure 6.22 Details of Logger with Serial Number 3606 Placed On Valve #27102

Details of logger 100 03 003622

Measurement location #1 100 03 03622
Remark (logger) 100 03 03622

No.	Transmission date	Minimum level	Frequency	Width	Graph
1	06.04.2010 - 10:36:29	**423**	333	104	X

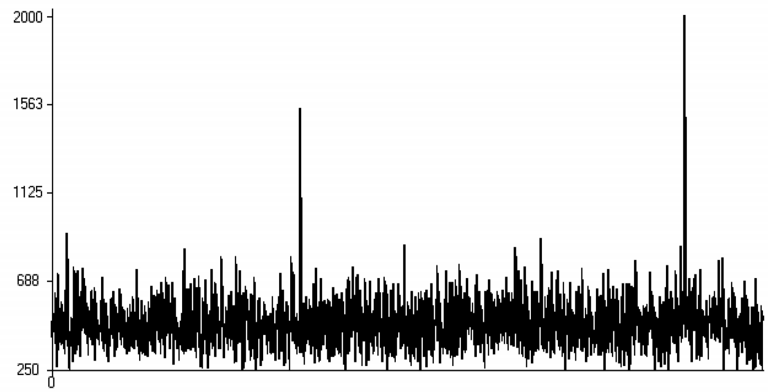


Figure 6.23 Details of Logger with Serial Number 3622 Placed On Valve #27104

Alert #5: Alert 5 is reported by logger #3612 on valve #31903. Alerting point is inside the borders of sub-DMA 2. The valve is located on Atatürk Boulevard, which is a highly crowded road at daytime and night hours. The Ø75mm PVC pipe that is connected to the Ø110mm PVC pipe on the boulevard passes through parcels as seen in Figure 6.24. This pipe is probably going to be cancelled out later on. In Figure 6.25 the reported graph by the software is presented. Minimum level is seen as 886, which is a high value compared to other alerts. It may be interpreted as a leak that is not so far away. Frequency of this measurement is reported as 666Hz and width is reported as 260 which is a little higher than the other measurements. Having a width higher than others can be explained with a higher interference noise as the valve is located on a busy street. Ground microphoning study is specially scheduled for a night listening to overcome the daytime traffic noise. Other alert points do not need to be listened at night because absolute silent moments can be reached during daytime.

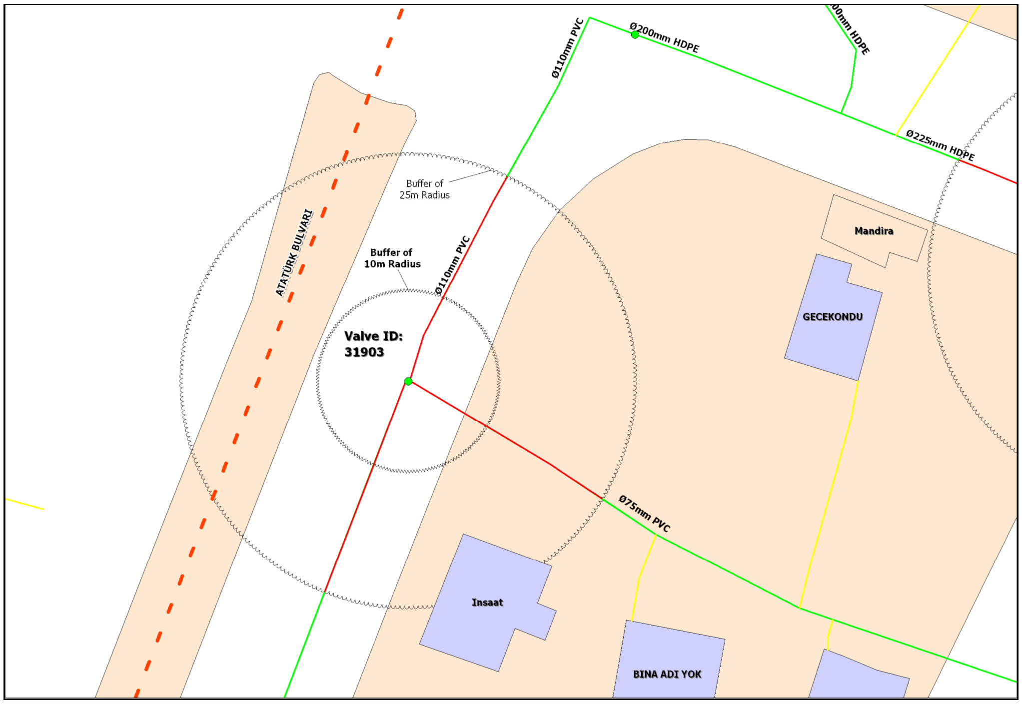
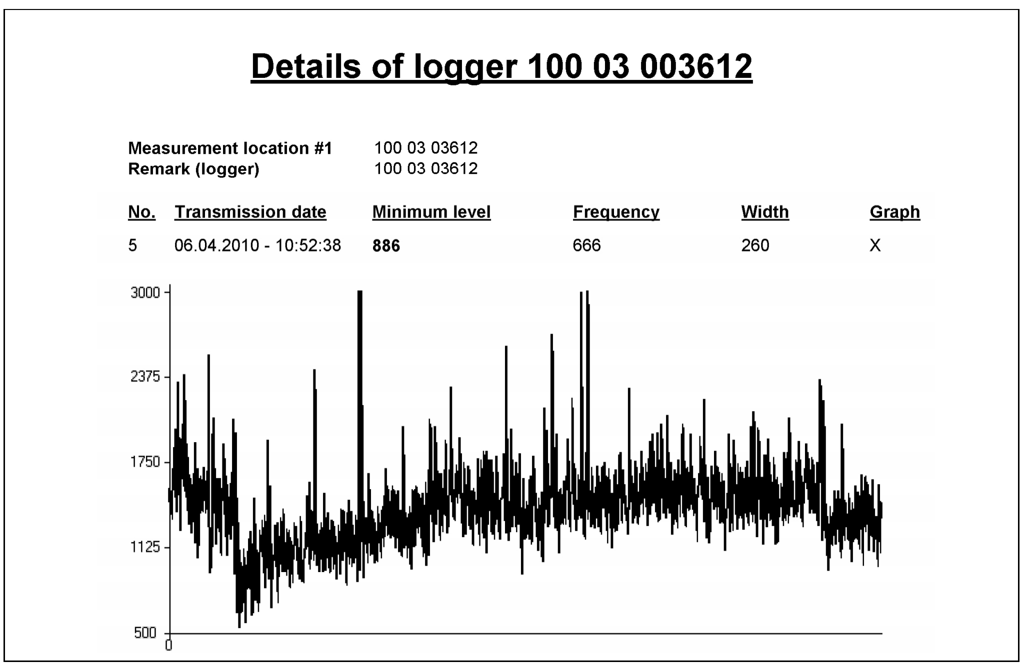


Figure 6.24 Noise Data Logger with Serial Number 3612 Placed On Valve #31903 and Its Corresponding Effective Areas



Details of logger 100 03 003612

Measurement location #1	100 03 03612
Remark (logger)	100 03 03612

No.	Transmission date	Minimum level	Frequency	Width	Graph
5	06.04.2010 - 10:52:38	**886**	666	260	X

Figure 6.25 Details of Logger with Serial Number 3612 Placed On Valve #31903

<u>Alert #7:</u> 7th alert was reported on the intersection of 555th and 530th streets. At this intersection, there are two valves one on Ø110mm asbestos cement pipe to the west, other one on

Ø110mm PVC pipe to east. Alerting logger having the ID 3641 was placed on the valve having ID 39582, which is on the asbestos cement pipe (Figure 6.26). Despite being valves next to each other, the alerting sound was not detected by the other logger placed on valve 39579. Reported measurement results are minimum level of 613, frequency of 492 Hz and width of 107. These values can be interpreted as a leak that is within a fairly near distance. With a width value of 107, low interference noises are the case again (Figure 6.27).

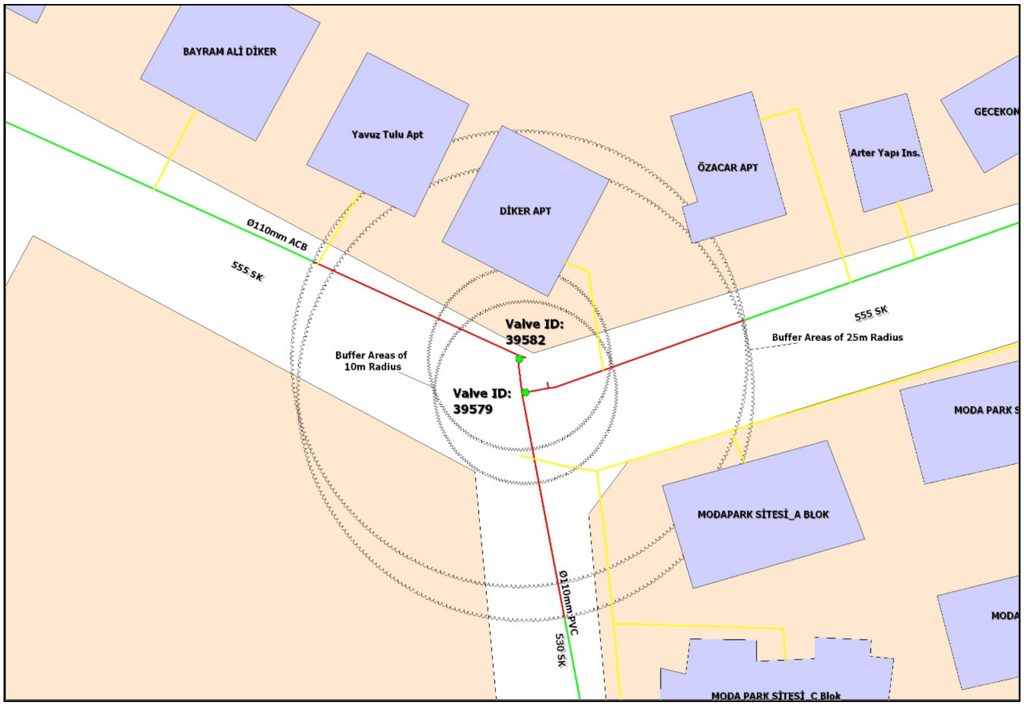


Figure 6.26 Noise Data Logger with Serial Number 3641 Placed On Valve #39582 and Its Corresponding Effective Areas

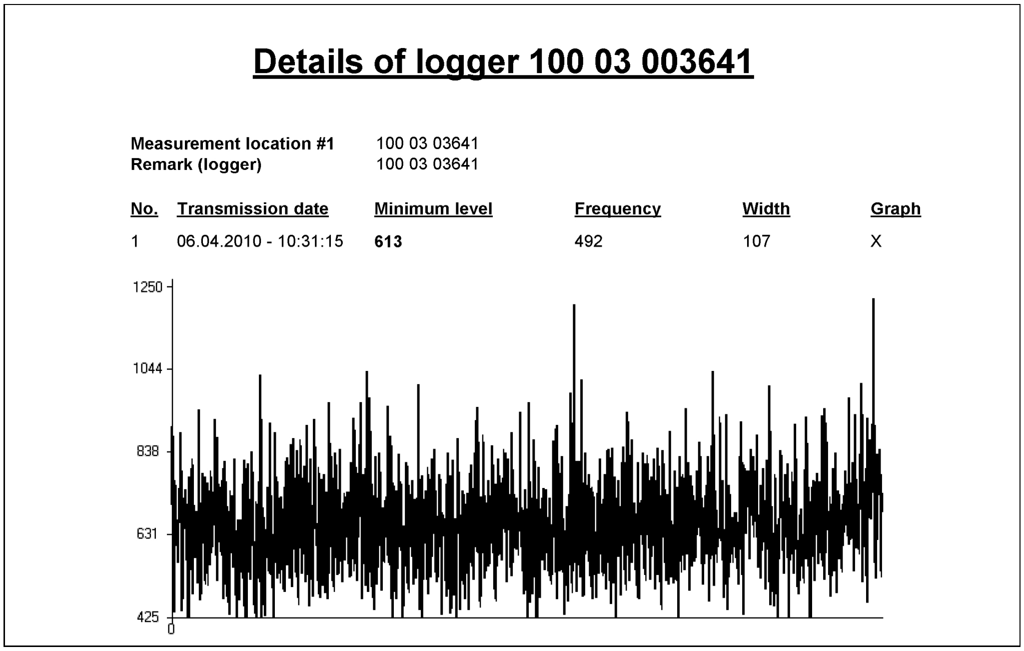


Figure 6.27 Details of Logger with Serial Number 3641 Placed On Valve #39582

6.2.4.2.Ground Microphoning in Logger Ineffective Areas

Ground microphoning is applied to zone 6 just after the logger study. Listening is done around leak sounding valves first. Listeners used either their field experiences or aligned themselves by looking at the valve positions on the asphalt surface in order to locate the network. All listening study is done by moving just on top of the pipes. Detailed investigation results for the seven data logger alerts are given below.

After having realized ground microphoning at the alert points, remaining listening schedules first focused on sub-DMAs 4, 5 and 6, because the result of the step test pointed these sub-DMAs as the weakest regions. If correlation study could have been done, that would be a guide way for the listening study. As that study is skipped, listening study focused directly on alerting valves. After listening the valves, nearby network may have been skipped based on the idea that loggers already listen the nearby network to some extent. However to be absolutely sure about the leaks in the network of zone 6, the entire network was scanned with ground microphones focusing first on the sub-DMAs stated above. Listening study of the whole zone lasted for three days.

With the careful examination of the listening staff, alert 1 turned out to be the noise coming from the zone isolation valve with ID 27069 that is separating zones 6 and 2. The point is on the border of sub-DMAs 4 and 8. It can be attributed to both of the areas. After ground microphoning the isolation valve, the staff made a judgement that the valve does not fully close itself and therefore it lets water passage from zone 6 to zone 2. Movement is in this way because zone 2 is a different system working under a constant reduced pressure of 2.9 bars. However, zone 6 is under an average pressure of 5 bars. These two systems are separated by this valve and it should be left closed at all times. A construction was scheduled related with this valve to be changed with a new one.

For the case of alert 2, the point is inside sub-DMA 5. When the ground microphoning crew listened the related valve, they detected a leak sound. However, a more careful visual examination revealed that the valve was bleeding out water from the sealing part of the valve (salmastra in Turkish). The amount of water that is leaking out from the system is very small indeed but the noise it generates is not negligible. So within the help of noise data loggers, a broken valve was found. Nevertheless, as stated in sections above, the administration was not willing to replace these kinds of working valves. Indeed, these kinds of leaking valves will affect the reliability of water loss studies in the future. The leaking noise may mislead the operators while searching for bigger leaks.

Alert 3 was on 6th avenue, on one of the new connected valves. The point is inside sub-DMA 1. Despite having a leak alert from the noise data loggers, ground microphoning crew did not detect any leak noise with their equipment. As a result nowhere was excavated because a recent excavation was done for the connection, and it is concluded by the administrative staff that if there were a leak, it would have been seen when the excavation was taking place.

Alerts 4 and 6 took place at the same location. The placing of the three valves was very close to each other. They were just in front of a public garden inside the borders of sub-DMA 2. One of the pipes is passing through the garden towards north-west. Listening crew scanned the area surrounding these valves, but did not catch a leak sound again. As no pinpointing of any leakage was possible, no place for excavation could be determined.

Fifth alert was on the logger with the highest minimum noise level and highest interference. This point is in sub-DMA 2. Listening study was done at night during 24:00 and 00:01. The boulevard's traffic reduces to a sensible level in terms of noise after 24:00. Despite listening entire road over the network, listening crew was unable to pinpoint a leak at this location.

Leak 2: For the case of seventh alert, by careful listening with the ground microphones, a leak was pinpointed in front of Diker Apartment. It is an apartment located in the sub-DMA 3. This time, pinpointed leak spot stays in the presumed 25m radius effective area of the leak noise logger. This leak was detected on an Ø110mm asbestos cement pipe at two pipes' connection point. This failure is said to be seen at almost every asbestos cement pipe connection. The failure is fixed with a piece called "collar repair clamp" (hazır tamir parçası in Turkish). The whole pipeline was not renewed with PVC pipes, so this remaining asbestos cement pipe remains as potential water leakage point (Figure 6.28). This resulting leak is named as "Leak 2" in this study.

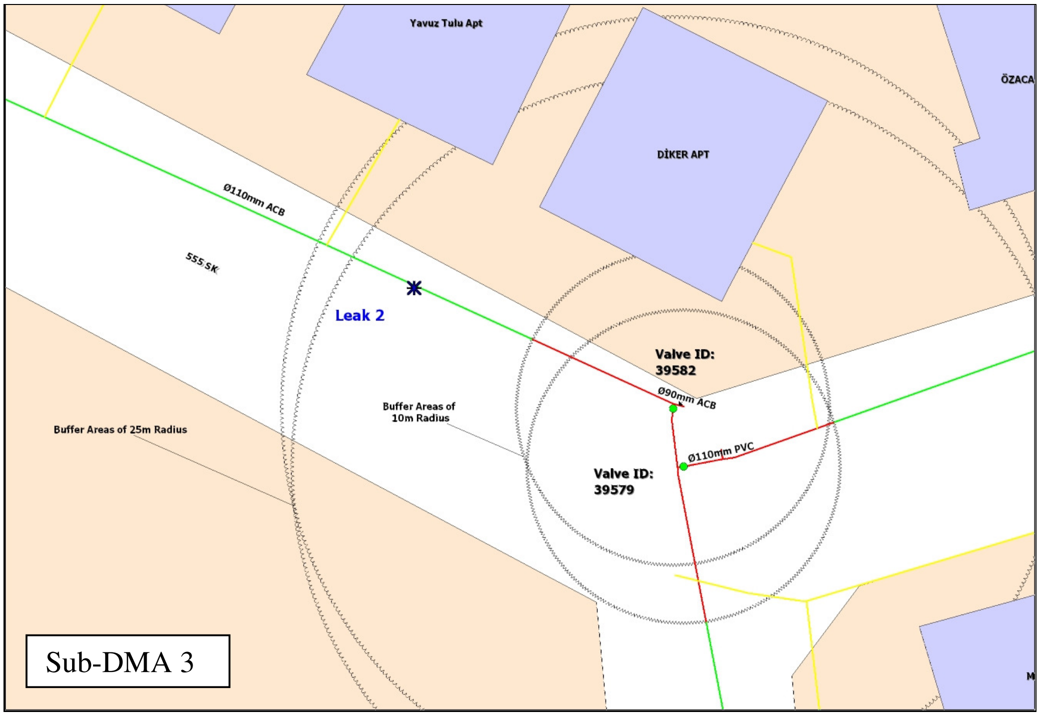


Figure 6.28 Position of leak spot and nearby logger effective areas.

Ground microphoning the logger ineffective areas resulted in four more water leak detections. Resulting leaks 1, 3, 4 and 5 are explained in detail below.

Leak 1: Water leak is detected by the ground microphoning crew on 521st street, in front of Elif Apartment that is inside the borders of sub-DMA 5. The failure occurred on the PE house connection with a diameter of Ø40mm (Figure 6.29). As the sewerage network was constructed after the water distribution network in Antalya, some water lines were displaced in the field. While making displacements, most of the house connections were improperly renewed and made potential water leakage spots. This leakage case was interpreted with this explanation. House connection pipe was used to be directly connected from the street to the house, but while sewerage network was being installed, a manhole was placed on top of the house connection pipe. So the house connection was improperly renewed with spare parts turning around the manhole to the house entrance. The points where spare parts exist became weak points and turned into water leakage points with time.

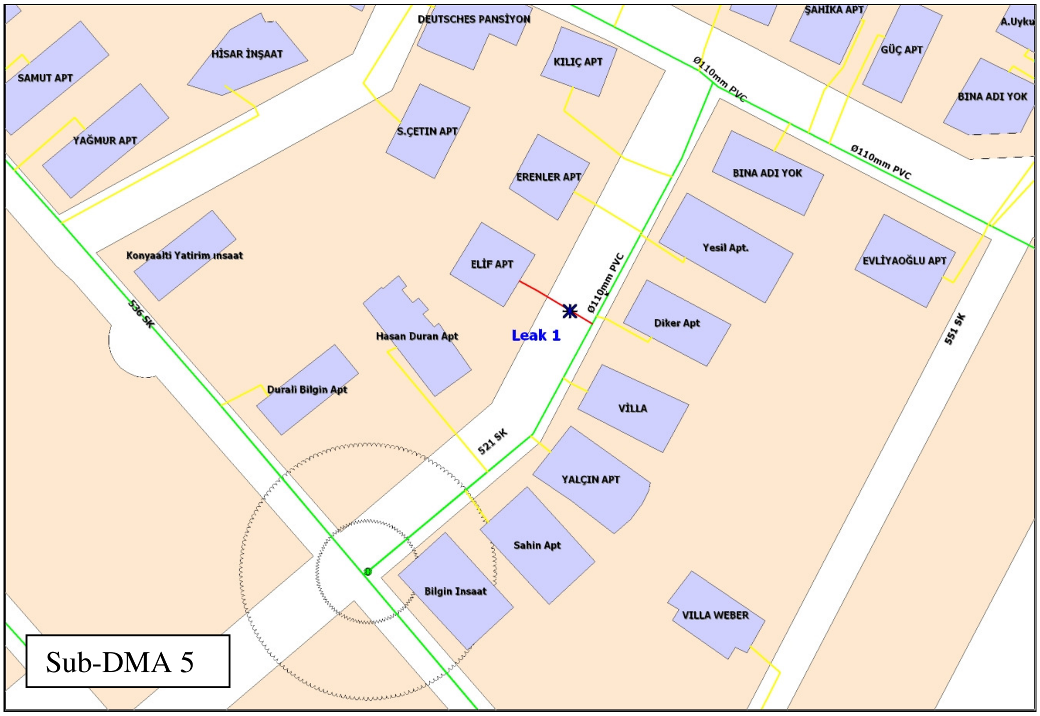


Figure 6.29 Position of leak 1 and the nearest valve location with effective areas.

Leak 3: This leak was detected on the intersection of 659th and 660th streets on an Ø90mm PVC pipe. It has no nearby valves so it cannot be detected by noise data loggers (Figure 6.30). The leak spot is located in sub-DMA 4. While making the ground microphoning study, on 660th street, near the leakage, some water bleeding through the asphalt surface was seen. It indicated a probable leak point but it looked like the water that may have been spilled from the sprinklers in the public garden just beside the leakage point. After making the ground microphone survey, the leak is pinpointed and excavation is done. After the excavation, the reason of the failure is seen at the connection point of the PVC pipe with the nearby PE pipe. The heads of the pipes were improperly connected and through time, this weak spot became the leak spot.

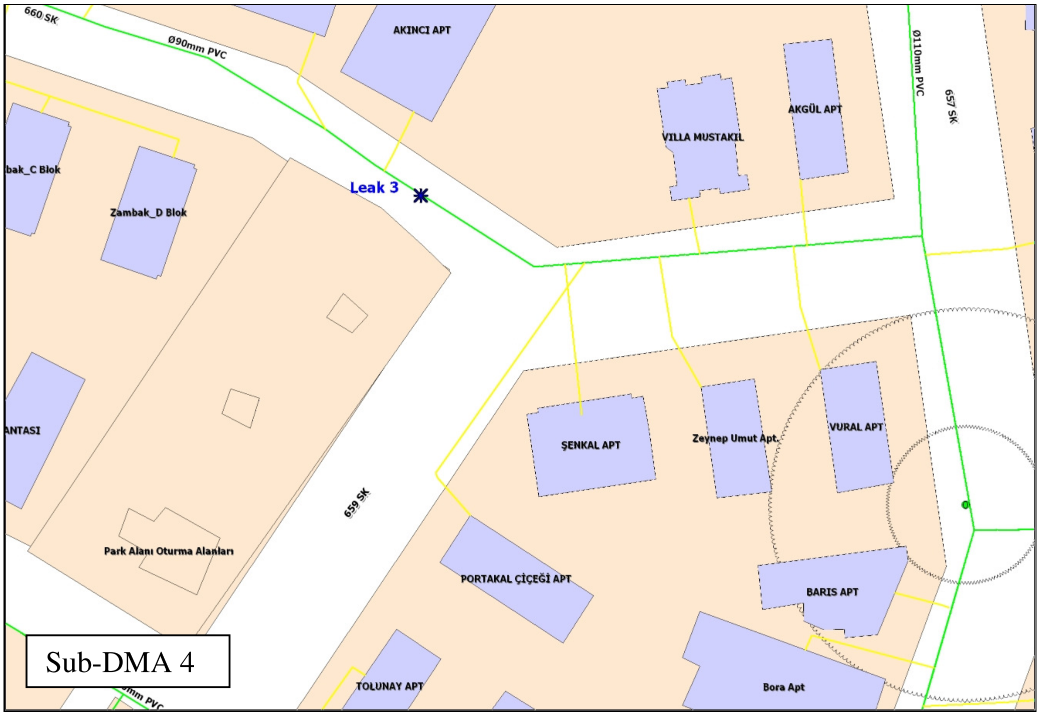


Figure 6.30 Position of leak 3 and the nearby valve with its effective area

Leak 4: Despite being in the logger effective areas, this leak was not detected by the noise data loggers. It is pinpointed by the ground microphoning crew at the intersection of 6th avenue and 657th street (Figure 6.31) in front of Aile Apartment. It is a failure occurred on the house connection, which is a galvanized Ø32mm pipe. The reason why the loggers did not detect the nearby leakage can be explained by a set of mistakes that are made during the digitizing operations. As explained at the beginning of this chapter, digitizing of all the house connections are done either by field crew's knowledge or by pipe detectors if the pipes are metallic. In this case, the door of the apartment is on 6th avenue but on 657th street. So by mistake, it is assumed that the house connection was connected to the Ø110mm PVC pipe on 657th street. Nevertheless, as the connection is known to be galvanized iron, the utility locator device is used to check the correct place of the house connection. The connection is traced with the pipe detector and found out to be connected to the Ø200mm HDPE pipe that is on 6th avenue. Also during the excavation, it is seen that the pipe is not buried but passes through a cement pipe. This is probably done to prolong the service life of the galvanized iron pipe. However, according to the picture it was not so successful at all. The wrong position and correct position of the galvanized pipe is seen in Figure 6.34. Another thing seen in the figure is that the two pipes on the 6th avenue and the pipe on 657th street are connected to each other with a series of connections. Therefore, a data logger placed on valve #27137 should be able to detect the leak occurring on the HDPE pipe (namely leak 4). However, as there are too many connecting pieces between the pipes and valves, the noise generated at the leak spot weakens as it travels to the data logger vanishing at some place between. With this correction made on the house connection, Aile

Apartment was understood to be in sub-DMA 8 not in sub-DMA 4. The whole house connection is renewed with a PE pipe as the galvanized iron pipe rusted at several point and was not a usable pipe anymore.

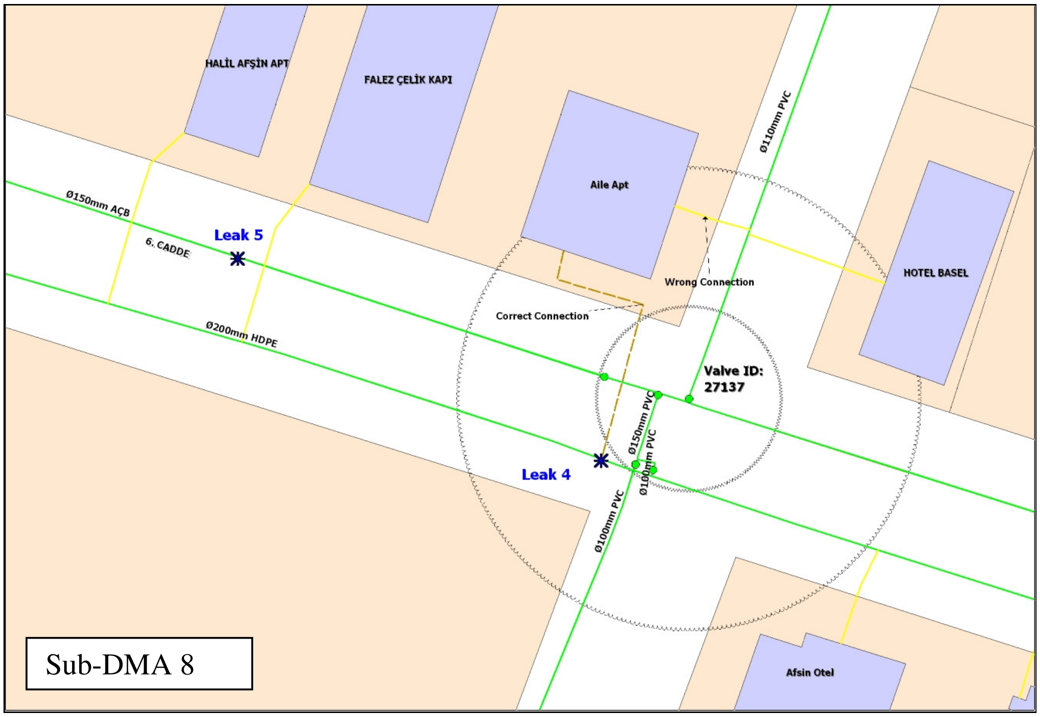


Figure 6.31 Leak spots 4 and 5 and the nearby data logger's effective area.

Leak 5: This final leak pinpointed by the ground microphones was only 50m west of the 4th detected leak spot on 6th avenue which is a leak spot in sub-DMA 1 (Figure 6.31). The pipe is given in the GIS layer as Ø150mm PVC but after the excavation of the pinpointed spot, the pipe was found out to be asbestos cement. The noise that the listening crew got was so weak that they were not so sure if there is a leak or not. During the excavation, the pipe was found at around 2 meter deep. This explains the weakness of the noise generated at the leak spot. The failure is just the same as the one faced in leak 2. The two asbestos cement pipes were improperly connected to each other. They were not in a straight line but making an angle of approximately 10˚ with each other. This made the connection a weak spot, and it turned into a leaking point within time. The failure is fixed with a collar repair clamp (Figure 6.32).

Figure 6.32 Collar Repair Clamp

6.2.5. Results

To overcome the water losses in zone 6 of Konyaaltı water distribution network, step testing, noise logger placements and ground microphoning studies are applied on the field. The total duration of the study was 2 weeks (10 working days). The same study could be made possible in a shorter period with more noise data loggers, more ground microphones and more operators. However, spending less than a week on a DMA may lead to superficial results.

As most of the pipes are plastic in the network, noise data loggers are effective only to a small extent. Accordingly, most of the study should be made with ground microphones. This means a lot more ground microphones should be purchased and more operators should be trained. The GIS layers have many mistakes in them that affect the water loss study deeply. This should be overcome by training experienced personnel that are responsible only for a well-defined area (a pressure zone, a few pressure zones or maybe a complete district). With this method, the responsible personnel will be in charge of all the events in the area and will keep the GIS layers up to date. In the case of Antalya, the responsible personnel are the people that have the valve and network knowledge and that are in charge of shutting the water of any region. Unfortunately, they do not have an engineering background so they may have difficulty working both on field and on projects. They prefer to use their own knowledge that depends on past experiences not on GIS system or printed projects.

The daily demand curves obtained from SCADA gave information about a minimum night flow of 28 – 30 m³/hour before the study (Figure 6.33 and Figure 6.34). It was detected in step tests that most of this flow was occurring in sub-DMAs 4, 5 and 6. Unfortunately, with almost no valves on sub-DMA 6, no water leakage points could be detected. In total, 5 leak points and an out of order valve was detected. This zone border valve was shut down, and the five leak spots were fixed neatly. As a summary, a table is given for leaks and their corresponding sub-DMAs (Table 6.9).

Table 6.9 Leaks, Their sub-Zones and Repair Dates

Leaks	Sub-DMAs	Repair Date
Out Of Order Valve	Between 4 and 8	05.04.2010
1	5	06.04.2010
2	3	07.04.2010
3	4	07.04.2010
4	8	09.04.2010
5	8	09.04.2010

To see the effect of each leak, daily demand curve obtained from SCADA between 04.04.2010 and 09.04.2010 should be examined (Figure 6.33 through Figure 6.38).

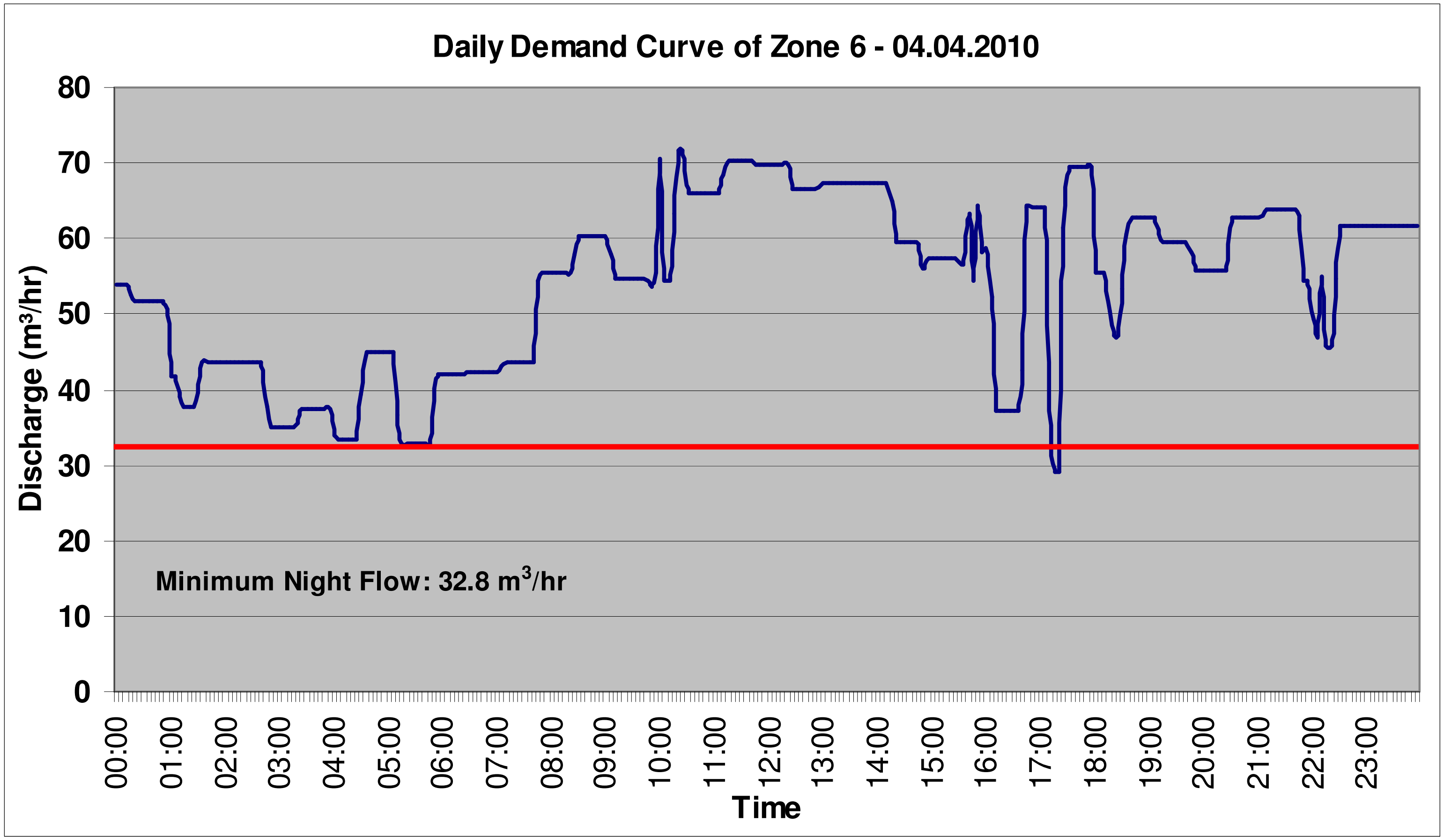


Figure 6.33 Daily Demand Curve of Zone 6 on 04.04.2010

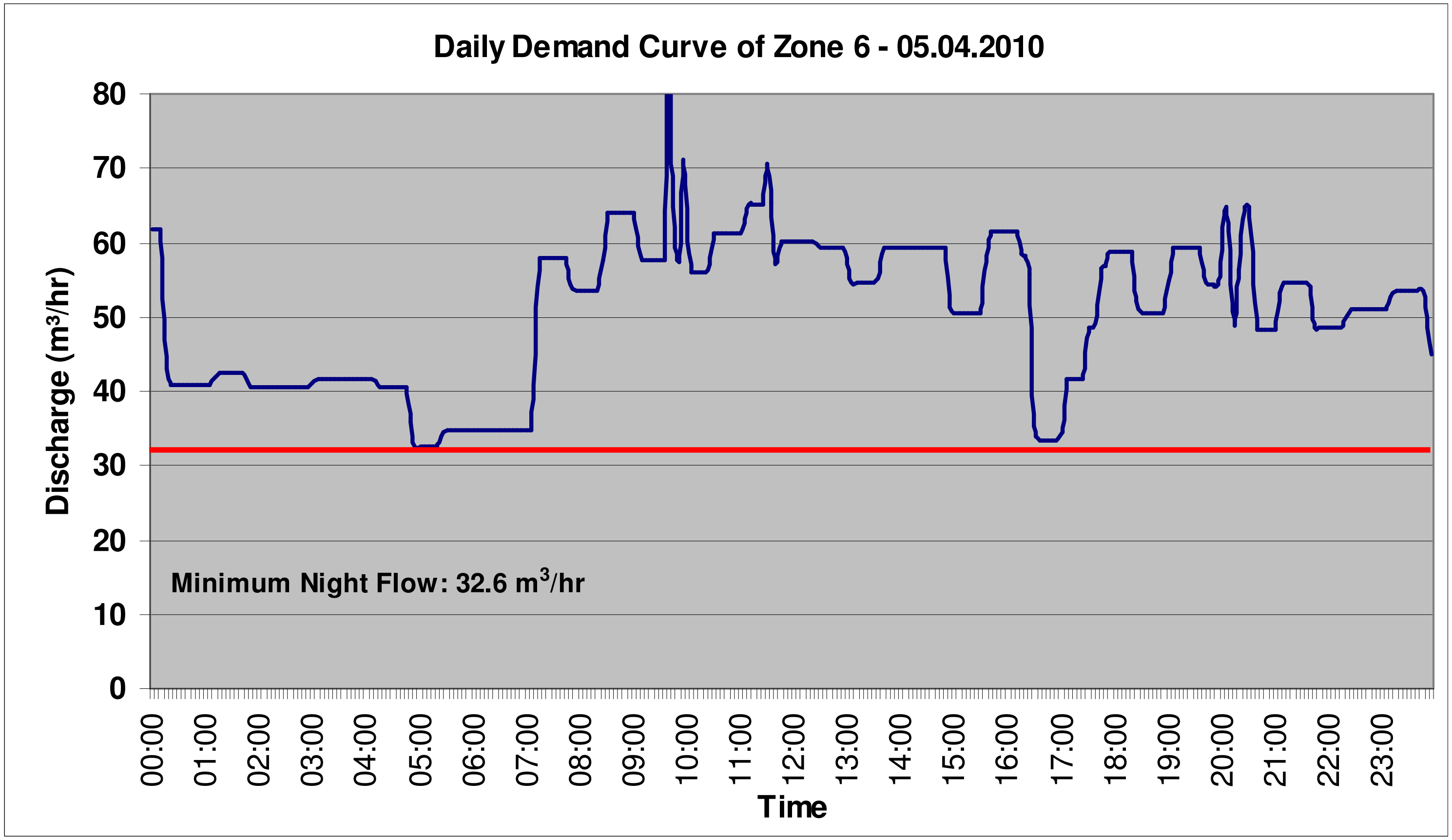


Figure 6.34 Daily Demand Curve of Zone 6 on 05.04.2010

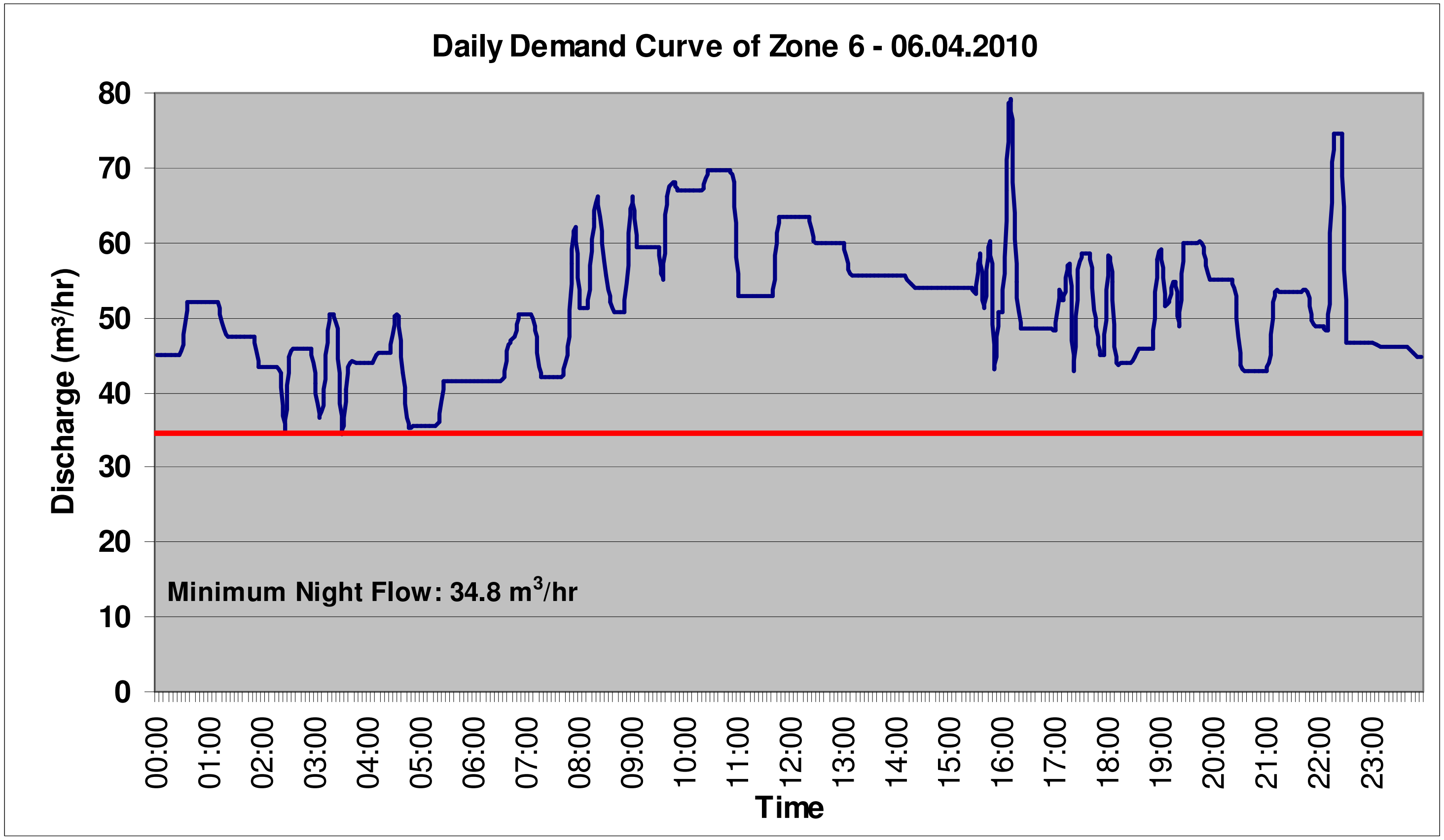


Figure 6.35 Daily Demand Curve of Zone 6 on 06.04.2010

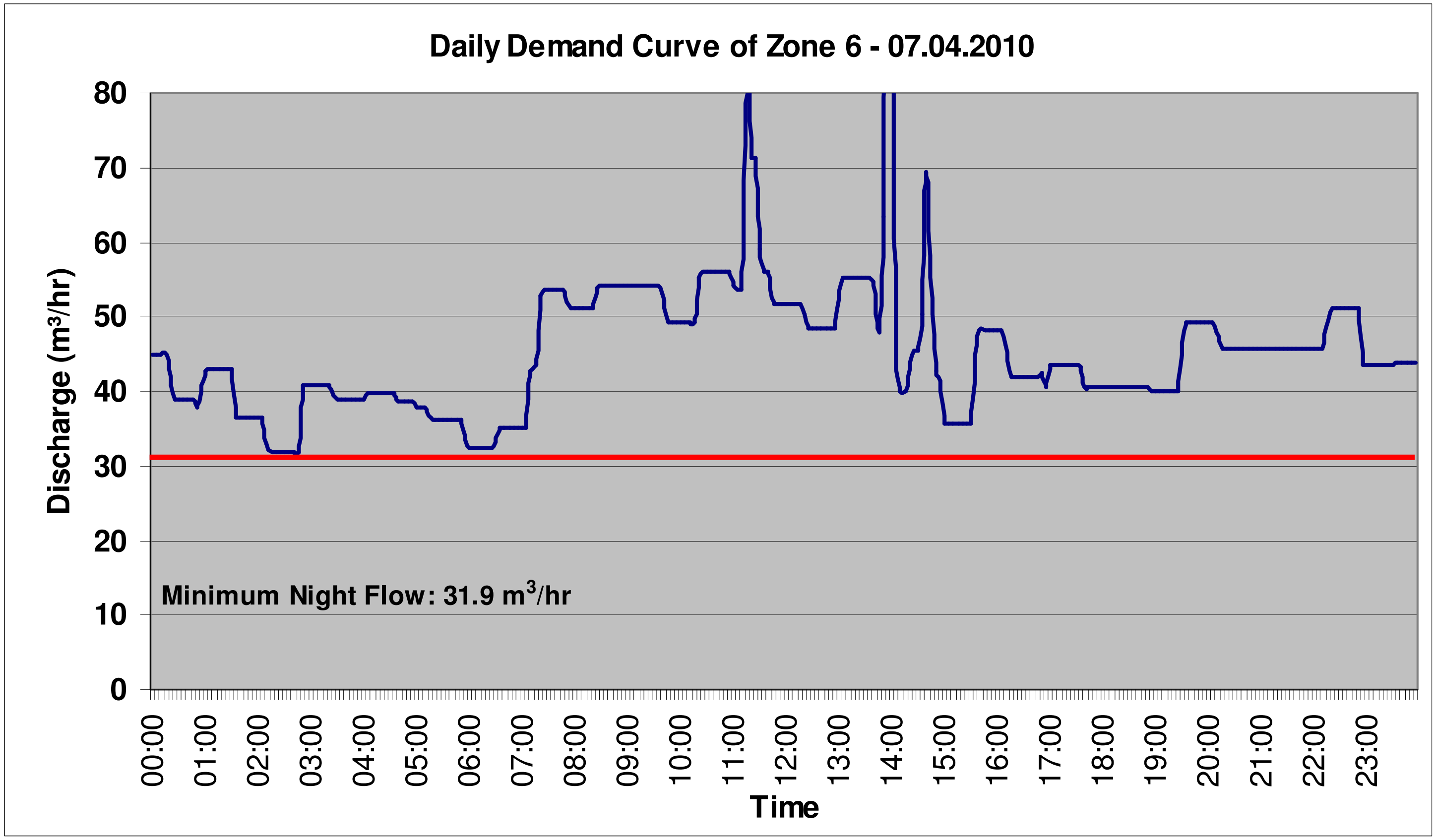


Figure 6.36 Daily Demand Curve of Zone 6 on 07.04.2010

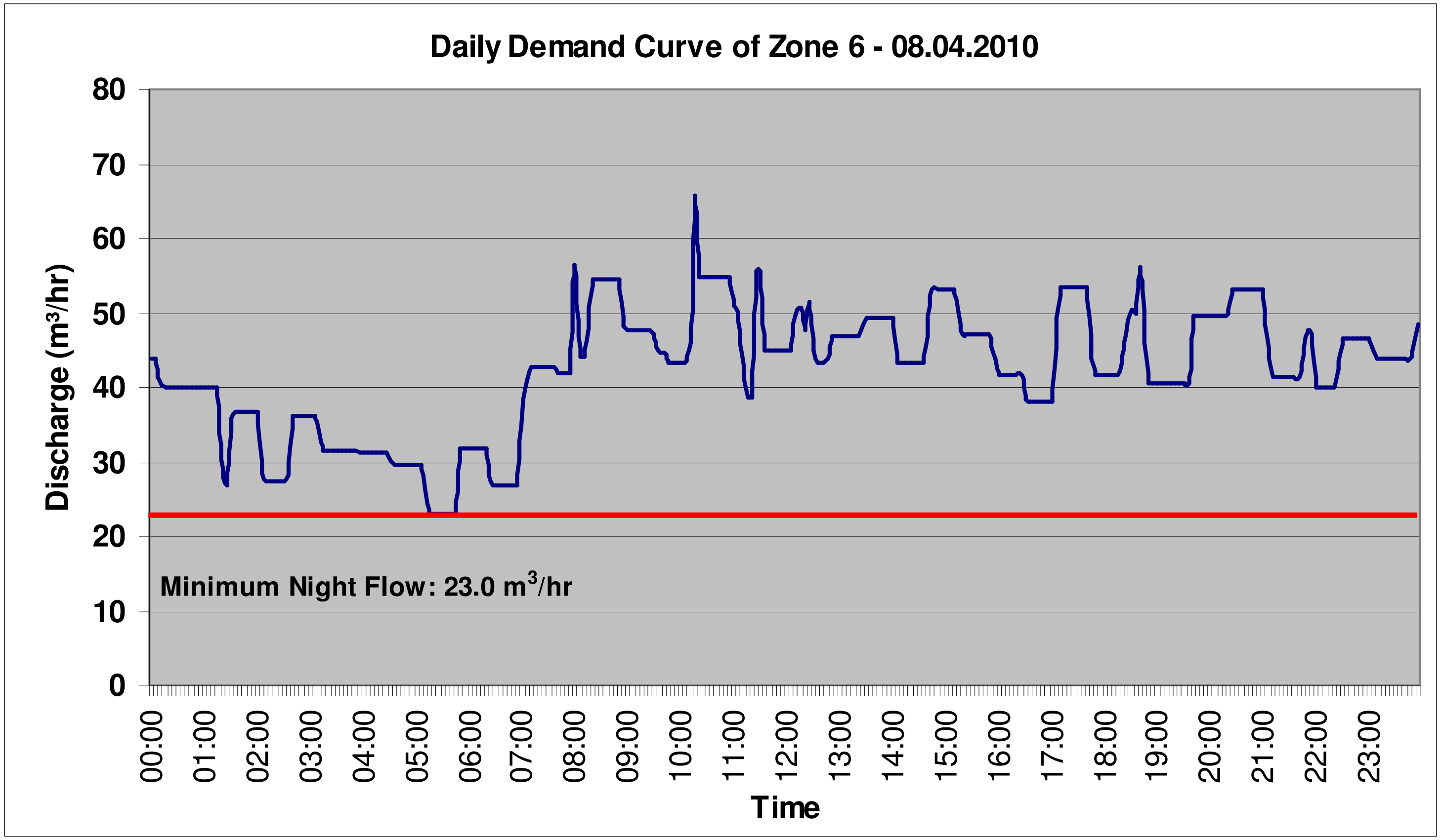


Figure 6.37 Daily Demand Curve of Zone 6 on 08.04.2010

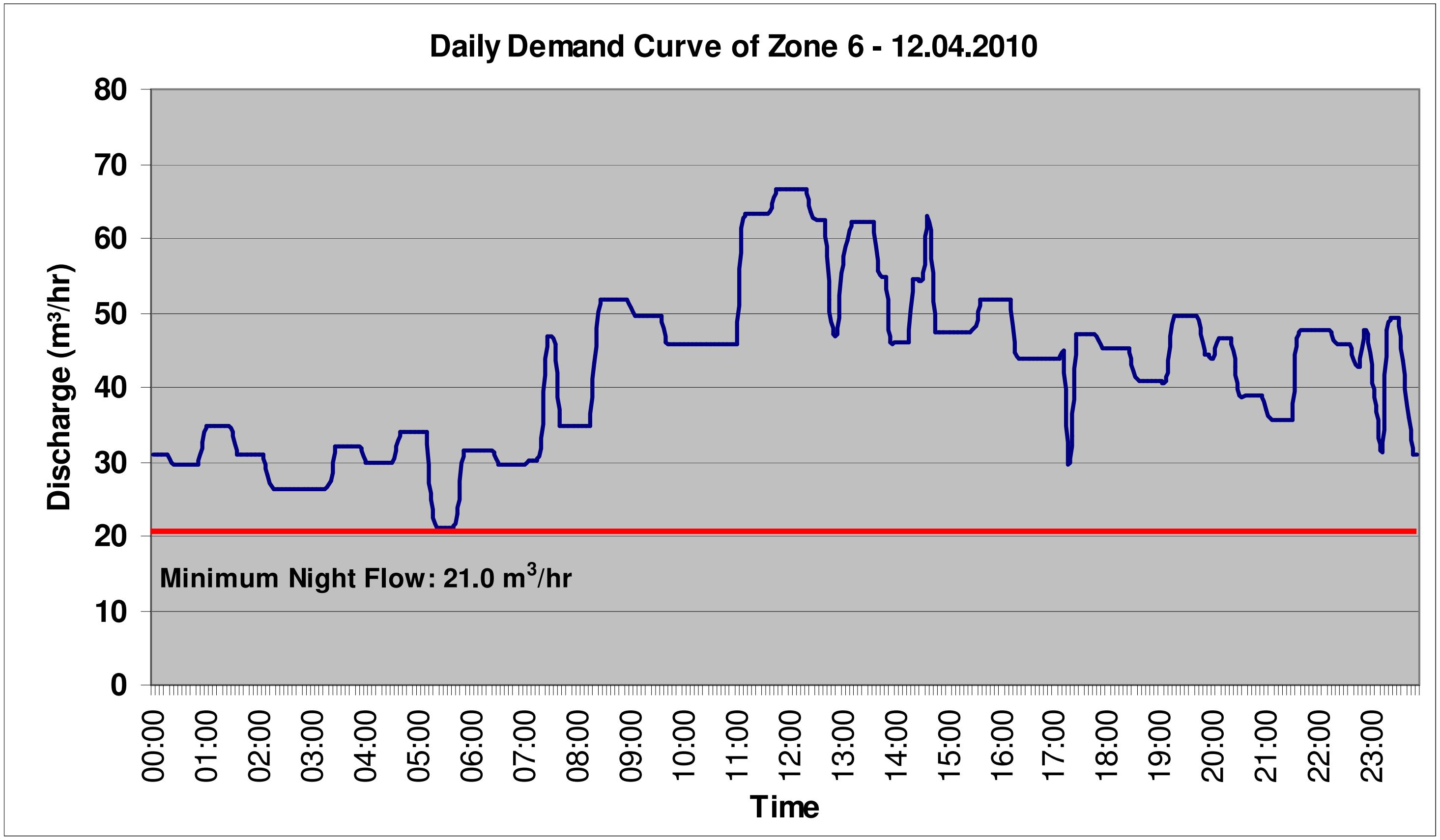


Figure 6.38 Daily Demand Curve of Zone 6 on 12.04.2010

It is seen from the daily demand curves that on 5th of April (Figure 6.34), the effect of renewing the isolation valve made an increase on the consumption that should not occur. This is an unexpected result because as this faulty valve is renewed, the neighbouring pressure zone with lower pressures would not be fed from this point anymore. The only reasonable explanation for this case is that after renewing, the valve was accidentally left slightly open. Therefore, a rise in the minimum night flows occurred from 32.6m³/hr on 05.04.2010 at 05:00 a.m. to 34.8m³/hr on 06.04.2010 at 03:30 a.m.

On 6th of April, leak #1 was fixed on sub-DMA 5. Moreover, the minimum night flow is decreased from 34.8 m³/hr to 31.9m³/hr at the very first night on 07.04.2010 at 02:35 a.m. Therefore, this leak corresponded to an approximate water loss of 2.9 m³/hr.

On 7th of April, two leaks were fixed, namely leak #2 and #3 on sub-DMAs 3 and 4 respectively. With these leaks fixed a huge amount of decrease occurred in minimum night flow of zone 6. It decreased from 31.9 m³/hr to 23 m³/hr on 08.04.2010 at 05:15 a.m. This means that these two leaks corresponded to an approximate water loss of 8.9 m³/hr.

On 8th of April, two more leaks were fixed, namely leak #4 and #5 on sub-DMAs 8. With these leaks fixed, some more decrease is observed in minimum night flow of zone 6. It decreased from 23 m³/hr to 21 m³/hr on 12.04.2010 at 05:20 a.m. This means that these two leaks corresponded to an approximate water loss of 2 m³/hr.

Totally, the five leaks and one faulty valve summed up to an 13.8m³/hr decrease in minimum night flow meaning a decrease in water loss of zone 6. Within two week's time, major water leaks were found and fixed in the zone. Most of the remaining leaks are believed to be in sub-DMA 6. It is one of the largest sub-DMAs in the zone and it is a much-uncontrolled area as it has too few valves and too long pipelines.

Some of the remaining leaks are very little dribbles of water that cannot be heard with any instrument (background leakage). The administration plans to build a pressure reducing valve at the entrance of DMA in order to minimize these very little water losses by pressure management. A similar study is being applied at the neighbouring pressure zone named Zone 2. In this zone, pressure is reduced at the entrance of the DMA from an average of 5.5 bars down to a stable level of 2.9 bars. By doing so, minimum night flows of the area decrease from around 55 m³/hr level down to 40 m³/hr level. This operation can be applied easily to the zone because there is not a topographic limitation in the zone meaning almost every customer is at the same topographic elevation. So reducing pressure to a minimum level does not affect the consumers. Buildings higher than 4 floors are forced to use their own pumping system (with small booster pumps) in the apartment regulated by law.

Minimum Night flows in the DMA showed a significant decrease after the completion of repairs. Parallel to this decrease, daily total volume of water entering to the zone decreased too. This indicates prevention of physical water losses is achieved. From 1 March 2010 to 1 June 2010 below is a table (Table 6.10) summarizing the effects of field works on water losses. Minimum night flow values on 27 March, 1 April and 13 April are not realistic values because at those nights step tests were performed (these values are given in italic). On the field, zero flow values were reached but SCADA system did not record those values maybe because of waiting for short periods when the whole DMA was waterless.

Table 6.10 SCADA Summary Table for Zone 6

Date	Days	Water Entering to Zone 6 (m^3)	Minimum Night Flow (m^3/h)	Minimum Flow Time	Total Lost Water (m^3)	Water Loss / Total Flow (%)
15.Mar.10	Mon	1150	32.3	06:25	774.00	67.304
16.Mar.10	Tue	1106	30.2	04:25	724.95	65.547
17.Mar.10	Wed	1194	29.6	04:10	710.25	59.485
18.Mar.10	Thu	1150	30.7	02:05	736.88	64.076
19.Mar.10	Fri	1150	33.5	03:10	804.00	69.913
20.Mar.10	Sat	1200	27.8	04:35	667.88	55.656
21.Mar.10	Sun	1200	35.5	07:05	851.25	70.938
22.Mar.10	Mon	1160	28.2	03:30	676.50	58.319
23.Mar.10	Tue	1146	32.5	02:45	780.00	68.063
24.Mar.10	Wed	1244	34.2	05:00	820.88	65.987
25.Mar.10	Thu	1200	30.4	03:05	730.50	60.875
26.Mar.10	Fri	1191	30.0	03:50	721.13	60.548
27.Mar.10	Sat	1159	*7.6*	04:05	*183.38*	*15.822*
28.Mar.10	Sun	1150	30.3	05:25	726.75	63.196
29.Mar.10	Mon	1300	37.3	04:45	894.75	68.827
30.Mar.10	Tue	1163	31.4	04:15	752.63	64.714
31.Mar.10	Wed	1257	37.4	05:25	897.75	71.420
01.Nis.10	Thu	1190	*20.3*	03:10	*486.75*	*40.903*
02.Nis.10	Fri	1290	34.6	01:50	830.85	64.407
03.Nis.10	Sat	1250	34.7	05:05	833.63	66.690
04.Nis.10	Sun	1300	32.8	05:15	787.50	60.577
05.Nis.10	Mon	1294	32.6	04:55	783.00	60.510
06.Nis.10	Tue	1216	34.8	03:30	834.75	68.647
07.Nis.10	Wed	1084	31.9	02:15	764.63	70.537
08.Nis.10	Thu	1016	23.0	05:15	552.38	54.368
09.Nis.10	Fri	1040	24.8	02:15	594.38	57.151
10.Nis.10	Sat	982	22.5	02:45	539.25	54.913
11.Nis.10	Sun	968	22.7	07:05	544.13	56.211
12.Nis.10	Mon	1020	21.0	05:20	504.38	49.449
13.Nis.10	Tue	980	*15.3*	02:35	*367.50*	*37.500*
14.Nis.10	Wed	950	20.1	02:15	481.50	50.684
15.Nis.10	Thu	950	30.2	05:50	724.50	76.263
16.Nis.10	Fri	1000	20.5	04:00	492.38	49.238
17.Nis.10	Sat	1048	23.5	01:50	564.38	53.853
18.Nis.10	Sun	1002	20.9	05:15	501.00	50.000
19.Nis.10	Mon	1000	21.5	05:00	516.75	51.675
20.Nis.10	Tue	926	24.1	02:25	579.38	62.568

In Figure 6.39 below daily total water entering to zone 6 is shown in continuous lines. It shows a change between 1100 m^3/h and 1300 m^3/h from day to day before the study. After fixing the leaks, this value drops down to 900 m^3/h - 1000 m^3/h level. Dashed line indicates the daily minimum night flow values. They are oscillating between 30 m^3/h and 35 m^3/h before the study; however, they drop down to 20 m^3/h after the study.

Within two weeks time the water entering to the DMA shows an increase an amount of 50 m^3 to 100 m^3. Also minimum night flow values show an increase of about 5 m^3/h. These increments may be an indication of new leaks on either recently repaired-spots or totally different weak spots. From another aspect, it may be explained as no minimum night flow occurs in some days in this DMA. Minimum night flow amounts changing every night by large values point an explanation of no minimum night flow occurrence.

To look at Figure 6.40, the decrease in water loss percentages can be seen too. On the graph there are three sharp drops on dates when step test are performed. They should not be taken into account. For other points, it is seen that the water loss percentage is between 60% and 70% before the study. It shows a drop of 10 points for two weeks after the study. Towards the end of May, the loss value climbs up a 5% becoming values between 55% and 65%. These results again show indications of new leaks.

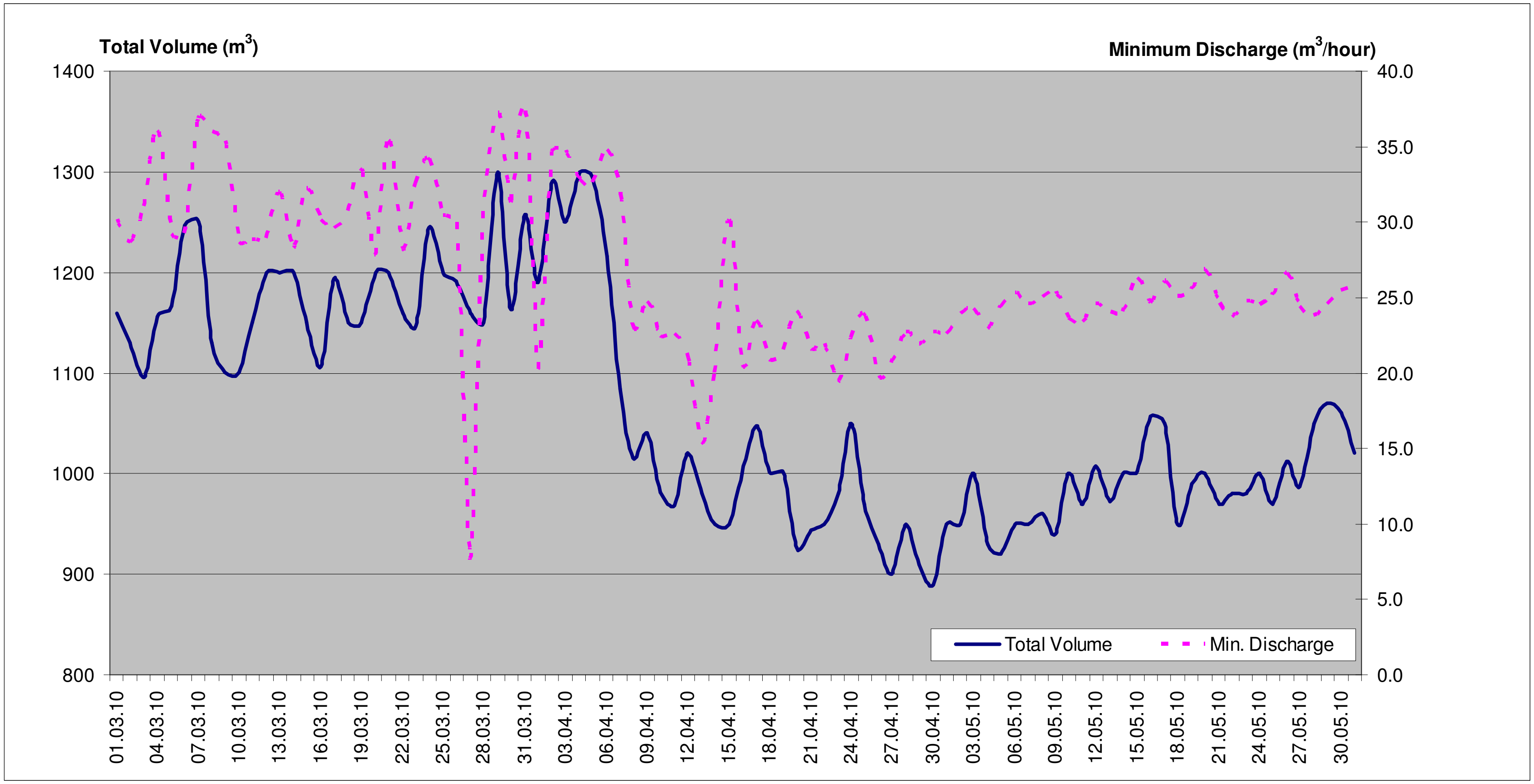


Figure 6.39 Total Water Entering and Minimum Night Flow Values vs. Days

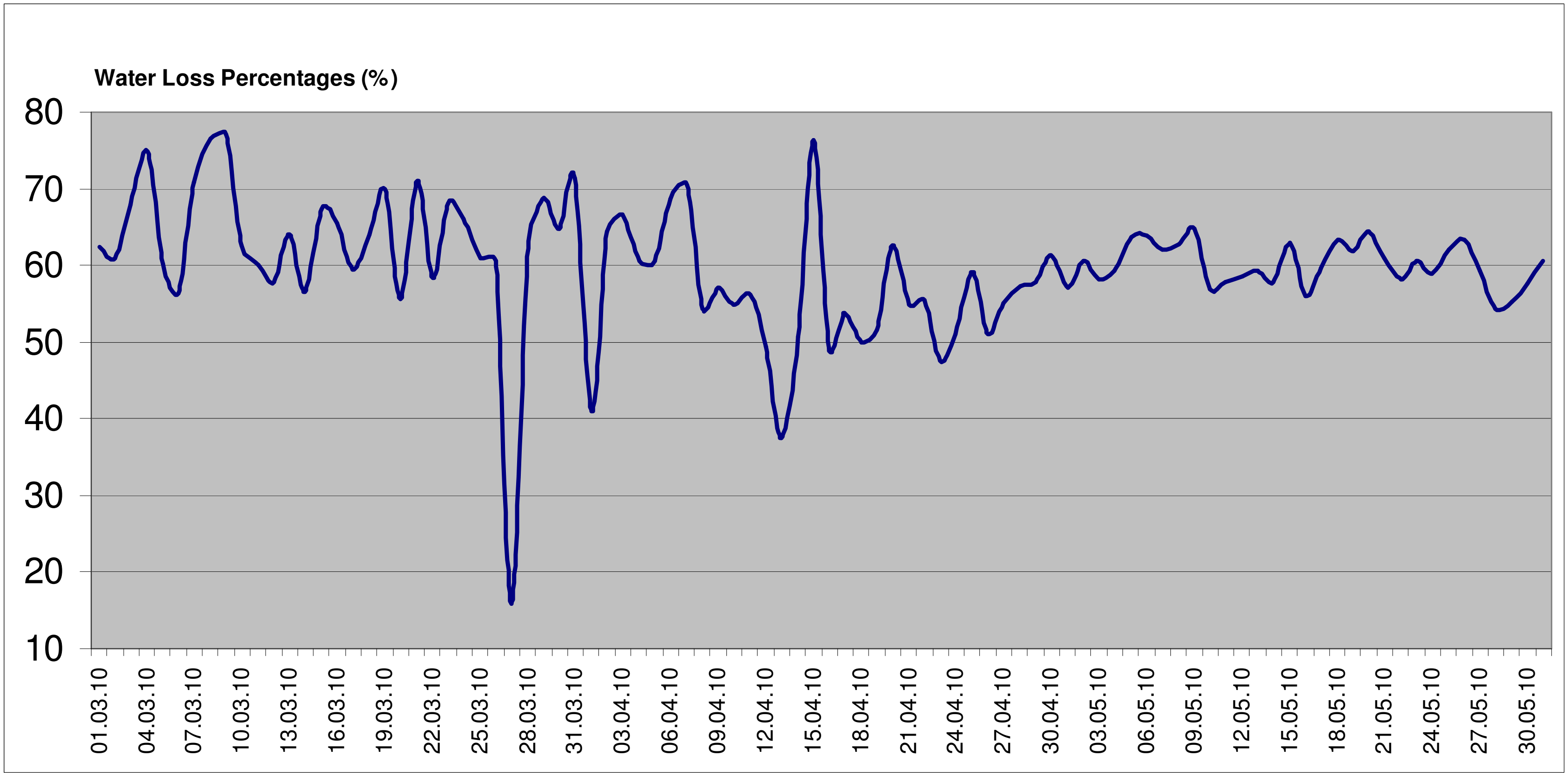


Figure 6.40 Water Loss Percentages vs. Days

To compare the revenue ratios before and after the study, SCADA and CIS data are used cooperatively. A resulting table (Table 6.11) and a figure (Figure 6.41) are provided below for historical inspection of revenue percentages over different revenue periods. The calculation formulas are given at the top row for each column.

It is seen that in summer period, the daily average water entering to zone 6 is around 1200 - 1300 m^3/day. With the decreasing population to winter months, water consumption decreases and daily average water entering to zone 6 decreases to 900 – 1000 m^3/day. The effect of repairing leaks is seen on April and May periods with a consistently decreasing water entrance to the zone. On March, 36000 m^3 water was pumped into the zone whereas on April and May this value dropped down to 30000 m^3. So a water loss of approximately 6000 m^3 was prevented per month.

In the CIS part, it is seen that in each period total revenue shows seasonal variations. Higher revenues in summer periods and lower revenues in winter periods are observed. With these CIS provided values compared to SCADA data, monthly revenue percentages are obtained. Comparing values of March, April and May, it is seen that there is an increase of 7% in April and 3% in May. Some of this increase is due to the repairs of leaks. In addition, some of the increase is due to increasing revenues due to summer season.

Similar comments can be made from Figure 6.41. The graph indicates increasing revenues in summer months and decreasing revenues toward winter. The only exception is in December period. The reason for this exception may be the shortages in SCADA data. SCADA data is reset 6 times at different days in December. There are similar shortages in other months but at this data shortage, there are long periods of time which there are no SCADA data available. With the best approximation done, the total water entering to zone 6 in December is calculated as 27820 m^3, which shows a significant difference from November and January. Therefore, this point in December stays a possible outlier in the whole dataset.

Table 6.11 Monthly Revenue Percentages

SCADA DATA				CIS DATA			Monthly Revenue Percentages (%)
Dates	Days	Water Entering to Zone 6 (m³)	Average Daily Water Entering to Zone 6 (m³)	Period	Period's Total Revenue (m³)	Daily Average Revenue (m³)	
A	*B*	*C*	*D = C / B*	*E*	*F*	*G*	*H = 100xG/D*
01.06.09 - 30.06.09	30	36700	**1223.33**	2009/6	15942	**530.57**	**43.37**
01.07.09 - 31.07.09	31	41000	**1322.58**	2009/7	18495	**609.10**	**46.05**
01.08.09 - 31.08.09	31	40430	**1304.19**	2009/8	23068	**645.23**	**49.47**
01.09.09 - 30.09.09	30	32690	**1089.67**	2009/9	14135	**584.96**	**53.68**
01.10.09 - 31.10.09	31	35489	**1144.81**	2009/10	16228	**537.14**	**46.92**
01.11.09 - 30.11.09	30	37971	**1265.70**	2009/11	14008	**484.51**	**38.28**
01.12.09 - 31.12.09	31	27820	**897.42**	2009/12	14135	**445.15**	**49.60**
01.01.10 - 31.01.10	31	32300	**1041.94**	2010/1	13459	**421.62**	**40.46**
01.02.10 - 28.02.10	28	31430	**1122.50**	2010/2	11163	**407.88**	**36.34**
01.03.10 - 31.03.10	31	36410	**1174.52**	2010/3	12051	**436.87**	**37.20**
01.04.10 - 30.04.10	30	30980	**1032.67**	2010/4	14981	**457.84**	**44.34**
01.05.10 - 31.05.10	31	30650	**988.71**	2010/5	14364	**473.15**	**47.85**
(01.06.09 - 31.05.10)	365	413870	**1133.89**	2009/6 - 2010/5	182029	-	**43.98**

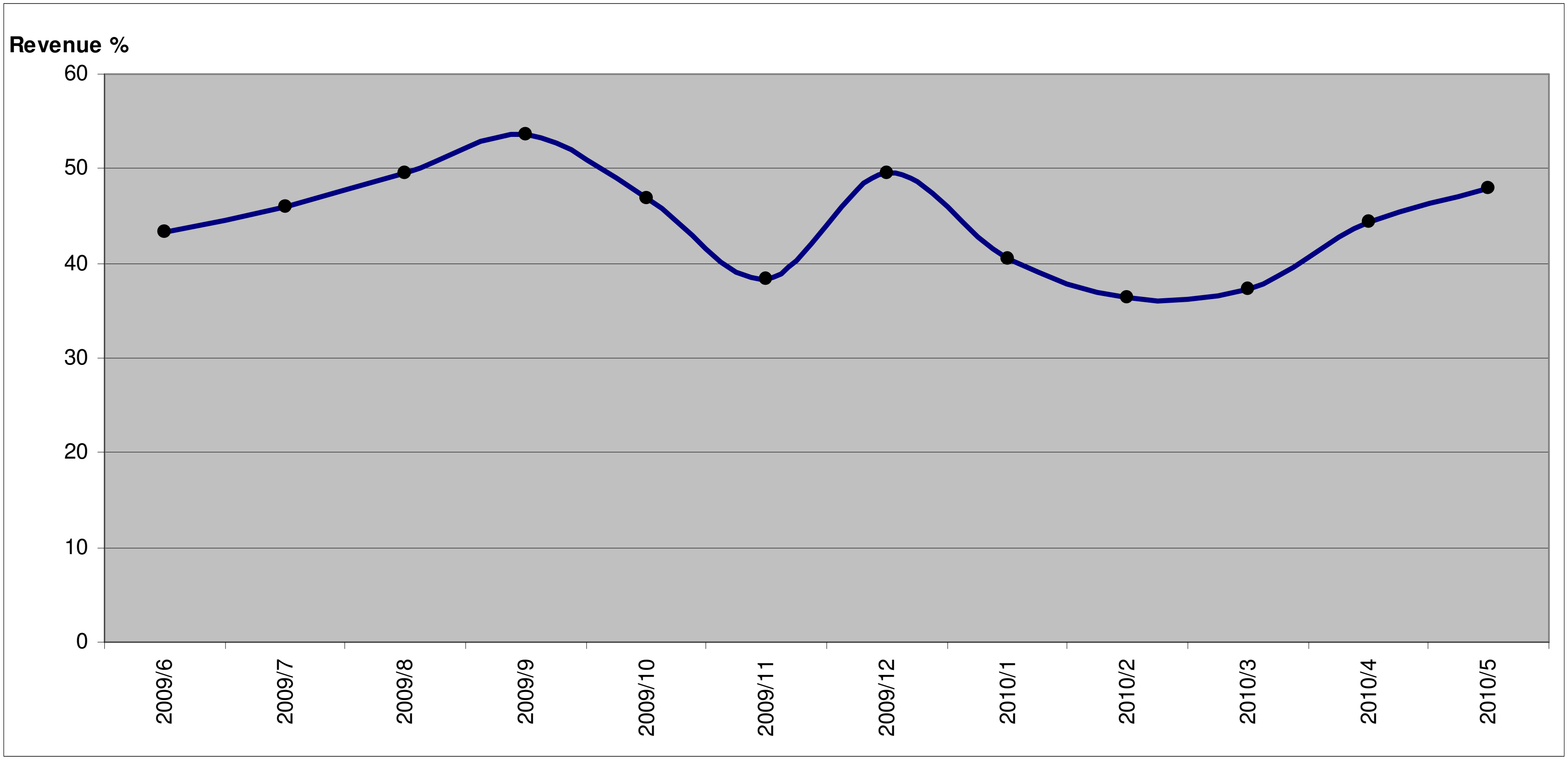


Figure 6.41 Revenue Percentages over Periods

6.3. Zone 2 Studies

After completing the studies on zone 6, to see the effects of pressure management over water leakages, a similar zone is picked for further studies. Second case study is performed on this DMA namely zone 2. The most important property of this DMA is the pressure management regulation that is being applied since 2009 August. With the SCADA and CIS data available, it is possible to investigate the water leakages in this zone:

- Without any pressure reduction
- With pressure reduction only
- Pressure reduction combined with locating and fixing water leakages

Zone 2 is another member of the Boğaçay Pump Station – Hurma Water Storage Tank system. It is located northeast of zone 6 still staying next to Mediterranean shores (Figure 6.42).

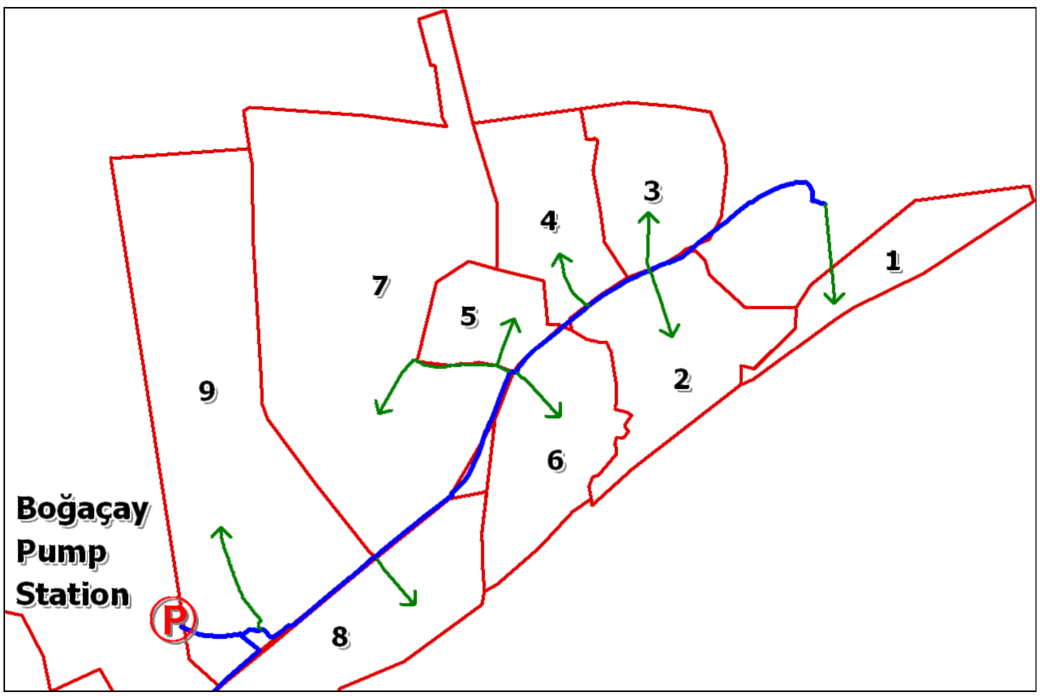


Figure 6.42 Zone 2 and 6 with Their Neighbouring Zones

6.3.1. Data Sources

6.3.1.1.Geographic Information Systems

6.3.1.1.1. Pipes

Just like zone 6, the name of DMA has two alternatives. It is named as zone 2 by the GIS crew and as metering point 68 by the SCADA crew. Zone 2 will be used throughout the text.

The main transmission line within the DMA is an Ø150 mm PVC pipe, and it serves to an approximately 12000 m of secondary pipes. Although there are Ø200 mm pipes in the network, they were not used as the main feeder pipe because their material is asbestos cement and they are being cancelled out whenever possible. The lengths of the pipes are given in the table below (Table 6.12).

Table 6.12 Pipe Diameters and Pipe Lengths in Zone 2

Pipe Diameter (mm)	Pipe Length (m)
63	369,8
90	1019,4
99	98,4
100	1770,7
110	5512,2
150	2081,3
200	1072,0
Total	**11923,8**

Pipes in this DMA consist of four different materials. The material distribution is given in the table below (Table 6.13). As the rehabilitation study is still going on in this area, most of the pipes were renewed with PVC pipes, and asbestos cement pipes are being planned to be converted to PVC as soon as possible.

Table 6.13 Pipe Materials and Pipe Lengths in Zone 6.

Pipe Material	Pipe Length (m)
PE	365,1
Asbestos Cement	907,5
HDPE	1731,5
PVC	8919,7
Total	**11923,8**

A more detailed table is provided for this DMA showing diameters and materials of pipes (Table 6.14). The most remarkable thing in this table and Table 6.12 is the 99 mm diameter pipes. This shows a typical example of an incorrect data entering go the GIS layers. As there is not a standard pipe diameter of 99 mm, those pipes may either be 100 mm diameter pipes or belong to a group whose diameters are not exactly known. In that case, "99" is the arbitrary entered value, maybe to be corrected in the future.

Table 6.14 Pipe Diameters, Pipe Materials and Pipe Lengths in Zone 6

Diameter (mm)	Pipe Material	Pipe Length (m)
63	PVC	369,8
90	PVC	1019,4
99	PVC	98,4
100	PVC	1473,5
100	HDPE	88,3
100	PE	134,5
100	Asbestos Cement	74,4
110	PVC	4143,1
110	HDPE	1138,6
110	PE	230,6
150	PVC	1815,4
150	Asbestos Cement	265,9
200	Asbestos Cement	567,2
200	HDPE	504,6
200	PVC	0,2
Total		**11923,8**

6.3.1.1.2. Fittings

According to the GIS data, there are 65 valves and 5 fire hydrants in zone 2. Due to time limitations, these valves were not examined one by one on the field. They were only examined shortly while noise data loggers were being placed on them. According to those examinations, most of them were in good shape and serves to the administration's needs. They might have small leakages like in zone 6 but they are not separately considered as water leaks in this study. Possible small leaks contribute to the overall leakage sum.

As stated before, zones 2 and 6 are connected to each other with an isolation valve that is kept closed at all times. The reason for this is applying different pressure regulations in these DMAs. While working in zone 6, this isolation valve was discovered to be faulty and it was renewed. Therefore, with this action it can be said that maximum isolation is obtained between these two zones working under different pressures. By this result, two zones can be separately examined by their

SCADA and GIS records in terms of water loss percentages.

6.3.1.1.3. Buildings

For the topography of zone 2, same things can be said with zone 6. They are almost similar in terms of topographic elevations showing almost no change. The most important difference between zone 2 and zone 6 is that they work under different pressures. The two DMAs are being fed from the same system, but at the entrance of zone 2, with the help of a pressure-reducing valve (PRV) pressures are reduced from an average value of 5.5 bars to a constant level of 3.0 bars. Minimum pressure that has to be supplied by the water administrations show large variations due to lots of factors like topographic elevations, number of floors of the buildings in that area etc. As the topographic elevation differences can be ignored in this DMA, the consideration of number of floors gains importance. With the available GIS data an analysis on floor numbers of the buildings is done. The first results are given in Table 6.15.

Table 6.15 Number of Floors and Buildings in Zone 2

Number of Floors	Number of Buildings
1	15
2	19
3	133
4	77
5	19
6	18
7	15
8	18
9	12
10	7
11	3
12	1
13	1
16	1
50	*5*
—9999	*130*
Total	**474**

The first things to be noted in this table are having a 50-floor building, which is not a correct thing, and having a sum of 130 buildings with -9999 floors, which mean their values were not entered to the system. Buildings having floors up to 16 are observed at the DMA so the rest of the data seems correct. To overcome these data inconsistencies the following assumptions are made. 50-floor buildings are ignored as they consist only around 1% of the total data. “-9999-floor buildings” were distributed to the other buildings proportional to their percentages in the total data. The resulting distribution is given in Table 6.16.

Table 6.16 Corrected Number of Floors and Buildings in Zone 2

Number of Floors	Number of Buildings	Percentages (%)
1	21	4,42
2	26	5,6
3	184	39,23
4	107	22,71
5	26	5,6
6	25	5,31
7	21	4,42
8	25	5,31
9	17	3,54
10	10	2,06
11	4	0,88
12	1	0,29
13	1	0,29
16	1	0,29
Total	**469**	**100**

As seen in the table, more than 70% of the buildings have number of floors between 1 and 4. With the majority of the buildings being like this, a pressure of 3.0 bars is considered adequate by the administration. Buildings having higher number of floors will face low-pressure problems, and some of them will not even have water in the top floors. For this situation, the administration applied a procedure explained step by step below:

- Without any warning, the pressure is reduced from 5.5 bars to 3 bars in the DMA.
- Low pressure and water shortage complaints are reported by the customers to the telephone support lines of ASAT.
- Those complaining customers are warned to install booster pumps at the entrance of their apartments to solve their pressure problems. These warnings were done according to the related rules of ASAT and Greater Municipality of Antalya.
- The pressures in the DMA were released to 5.5 bars for 1 month to let the complaining customers install their booster pumps.
- At the end of one month, the pressures were permanently reduced to 3.0 bars.

With this procedure, the administration meets the minimum pressure requirements, which may exist as a legal written document or a practical rule, and decreases the water leakages in the DMA considerably. Also regulating pressure to constant values provides the users constant quality water at all times of the day. The disadvantage of reducing pressures is, hiding some of the water leaks from detection as the leaks are directly related to system's pressure. However, the problem is solved by releasing pressure while working in the zone for leak detection purposes and reducing the pressures after locating and fixing the leaks. The studies about this concept are explained in the next chapters.

Unlike zone 6, the administration was not advised to construct any new connections or install new valves in zone 2. The studies are performed in the DMA without any step test applications.

The DMA has two big streets crossing each other. They divide the DMA into three nearly equal pieces (A, B and C), which are seen in Figure 6.43. These regions are taken as the basis of the field works. It is planned to work on parts A, B and C for one day each. Total studying time is planned as five days, so for the remaining two days all the excavation and water leak repair studies are scheduled.

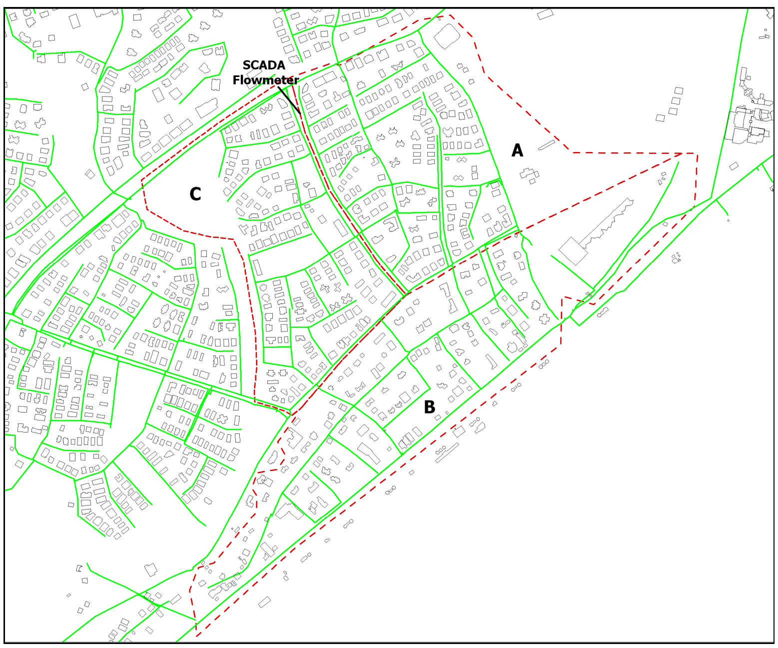


Figure 6.43 Zone 2 Divided Into Three Pieces

6.3.1.2.Customer Information Systems

Zone 2 of Konyaaltı network is one of the two neighbouring zones of zone 6. Zone 2 is larger than zone 6 in terms of both area and population. CIS records state 3025 customers located in 474 buildings. In zone 6 the corresponding values were 1800 customers in 344 buildings.

The structure of CIS is exactly the same with zone 6 as they are both a part of the same database.

6.3.2. Calculating Water Loss Percentages

Water loss percentages are computed through two aspects for zone 2. Compared to the case for zone 6 the SCADA records are carefully investigated to catch the pressure reduction date and time. According to the records, after warning the customers about the new regulations, pressure is reduced from 5.5 bars to 3.0 bars in two stages. On 12 August 2009 at 11:30, pressures were reduced to 3.5 bars. After some time on 28 September 2009 at 10:00, pressures were finally reduced down to 3.0 bars. These actions deeply affected water loss percentages in both monthly revenue aspect and minimum night flow aspect.

6.3.2.1.Monthly Revenue Aspect

Procedure already explained for zone 6 is applied to zone 2 gathering the necessary SCADA and CIS data. Before the pressure reduction, revenue percentage in the zone was around 55% (meaning a revenue loss of 45%) while after the pressure regulation revenue percentage increased to 70% level (meaning a revenue loss of 30%)

Similar comments can be made by looking at the monthly water meter indexes. Before the regulation, monthly water entering to the zone was at 60000 m^3 level on the other hand after the regulation this value reduced down to 45000 m^3 level. It clearly states that water leaks are reduced just by getting rid of the excess pressure at the zone entrance.

After the field works there has been some further improvements in the water leak percentages. They are discussed in more detail in the Results section.

6.3.2.2.Minimum Night Flow Aspect

Similar to zone 6, daily demand curves are investigated. This time, they are investigated in more detail, especially considering July, August, September and October of 2009 to see the effect of pressure reduction alone. Three daily demand curves are picked to see the stages of water loss. Three of the curves were picked from Fridays. The dates are, 31 July 2009, 21 August 2009 and 2 October 2009.

31 July 2009 curve (Figure 6.44) represents a sample day (Friday) without any pressure regulation. Pressure oscillates between 5 bars and 5.7 bars. The minimum night flow value is 65.1 m^3/h in this sample day with unreduced pressure. Maximum flow values reach up to 120 m^3/h

maximum consumption hours. With the proposed procedure, calculation of water loss percentage yields up to 69.5%. That calculation was done by proportioning the area under minimum night flow line to the total area under the daily demand curve (B/ (A+B)). On this day, a total volume of 2250 m^3 water passed through the water meter at the entrance of DMA according to SCADA records.

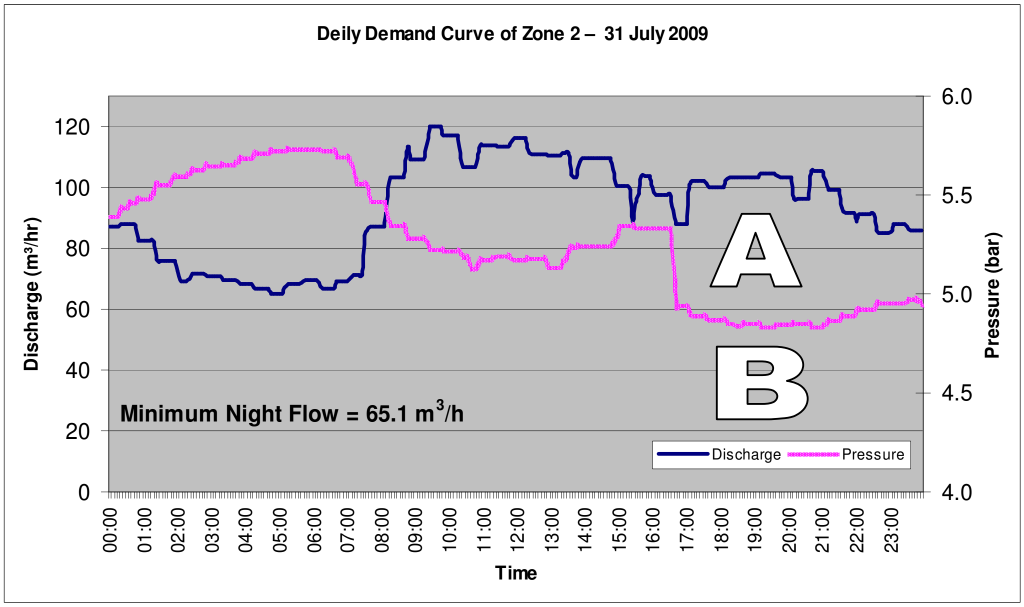


Figure 6.44 Sample Daily Demand Curve of Zone 2 Showing Minimum Night Flow on 31 July 2009

For a comparison, another Friday just after the first stage pressure regulation is picked. That day is 21 August 2009. As seen in that curve (Figure 6.45) pressure is reduced down to 3.6 bars with little oscillations through the day. With the reduction of pressures, minimum night flow value decreased down to 47.7 m^3/h immediately. When compared to 31 July 2009, which means a loss of 17.4 m^3/h is prevented. Calculation of water loss percentage for this day results in a loss percentage of 64.2%. That is a prevention of 5.3% water loss. Looking at the peak hours, it is seen that peak hour discharges reduced to 90 m^3/h level. For comparison, a total volume of 1785 m^3 water passed through the water meter on this day. From this value, it can be seen that a reduction of 465 m^3 occurred in the water indexes.

In the Figure 6.45, one thing draws attention too. That is the interruption of both discharge and pressure values at around 02:00. This probably means an energy shortage or a data transmission failure. In 30 – 45 minutes time the data comes back again and reports the values as before. In fact, SCADA records obtained from ASAT are full of shortages and missing data values like this. Most of the small shortages are corrected through this study by considering the nearest values before and after the missing values. However, in this case the shortages are left uncorrected to illustrate an example about the problem.

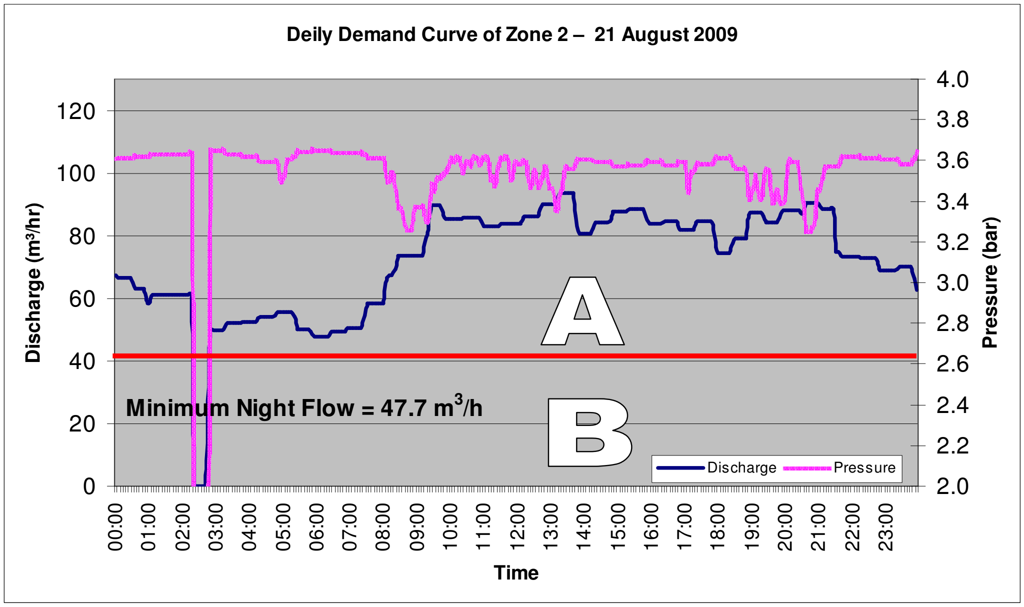


Figure 6.45 Sample Daily Demand Curve of Zone 2 Showing Minimum Night Flow on 21 August 2009

Taking a step further and reducing the pressure of the DMA down to 3.0 bars, had an effect on the SCADA values as expected. The selected sample day is again a Tuesday, 2 October 2009. The curve shows again a decrease in minimum night flows (Figure 6.46). The reduction is not as much as the previous action but it is still valuable. Minimum night flow this time is 38.7 m^3/h. That means a 9 m^3/h more decrease in the losses. This final decrease makes the water loss percentages 58.1%. 1600 m^3 is the total volume of water entering to the DMA on 2 October 2009.

As seen from the Figure 6.46, pressure values are stabilized to 3 bars with very little oscillations which may be ignored when compared to previous situations.

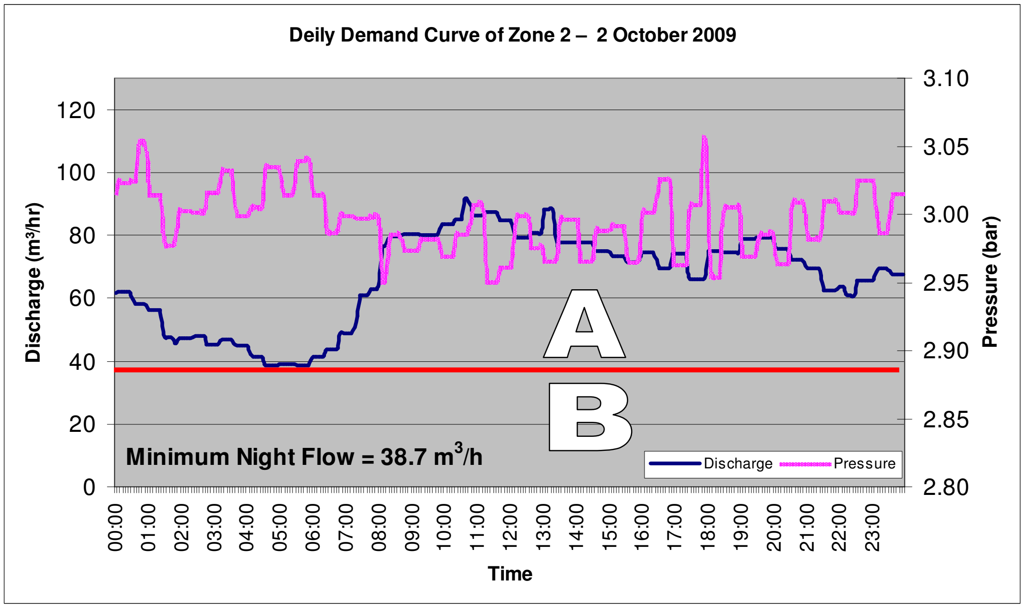


Figure 6.46 Sample Daily Demand Curve of Zone 2 Showing Minimum Night Flow on 2 October 2009

Considering these three days alone, 26.4 m^3/h decrease in minimum night flow is obtained. 650 m^3/day decrease in volume of water entering to DMA is achieved. Overall, a decrease of 11.4% is obtained in water loss percentages. All these achievements are done without fixing any leaks in the system but only reducing the pressure with the help of a PRV.

To summarize all of these operations, following graphs in Figure 6.47 and Figure 6.48 can be considered. Figure 6.47 illustrates the three different day’s values in the same graph. In the other figure, with the historical values, the drop of minimum night flows with the reducing pressure is clearly seen.

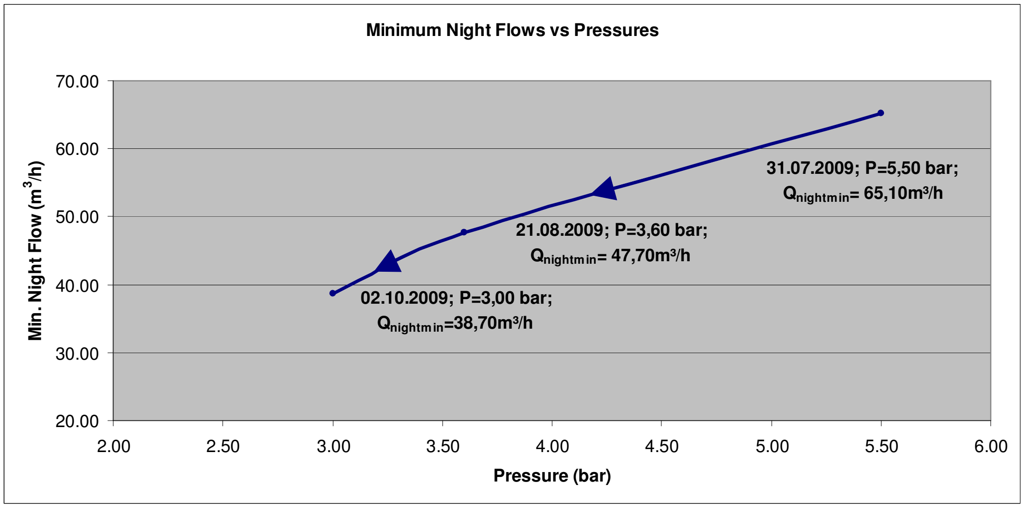


Figure 6.47 Minimum Night Flows vs. Pressure Under PRV Effect

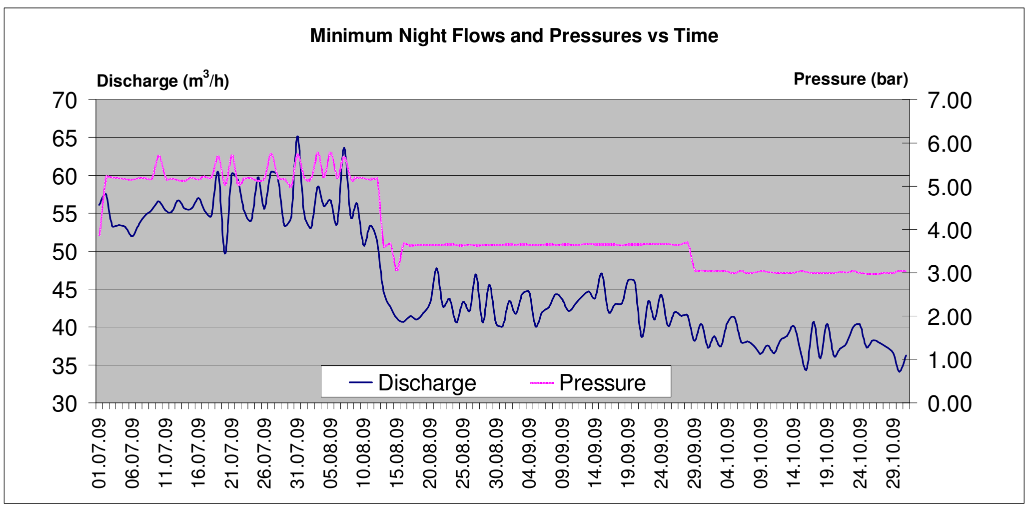


Figure 6.48 Decrease of Minimum Night Flows with the PRV

6.3.3. Forming and Prioritizing Sub-DMAs

Unlike zone 6, no sub-DMA formation is done in the network of zone 2. Instead, the DMA is virtually divided into three parts with the two avenues; 5th avenue and 7th avenue while studying (Figure 6.43). Virtually dividing means no valve isolation actions done to divide the DMA. This division is only for practical purposes. At each divided region, one day's of working is done with the noise data loggers. This lead to a quicker sweeping of the DMA when compared to zone 6. Of course, this choice brought its disadvantages with it. Most important disadvantage is that no step test could be performed which in the other zone. Therefore, without having an idea about which part of the network is the weakest part, water leak detection studies are performed.

6.3.4. Locating Physical Water Losses

6.3.4.1.Forming Buffer Areas for Leak Noise Loggers

As no sub-DMA formation studies are done, buffer analysis is done on the whole valve layer with again 20 m and 50 m diameter values. By paying attention to cover the maximum area using up to 20 noise data loggers, candidate valves were chosen for logger placement. As the network suffers from the same problems as zone 6 (having mostly plastic pipes, long dead end connections, etc.), noise data loggers are effective up to a certain extent. At the point where data loggers become ineffective, ground microphoning crew will step in. In Table 6.17 number of valves and number of loggers placed in each artificially divided region are given.

Table 6.17 Number of Valves and Loggers Placed in Zone 2

Region	Number of Valves	Number of Loggers Placed
A	28	20
B	17	12
C	20	16
Total	65	48

Before starting field works in zone 2, SCADA centre is informed to deactivate the pressure-reducing valve at the entrance of the zone. With this action done, a higher pressure will be present in the system which will make the water leaks flow in higher amounts and generate higher sounds. When the leaks generate higher sounds and vibrations, both leak noise logger devices and ground microphone devices will be able to detect and pinpoint the leaks better.

According to the SCADA records, the pressure is released to its normal level on 12.04.2010 at 14:20. With this action, water entering to zone 2 and minimum night flows of the zone increased in high amounts.

With the equipped 20 loggers, data logger study was first done in region "A" (east of 7th avenue and north of 5th avenue) on 12.04.2010. The loggers were programmed to record possible leak noises between 02:00 and 05:00 in 10-second intervals ensuring similar conditions done in zone 6. They are programmed to send the recorded data to the master unit, the day after between 10:00 and 12:00. On 13.04.2010, 16 more loggers were placed on region "C" (west of 7th avenue and north of 5th

avenue). Finally, on 14.04.2010 12 loggers were placed on region “B” (south of 5th avenue).

In region A, three leak alerts were received from loggers #3605, #3645 and #3612. First two of these pointed the same point. These alerts were named as alert 8, alert 9 and alert 10.

In region C, three more leak alerts were received from loggers #3652, #3641 and #3625. These alerts are named as alert 11, alert 12 and alert 13.

Finally, in region B, one leak alert was received from logger #3622. This is named as alert 14. These 7 alerts are explained in detail below. After collecting these leak alerts, ground microphoning studies are performed. Those studies are explained in the next section.

Alert #8 and Alert#9: Three data loggers were placed on three different valves located on 625th street, in front of “Hotel Starlight” as in Figure 6.49. Two of these data loggers reported leak alert. These two loggers have the serial number 3605 and 3645. Their corresponding noise graphs are given in figures below (Figure 6.50 and Figure 6.51).

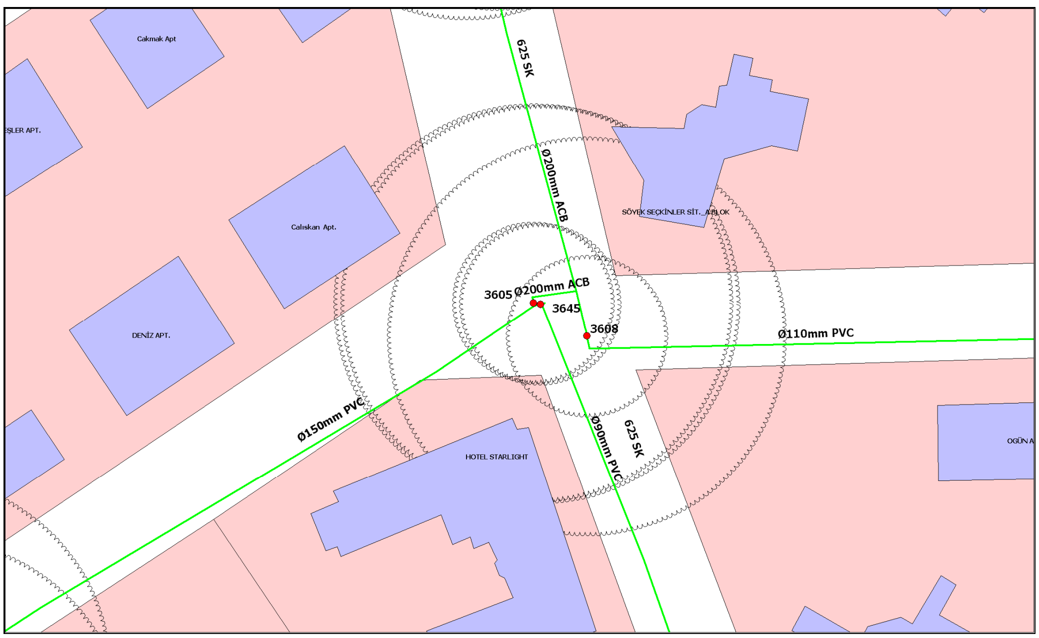


Figure 6.49 Noise Data Loggers with Serial Numbers 3605, 3608 and 3645 Placed On Valves #20814, #20854 and #20815 with Their Corresponding Effective Areas

In this measurement, the third data logger did not receive a leak sound. It can be interpreted as the possible leak is either on Ø150mm PVC pipe or on Ø90mm PVC pipe, as they are not directly connected to the valve that did not receive leak sound. The effective area of logger #3608 may not include the leak spot either. Another interpretation can be the use of 90-degree elbow and reduction fittings may have an effect on the fading out of the leak noise. As seen from the figure, there are four different pipe diameters at the intersection point, and there has to be some diameter reduction fittings in the connections. These fittings may have reduced the sound of a possible leak.

Details of logger 100 03 003605

Measurement location #1 100 03 03605
Remark (logger) 100 03 03605

No.	Transmission date	Minimum level	Frequency	Width	Graph
8	13.04.2010 - 14:33:14	**424**	15	147	X

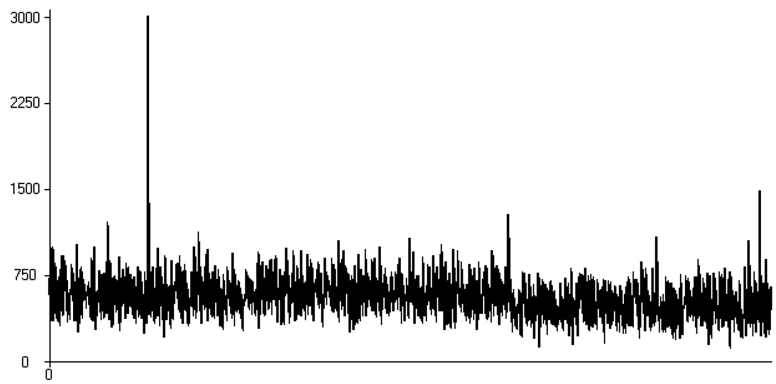


Figure 6.50 Details of Logger with Serial Number 3605 Placed On Valve #20814

Details of logger 100 03 003645

Measurement location #1 100 03 03645
Remark (logger) 100 03 03645

No.	Transmission date	Minimum level	Frequency	Width	Graph
2	13.04.2010 - 14:35:47	**1794**	523	362	X

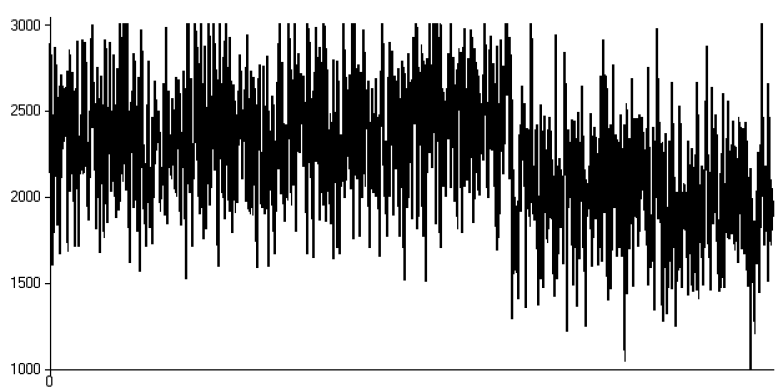


Figure 6.51 Details of Logger with Serial Number 3645 Placed On Valve #20854

When looking at Figure 6.50 and Figure 6.51, it is easy to say that the possible leak point is nearer to valve #20854 as its minimum sound level is 1794 whereas from valve #20814 only a minimum sound level of 424 is recorded. In addition, there is a big difference in the frequency values. Valve #20854 seems to point a leakage better than valve #20814 by having a frequency of 523 Hz. Width values are better in $20814 therefore its recording has less interference and represents a better recording quality.

The ground microphone studies cleared this spot and a leak was found. It is explained as "Leak 7" in the next chapter.

Alert #10: The logger having the serial number of 3612 is placed on the valve with ID 31910 on 600th street, in front of Villa Park Apartment. Below in Figure 6.52 the position of the valve is seen. In addition, the corresponding buffer areas with 10 meter and 25 meter radius can be seen too. Pipes at this corner are coded as Ø110mm PVC and Ø200mm HDPE pipes.

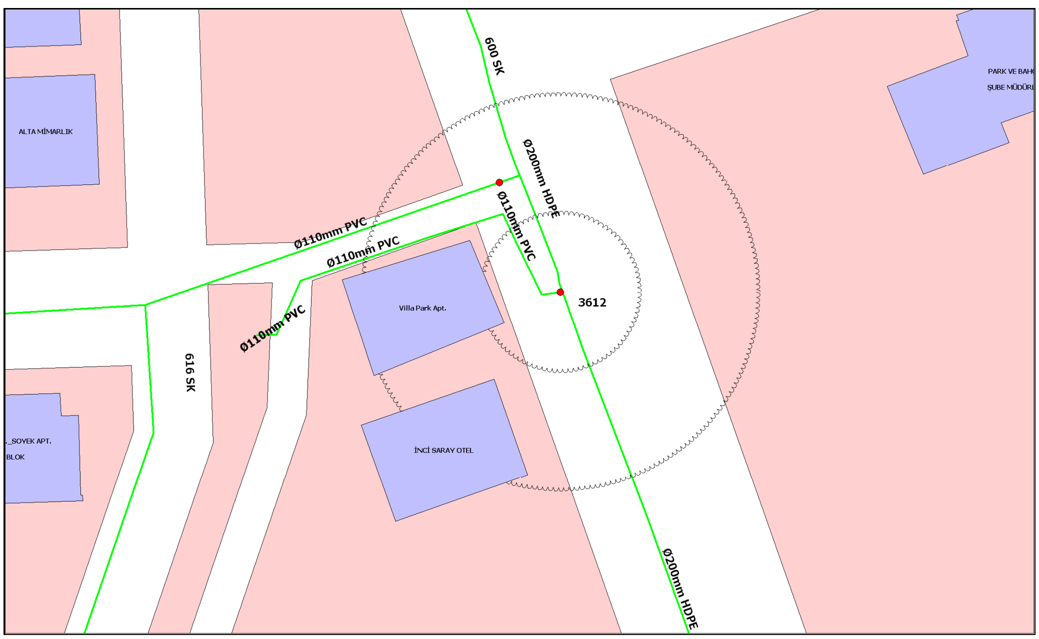


Figure 6.52 Noise Data Logger with Serial Number 3612 Placed On Valve #31910 and Its Corresponding Effective Areas

Details of logger 100 03 003612

Measurement location #1 100 03 03612
Remark (logger) 100 03 03612

No.	Transmission date	Minimum level	Frequency	Width	Graph
6	13.04.2010 - 14:12:38	**159**	222	191	-
7	13.04.2010 - 15:15:18	**159**	222	191	X

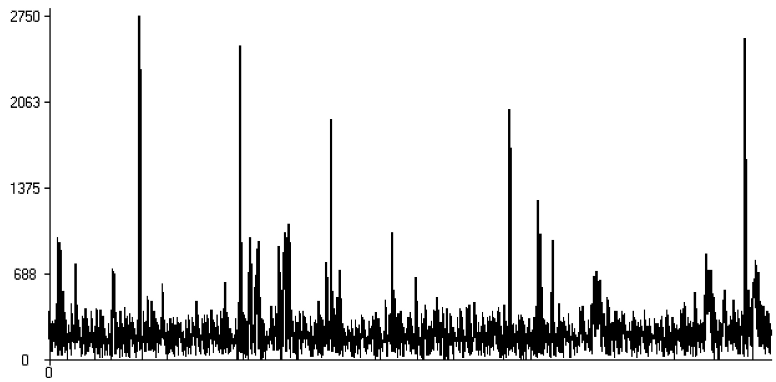


Figure 6.53 Details of Logger with Serial Number 3612 Placed On Valve #31910

Above, it is given the output figure for the logger with serial number 3612 (Figure 6.53). It gives a minimum level as 159. Frequency is reported as 222 Hz. Width is given as 191. According to the minimum level value, the possible leak is either a small leak or it is at a distance away from the valve. To find and pinpoint the probable leak, a ground microphoning study was scheduled. While studying at this place, it was also seen that a small water puddle in front of the next building (İnci Saray Otel). As the puddle was inside the garden, it was thought of an accumulation of water because of watering the plants. Still it was noted as a possible leaking spot. After the ground microphoning studies the leak was found. It is discussed in detail as “Leak 6” in the next chapter.

Alert #11: Leak noise logger with serial number 3652 was placed on the valve with ID 27070 on 6th avenue (Figure 6.54). This valve is the valve at the connection point between zone 6 and zone 2. During the studies in zone 6, a nearby valve pointed out this valve to be faulty and the administration decided to install a new valve assuming that it is faulty. After renewing the valve and shutting it, a possible connection between these two pressure zones are assumed to be blocked. However, during this last data logging study, the valve sounded like a leak sound. This time the minimum sound level exceeded the noise data logger’s ranges and recorded a maximum level of 3000 with a frequency 761 Hz (Figure 6.55). This situation first lead to a thought that if the valve was left slightly open unintentionally after the construction studies. To prove this, the isolation valve was checked and seen that it was closed firmly. Then the field staff of ASAT warned the ground microphoning crew about the pipeline located there is not buried to the ground due to the bridge over the creek at that point.

Finally the sound being recorded is interpreted as the environmental sound hitting the pipeline under the bridge and being detected at the noise data logger.

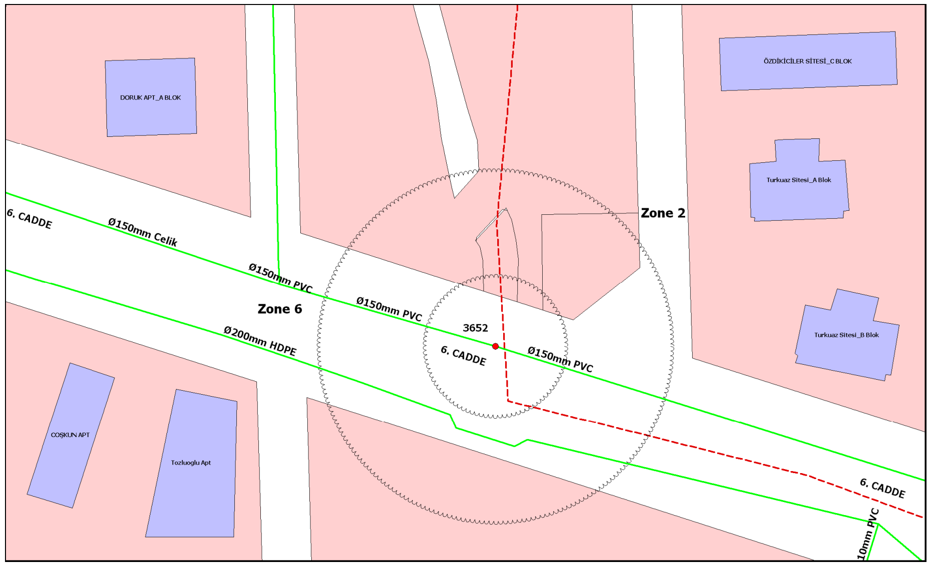


Figure 6.54 Noise Data Logger with Serial Number 3652 Placed On Valve #27070 and Its Corresponding Effective Areas

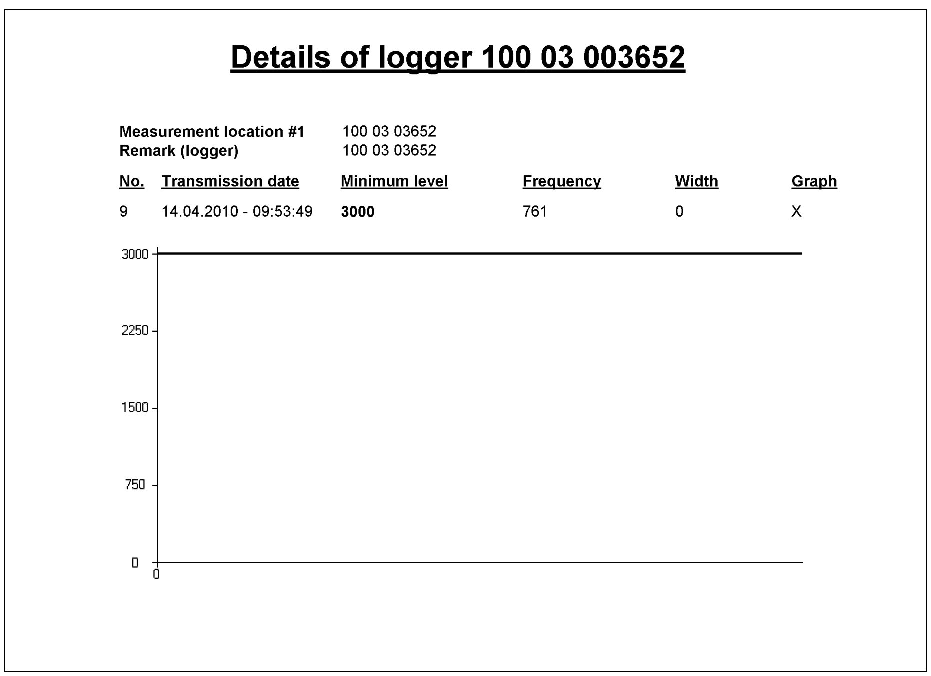


Figure 6.55 Details of Logger with Serial Number 3652 Placed On Valve #27070

Alert #12: At the intersection of 655th street and 5th avenue, noise data logger with serial number #3641 is placed on the valve. There are Ø100mm, Ø110mm and Ø150mm PVC pipes and

Ø150mm asbestos cement pipes at this place (Figure 6.56). Placed logger reported a leak alert depending on the measurements of minimum level of 1392, a high value and frequency level of 761 Hz. The width value showing the quality of measurement is 240, which can be considered as a moderate value (Figure 6.57). According to these results, a water leakage seems almost certain in nearby locations. However with the ground microphoning studies done carefully on this location, operators were unable to pinpoint a leak spot. They were not able to hear a water leakage with their devices. So nowhere at this intersection was excavated.

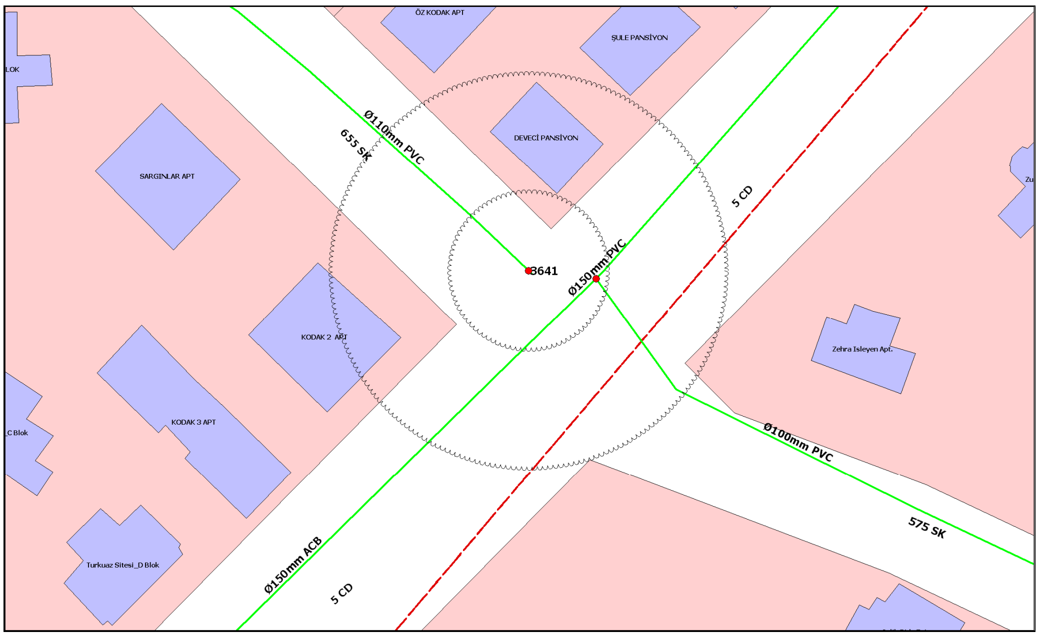


Figure 6.56 Noise Data Logger with Serial Number 3641 Placed On Valve #27259 and Its Corresponding Effective Areas

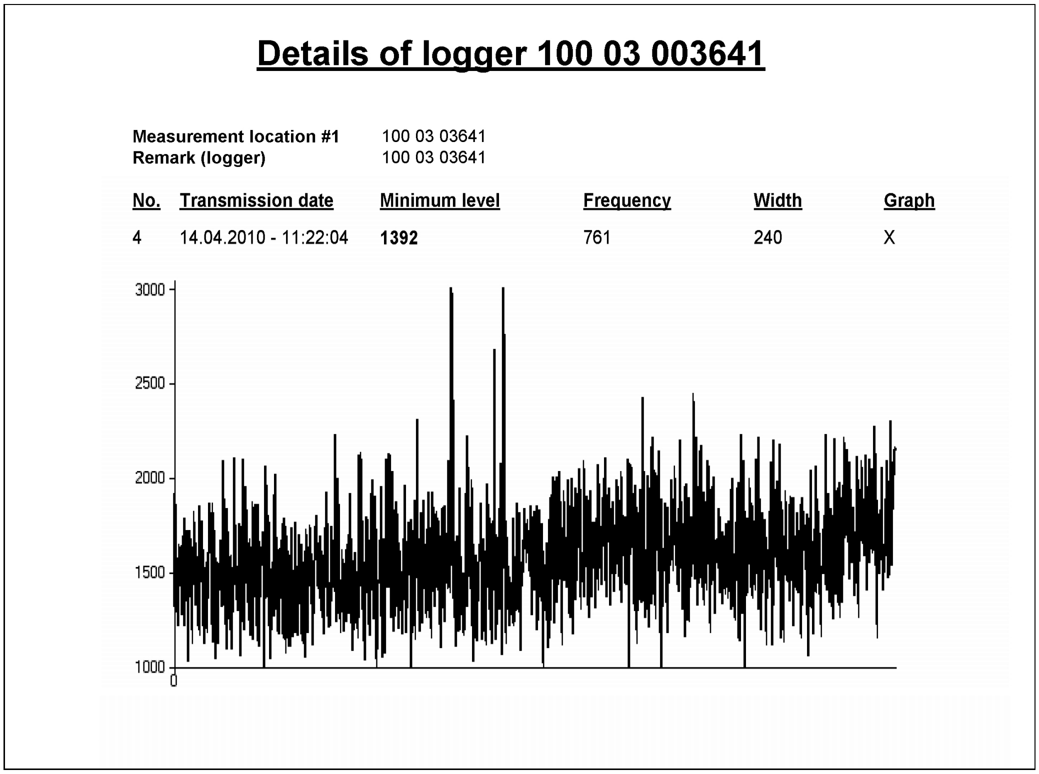


Figure 6.57 Details of Logger with Serial Number 3641 Placed On Valve #27259

Alert #13: Alert 13 is reported by logger #3625 on the intersection of 5th avenue and 600th street. At this intersection, there are totally three valves located on the pipes as seen in Figure 7.17. Three noise data loggers were placed on these valves but only logger #3625 reported a leak sound with a graph shown in Figure 6.58. This might be interpreted as the possible leak may be either on Ø150mm PVC pipe to the west, as the sounding valve is the only valve on that pipe, or the leak may be on the Ø200mm HDPE pipe towards north in a place that only #3625 can hear its sound not the other two. This can be supported by having a possible leak at the other end of 600th street, which is a case explained in alert #10. However a distance of around 100m between these two locations invalidate this thought as sound of a leaking spot is not seen to travel this much of a distance in plastic pipes as far as in this study. With a relatively low minimum sound level of 303 and a frequency level of 365Hz the possible leak seems to be small or far away from the valve (Figure 6.59). After getting these results, a ground microphoning study was performed. Even though listening the nearby streets with more effort than usual listening, no sign of a water leakage was heard by the operators. No operations were performed at this place.

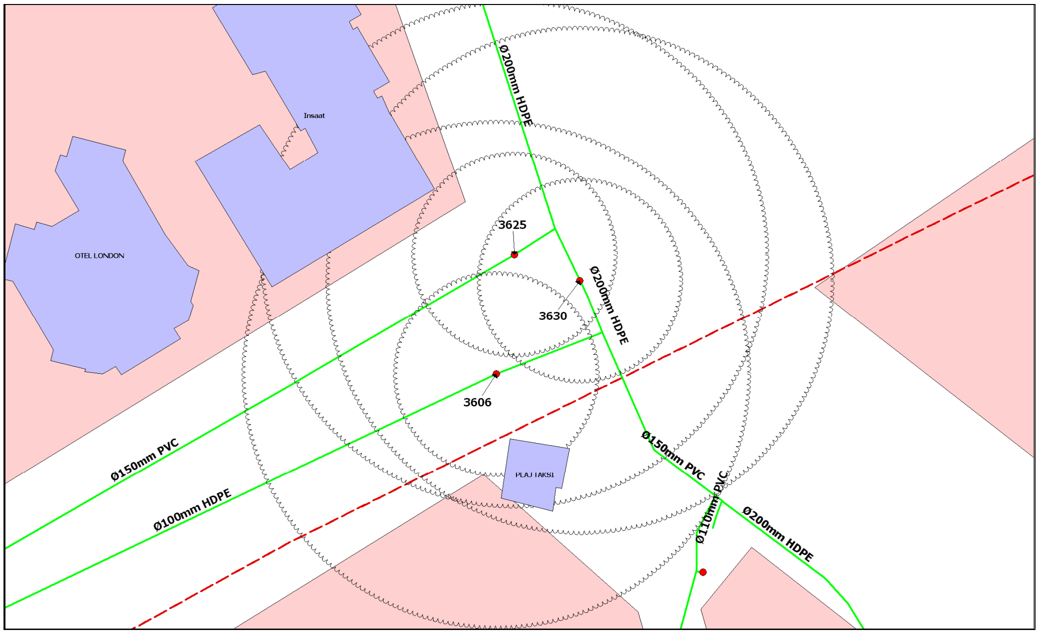


Figure 6.58 Noise Data Logger with Serial Number 3625 Placed On Valve #20716 and Its Corresponding Effective Areas

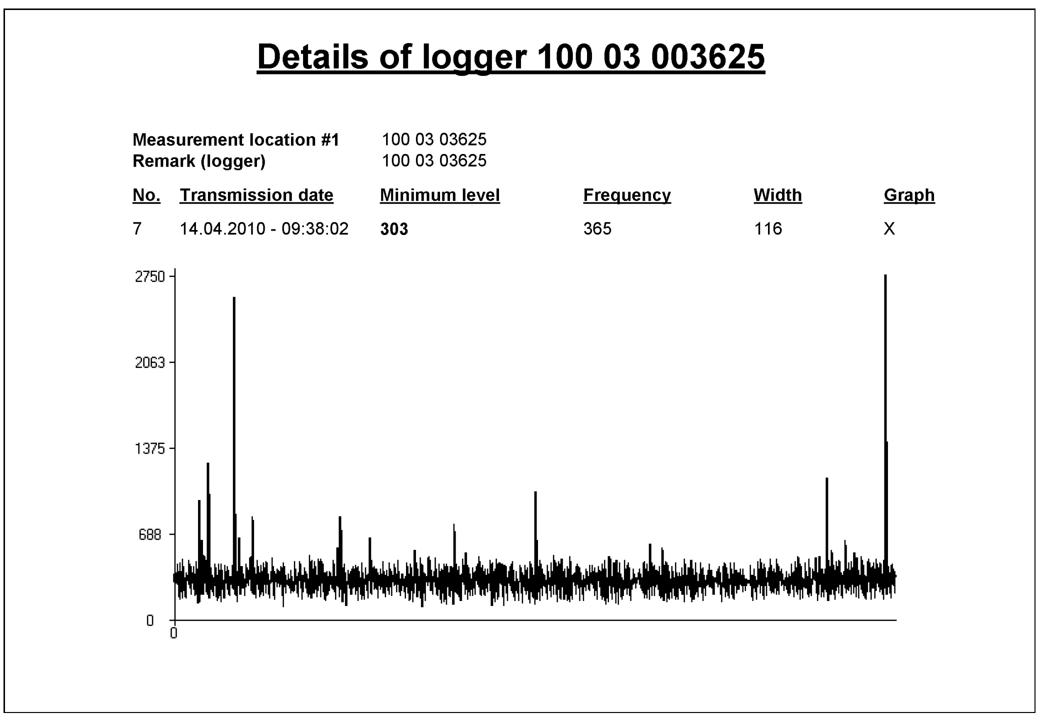


Figure 6.59 Details of Logger with Serial Number 3625 Placed On Valve #20716

Alert #14: Last alert was reported on the intersection of 603rd and 607th streets in front of a mosque named “Deniz Kenarı Cami” (Figure 6.60). At this place, five different pipes intersect on two different points. Similar to the previous situation, only one of the three placed loggers reported a leak sound. This logger had the serial number of #3622. According to the theoretical buffer areas generated, the leak may be present towards the 607th street (on Ø110mm HDPE pipe) or towards the unnamed street which goes to the mosque entrance (Ø100mm PVC pipe).

Having a low minimum noise level of 315 may indicate that the leak is at some distance away from the valve. The measurement had a very low width value of 62 (Figure 6.61). This states a good quality measurement. Scheduled ground microphoning studies revealed this alert and a leak was found on Ø100mm PVC pipe. This is explained as "Leak 11" in the next section.

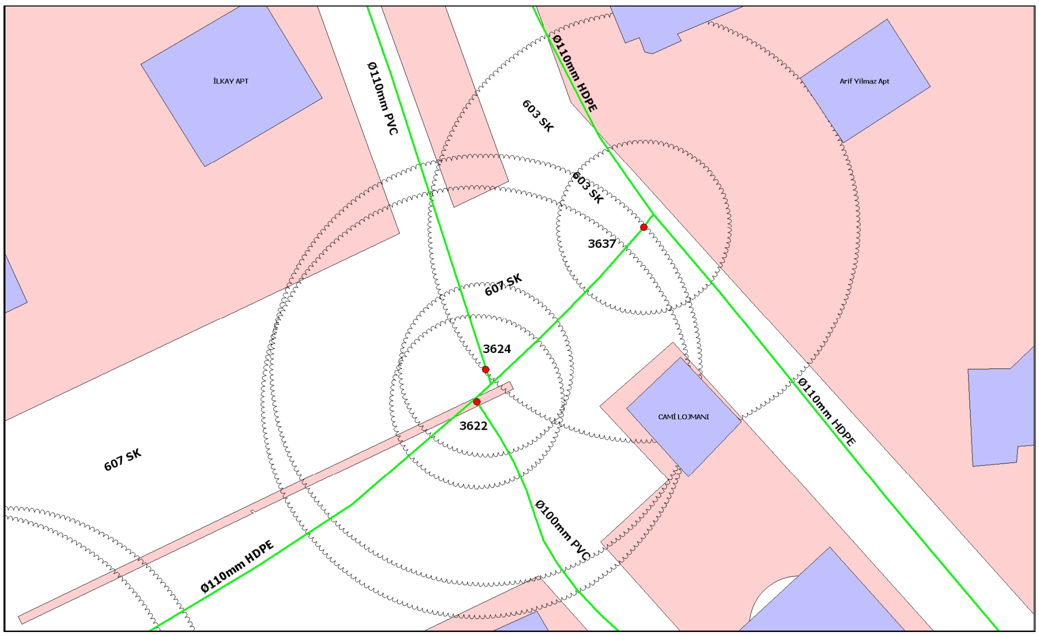


Figure 6.60 Noise Data Logger with Serial Number 3622 Placed On Valve #21037 and Its Corresponding Effective Areas

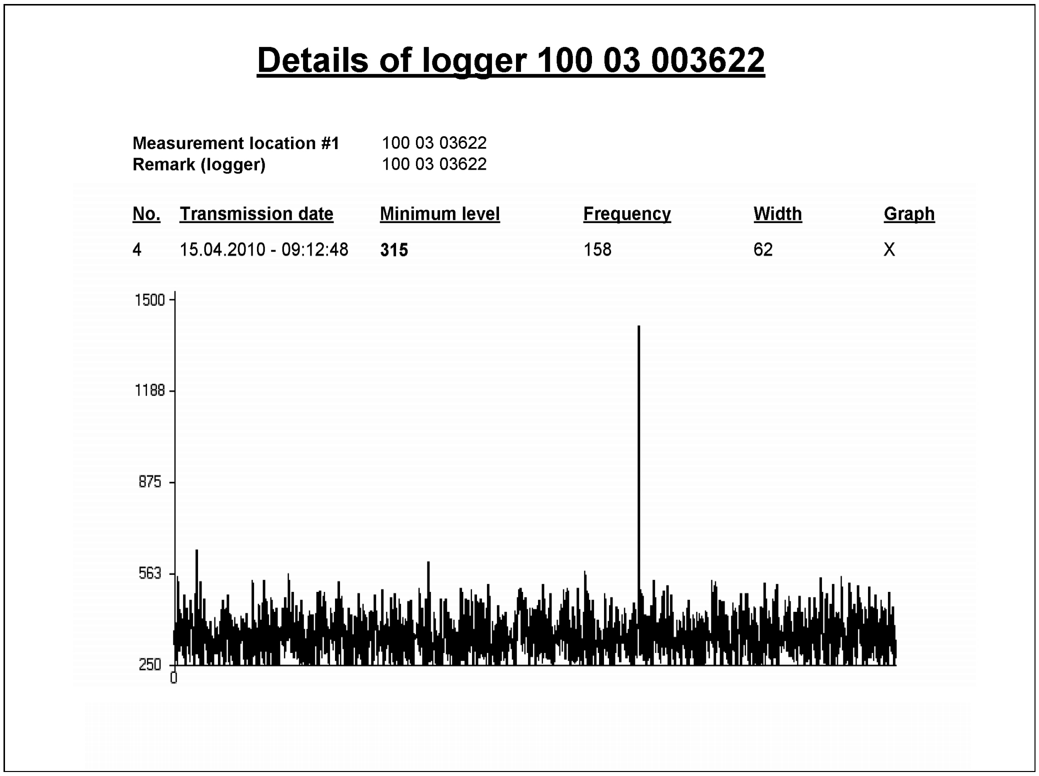


Figure 6.61 Details of Logger with Serial Number 3622 Placed On Valve #21037

6.3.4.2.Ground Microphoning in Logger Ineffective Areas

Ground microphoning is applied to zone 2 when the logger study was still running. This is done due to time limitations. Applying logger first, and according to their results running ground microphone studies requires more than a week's time as the DMA is larger. To cover the whole area in five working days, logger study and ground microphoning were applied as concurrent events. As a matter of fact, logger effective areas were also scanned with ground microphones. The thing to note at this point is that, ground microphoning study did not obviate data logger studies. Data logger studies cleared the way for ground microphoning studies, and ground microphoning studies helped pinpointing of the leaks as a supportive action. In general terms, the methodology was applied on the field completely.

Although running both data logger and ground microphoning studies at the same time, only two thirds of the zone could be listened with the microphones. These regions are A and B (Figure 6.43). For region C, an agreement was done with the water authorities of Antalya, to schedule the ground microphoning crew as soon as possible before the pressures are reduced again. Unfortunately, listening of region C was done about one month later and with reduced pressures. This is figured out by exploring through the previous SCADA records. The pressure was released while working with the noise data loggers. Moreover, this release lasted one week (7 days) only. After 7 days, the pressure is reduced to 3.0 bars and it was not released during the days when region C is said to be listened. This deeply affected the study as no leaks are found in region C. During the logger studies combined with ground microphones in regions A and B a total of 6 water leaks are found and repaired. This event also proved that under high pressures it is easier to find leaks. With 5.5 bars, both ground microphones and data loggers are able to detect leak sounds. However when this pressure is reduced to 3.0 bars, no leaks could be discovered by the microphones.

Ground listening staff examined the regions A and B as stated. They gave extra importance to the alerting points. However, alerts 11, 12 and 13 did not result in a physical water loss. Alerts 8 and 9 turned out to be a leaking point explained below in "Leak 7". Alert 10 was pointing "Leak 6". And alert 14 was an indication of "Leak 11". In the logger ineffective areas, listening crew also was able to pinpoint some leak points. These are named as leaks 8, 9 and 10. They are explained in detail below. In the scanned two thirds of the zone, a total of six leaks were found and repaired.

<u>Leak 6:</u> The alerting spot in front of "Villa Park Apartment" is investigated by the ground microphoning crew (Figure 6.62). Before their listening study, a water bleeding spot at the next building was already seen. That suspicious point turned out to be a water leak at the house connection of "İnci Saray Otel". The repair works were done on 14 April 2010.

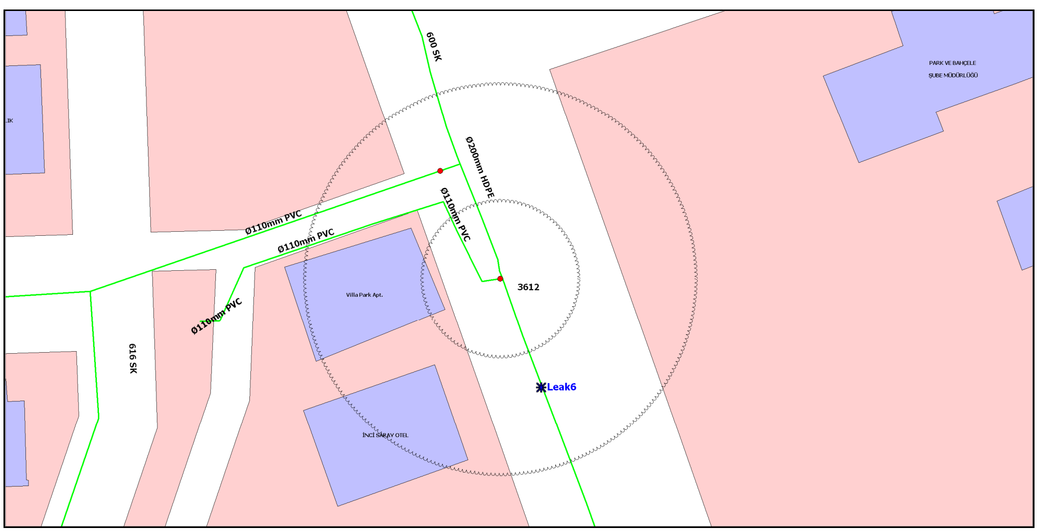


Figure 6.62 Position of leak spot 6 and nearby logger effective areas.

<u>Leak 7:</u> This situation named as "Leak 7" is one of the most interesting situations faced throughout the study in Konyaaltı. When the ground microphoning crew listened the suspicious valves, they faced with a very high sound and pinpointed that most sounding spot. After the excavation not a leaking point was discovered but a corporation cock (priz musluğu in Turkish) was found. This fitting named corporation cock is a valve (mostly a spherical valve) at the connection

between a house connection and a street pipe. This valve was not leaking any water but making sound like a leaking sound. It was checked and seen completely open meaning water was flowing through it. With the careful investigations of the valve and the corresponding house connection after it, it was discovered that none of the buildings were taking water from that pipe. Therefore that valve was closed completely. Again, every nearby building is checked if there was any water shortage or not. None of the customers complained about any water shortage problem. As a result, the valve was left closed and buried. The reason for a ghost valve and a house connection was said to be an old house connection, which is forgotten to be closed after the cancellation of the service pipe. For a long time this house connection was letting water flow (Figure 6.63).

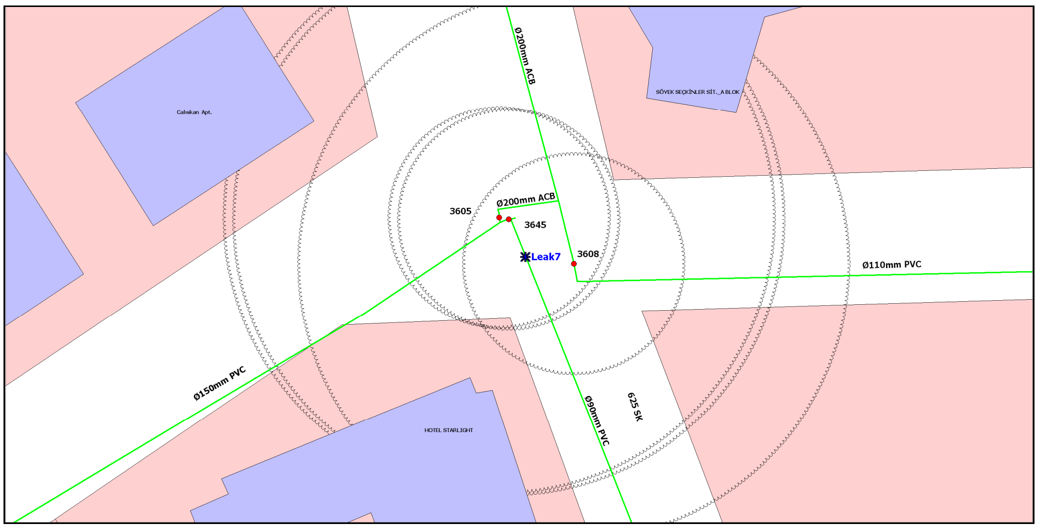


Figure 6.63 Position of leak 7 and the nearby valves with effective areas.

<u>Leak 8:</u> This leak was detected on 621st street on an Ø150mm PVC pipe by the ground microphoning study. The nearest logger placed valve did not receive any leak sound because the leak spot is approximately 70 meters away (Figure 6.64). Leak spot was in front of Baylav Apartment. The failure occurred on the main PVC pipe. Failure reason is reported as the bad workmanship done during the displacement of water pipes. The displacement is done because of the installation of sewerage lines. Unlike most cities in Antalya, this is the common problem. Sewerage lines were installed much later than water lines, and due to displacements of water pipes, failures occur. The failure is repaired on 15 April 2010.

Figure 6.64 Position of leak 8 and the nearby valve with its effective area

Leak 9: This leak was detected on a nearby street as leak 8. It is very far away from the nearest valve (approximately 90 meters). So its sound was not recognized by the data logger at that valve (Figure 6.65). The leak was pinpointed by the ground microphoning crew. On the repair day of 16 April 2010, the failure is seen on the house connection of Yusuf Apartment. The house connection was a low quality pipe, which is called by the workers as “black pipe” due to its colour. It is indeed a black, plastic pipe but its main disadvantage is being a brittle material. Therefore, failure is inevitable on these kinds of pipes. Luckily, they are not being used at all nowadays.

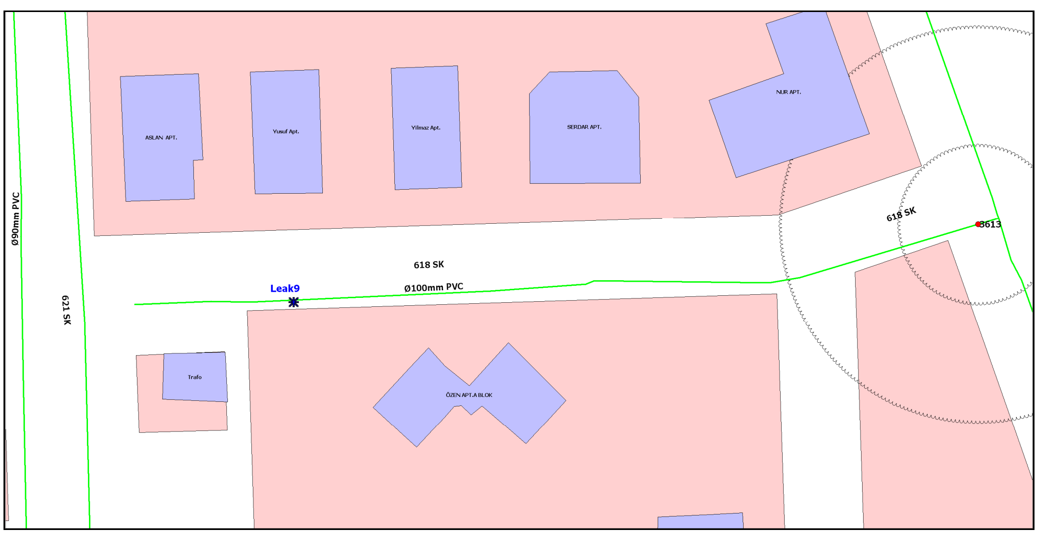


Figure 6.65 Leak spot 9 and the nearby data logger’s effective area.

Leak 10: This leak is pinpointed by the ground microphoning crew again. As seen in Figure 6.66, it is very far to the effective areas of data loggers. The failure was at the house connection of

"Ufuk Sitesi B Blok". It is fixed by the ASAT workers on 16 April 2010.

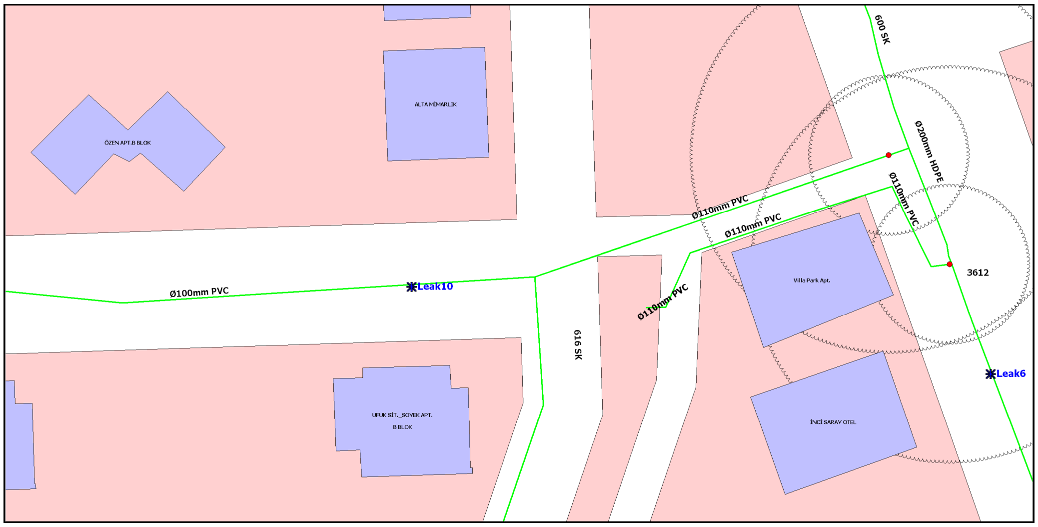


Figure 6.66 Leak spot 10 and the nearby data logger's effective area.

Leak 11: In this final pinpointed leak, the point was detected by the data loggers as alert #14. According to that alert, the leak should be either on Ø110mm HDPE pipe or on Ø100mm PVC pipe. With the careful examination of ground microphone crew, the leak was pinpointed on the house connection of the mosque in 604th street (Figure 6.67). It is again repaired on 16 April 2010.

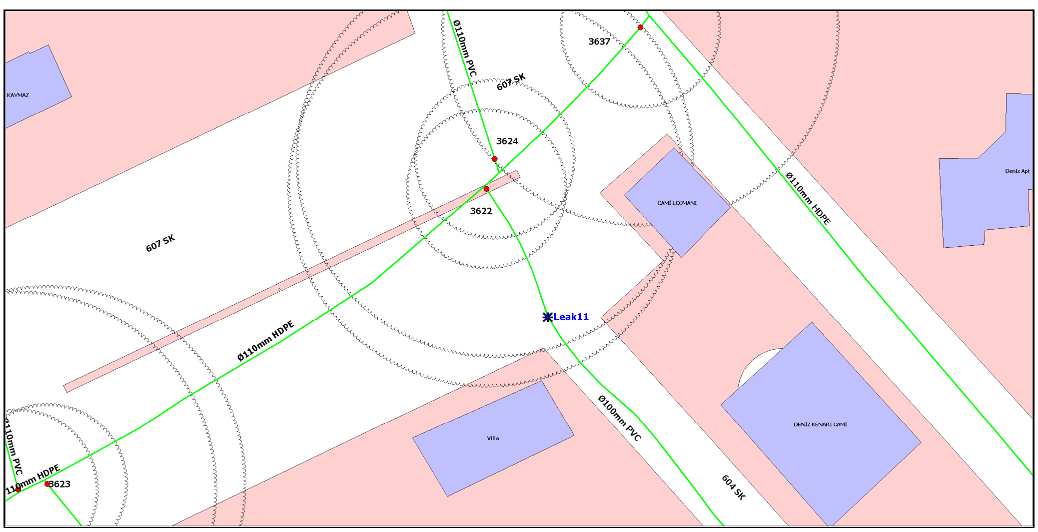


Figure 6.67 Leak spot 11 and the nearby data loggers' effective areas.

6.3.5. Results

In zone 2 of Konyaaltı water distribution network, two major actions have been done to avoid physical water losses. First step was to reduce the pressure of the zone to a constant value. This action was done in August 2009 and its effects are discussed in two aspects. They will be studied below with more detail. As a second step, within the limited working time of one week, physical water loss detection studies are performed. The studies are performed using noise data loggers and ground microphones. To detect and pinpoint the leaks precisely, pressure of the network was released for one week. After fixing the leaks, pressures are lowered again to the constant value.

With applying these two steps of pressure reduction and physical water loss detection studies, a considerable amount of water loss is prevented. In the light of results obtained, it is concluded that applying both pressure management and active leak detection techniques together are indispensible. Two methods are highly effective on their own, however when they are combined, their effects increase.

To examine the graphs and results below, it may be necessary to recall the actions done in the DMA; that are summarized in Table 6.18 and Table 6.19.

Table 6.18 Applied Pressure Regulations on Zone 2 with Their Dates and Times

Applied Action	Date and Time
Pressure Reduction from 5.5 bars to 3.6 bars	12.08.2009 – 11:30
Pressure Reduction from 3.6 bars to 3.0 bars	28.09.2009 – 10:00
Pressure Release from 3.0 to 5.5 bars	12.04.2010 – 14:10
Pressure Reduction from 5.5 bars to 3.0 bars	19.04.2010 – 10:50

Table 6.19 Leaks, Their Regions, Discovery Methods and Repair Dates

Leaks	Region	Discovery Method	Repair Date
6	A	Logger + G. Microphone	14.04.2010
7	A	Logger + G. Microphone	14.04.2010
8	A	G. Microphone	15.04.2010
9	A	G. Microphone	16.04.2010
10	A	G. Microphone	16.04.2010
11	B	Logger + G. Microphone	16.04.2010

The effects of pressure reduction done in 2009 are studied in earlier chapters. To see the effect of pressure release followed by the leak repairs, the daily demand curves of the DMA between 11 April and 20 April should be examined. They are given below in Figure 6.68 to Figure 6.77.

First thing that draws attention from the daily demand curves is the rise of discharge values with the released pressure. On 11 and 12 April 2010, minimum night flow values are on 36 m^3/h level (Figure 6.68 and Figure 6.69). When the pressures are released, this value jumps up immediately to 49.3 m^3/h (Figure 6.70). This means that an additional loss of 13 m^3/h is created by releasing the pressure from 3 bars to 5 – 5.5 bars.

With the detection of physical water losses and repairing them, minimum night flow values decrease gradually day by day. They are clearly seen in each day's daily demand curve. Total decrease is from 49.3 m^3/h to 38.6 m^3/h avoiding a water loss of 10.7 m^3/h (Figure 6.71 to Figure 6.77). The only exceptional day to this gradual decrease is 18 April 2010. According to the SCADA records, a higher minimum night flow is observed on 18 April when compared to 17 April. That can be interpreted as a false minimum night flow value. At that night, the customers showed high night usage, so the SCADA records were not able to capture the minimum night flow values.

Another thing that is worth mentioning is the short periods of discharge and pressure recordings of zero values. These are seen on 14, 15 and 16 April 2010. These shortages are generated by the workers of ASAT, in order to fix the leaks. Short periods of announced water shortages help the workers to fix the leaks quicker.

Similarly, when the pressure is reduced down to 3.0 bars again, a drop of 9.3 m^3/h is observed. It is clearly seen when 19 April and 20 April graphs are examined. Therefore, both pressure reduction and active water leak detection are actions worth doing to prevent water losses (Figure 6.77).

In Figure 6.78, the effects of overall actions on the DMA can be seen in a single graph. Starting from 12 April, first the pressures are released. Then repairs are done in the network dropping the minimum night flows. Lastly, pressures are again reduced and a drop in minimum night flows occurred again.

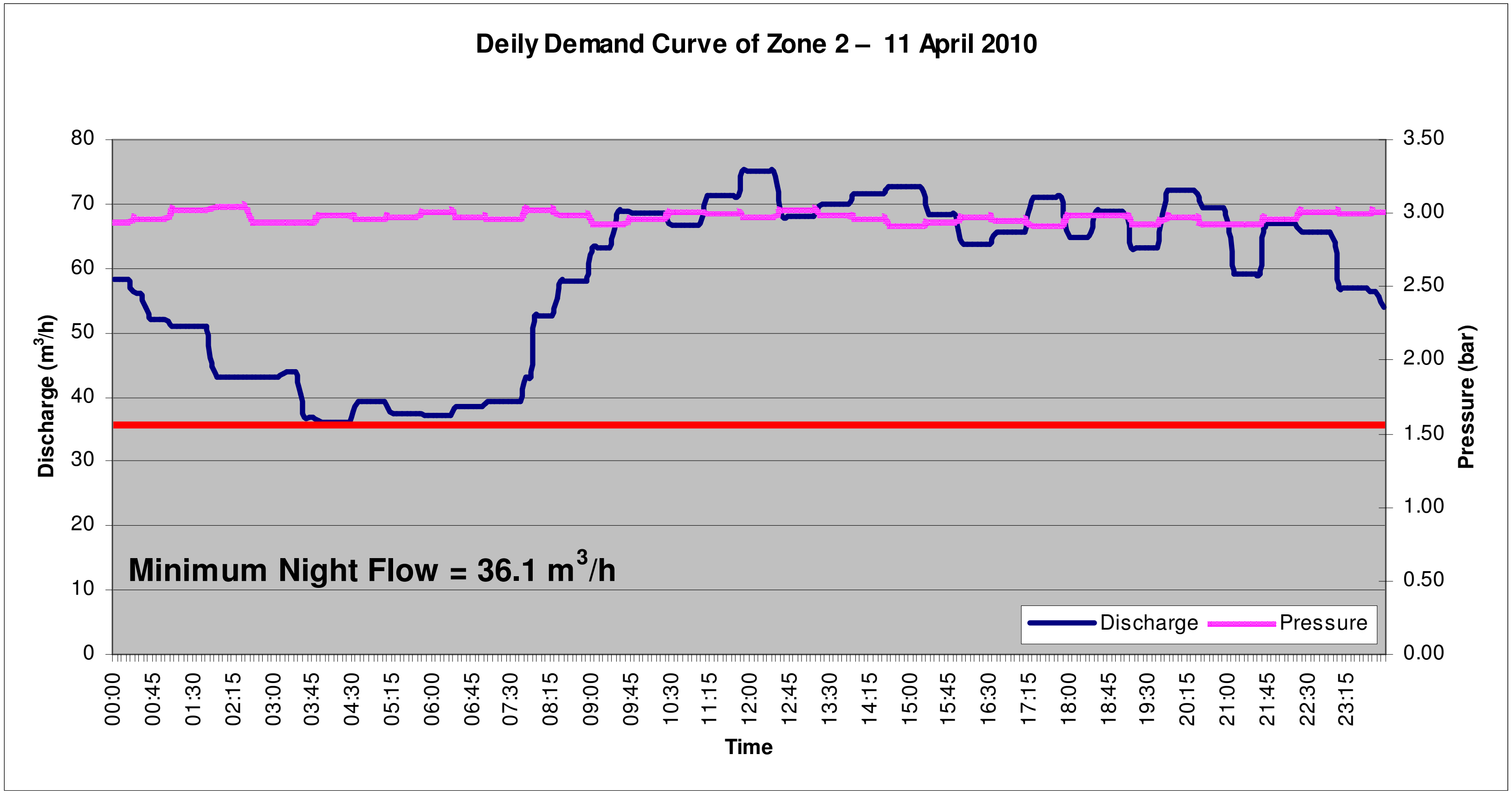


Figure 6.68 Daily Demand Curve of Zone 2 on 11.04.2010

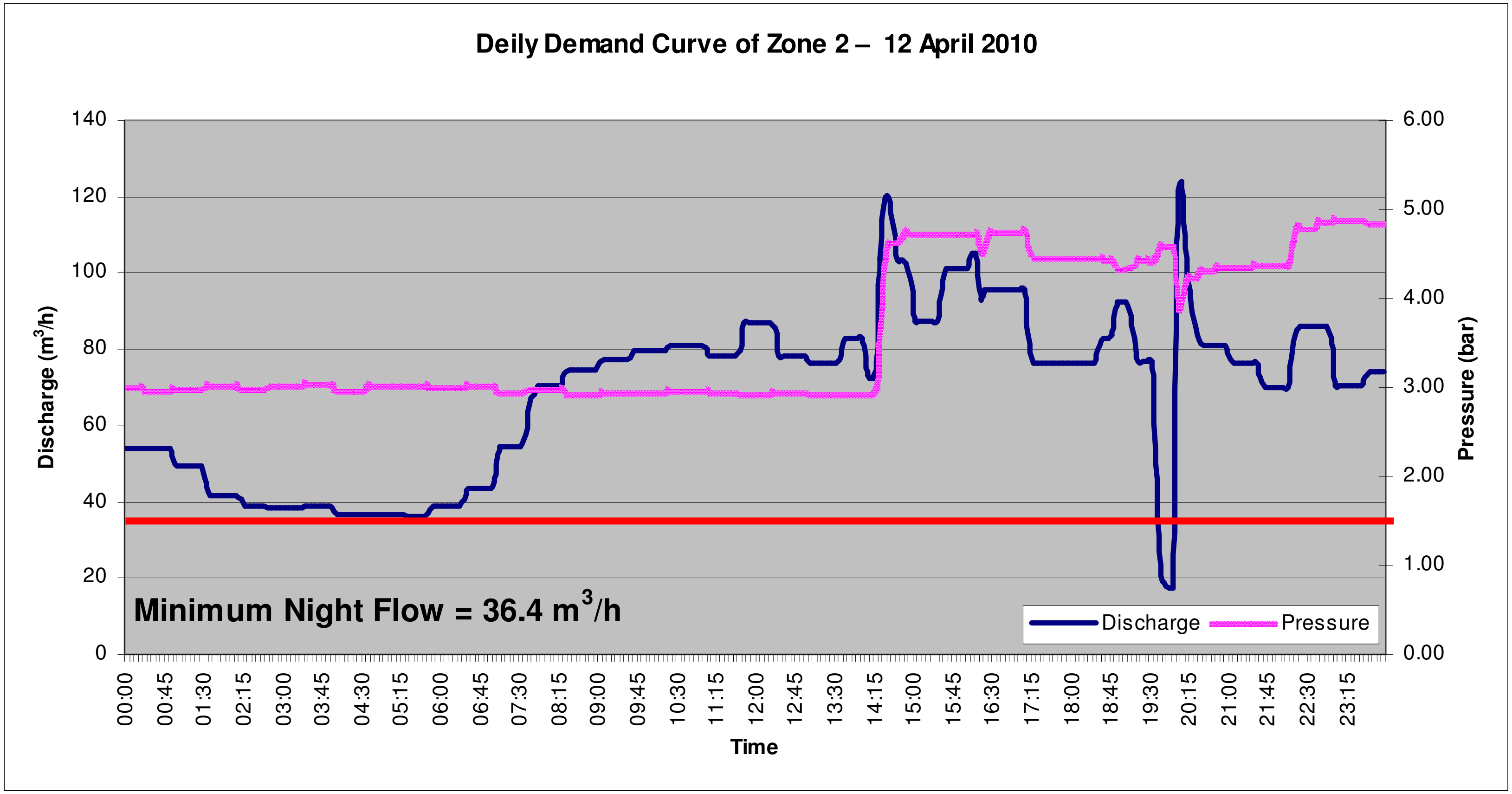


Figure 6.69 Daily Demand Curve of Zone 2 on 12.04.2010

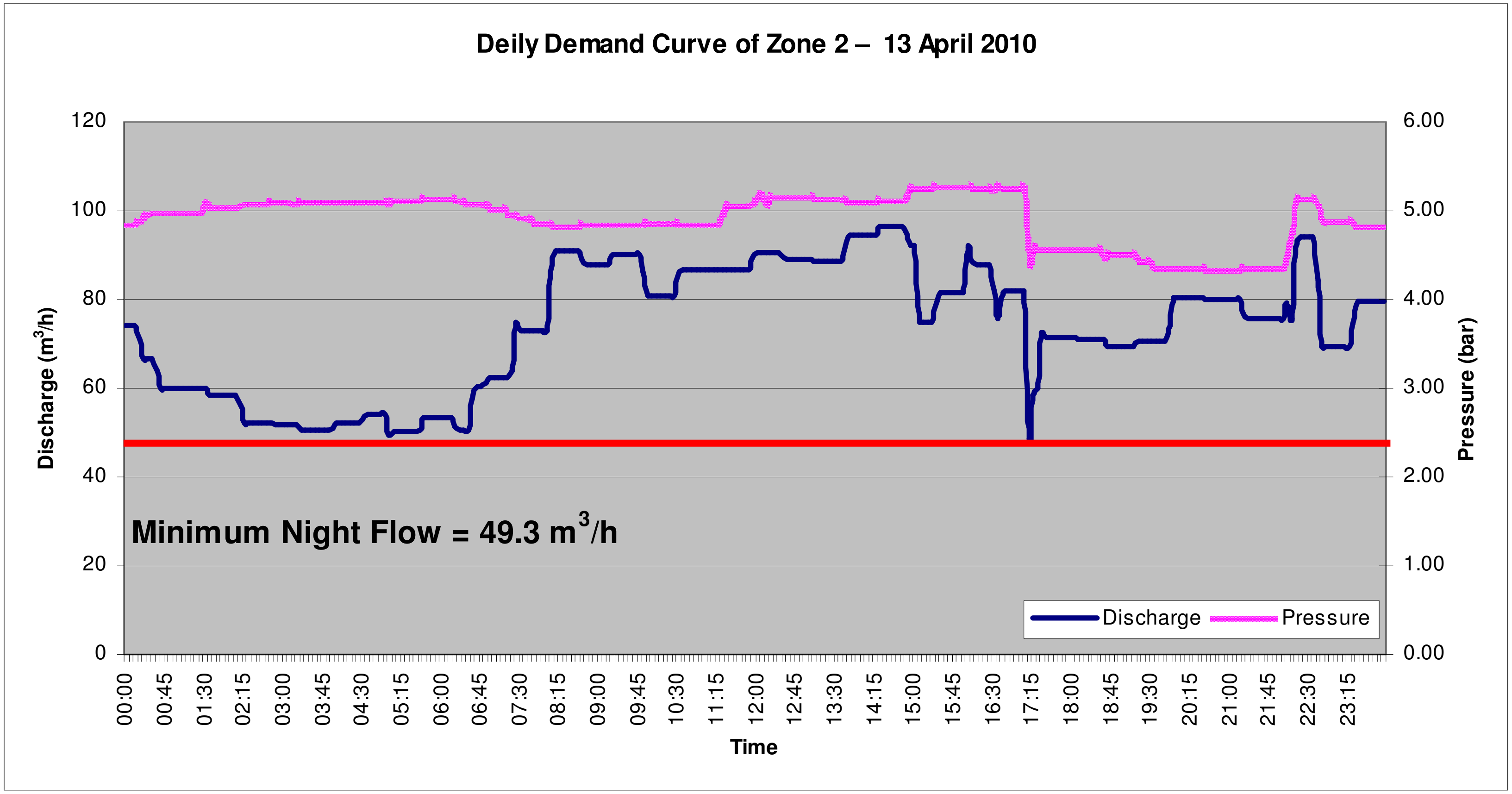


Figure 6.70 Daily Demand Curve of Zone 2 on 13.04.2010

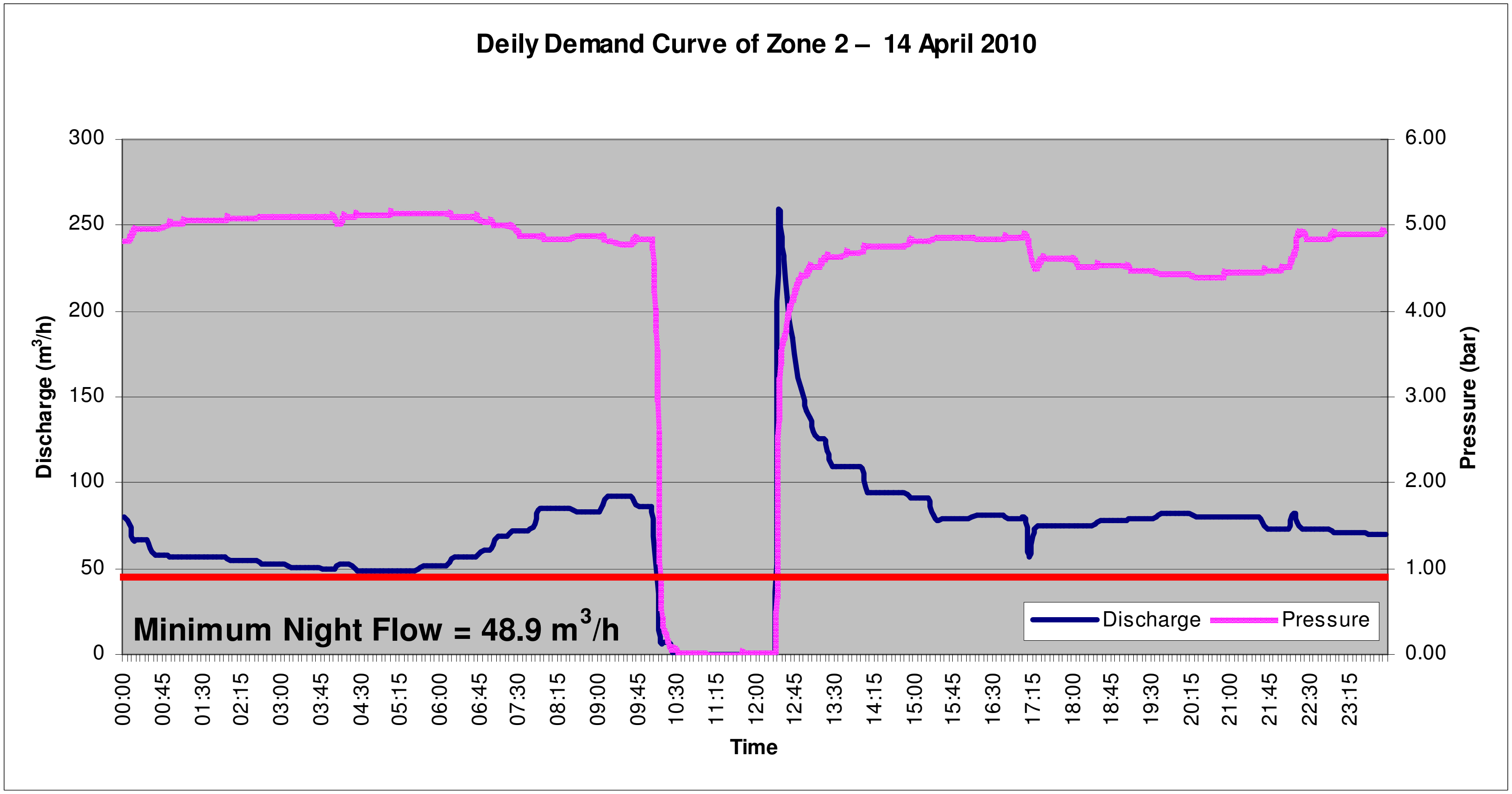


Figure 6.71 Daily Demand Curve of Zone 2 on 14.04.2010

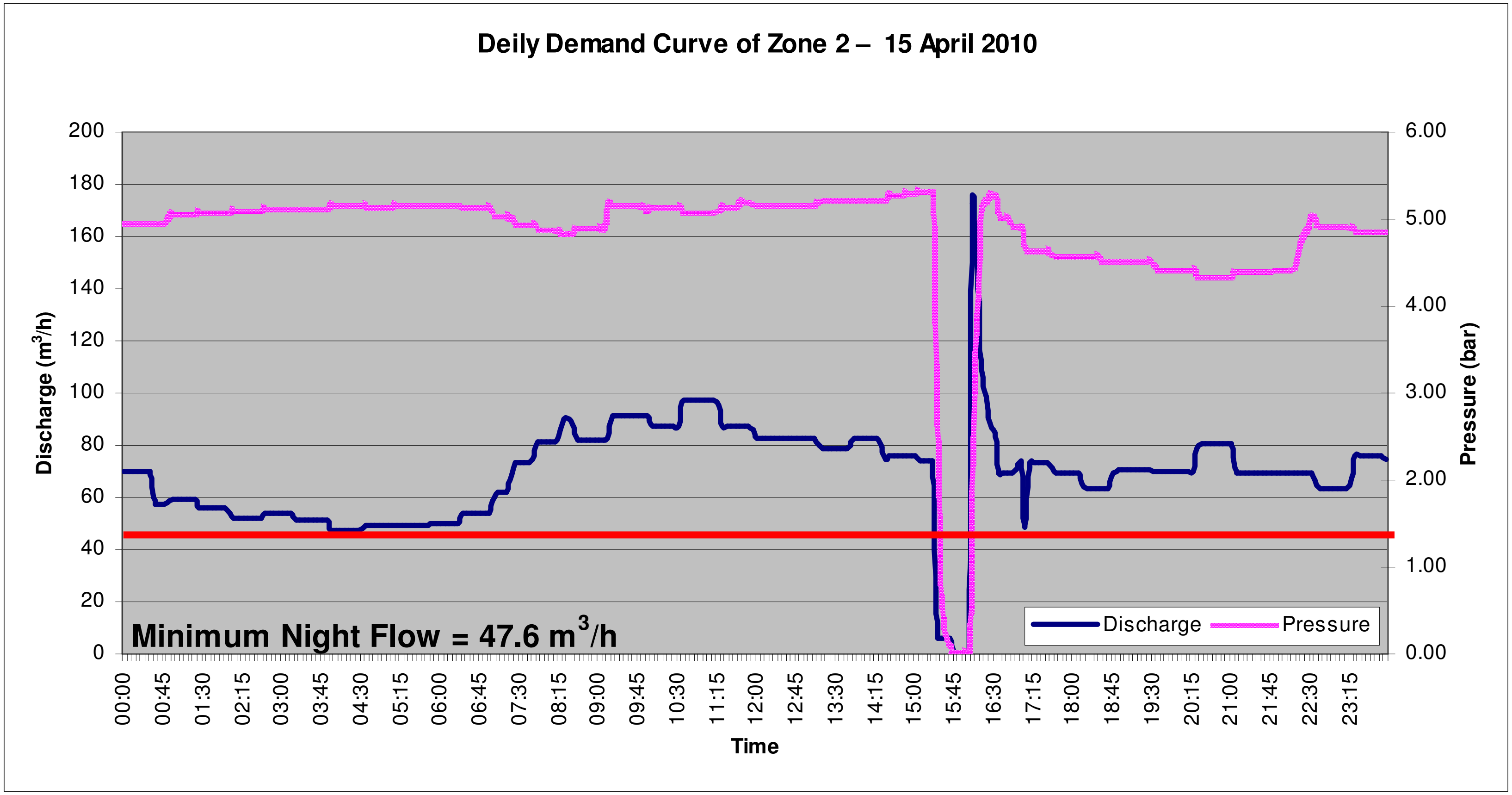


Figure 6.72 Daily Demand Curve of Zone 2 on 15.04.2010

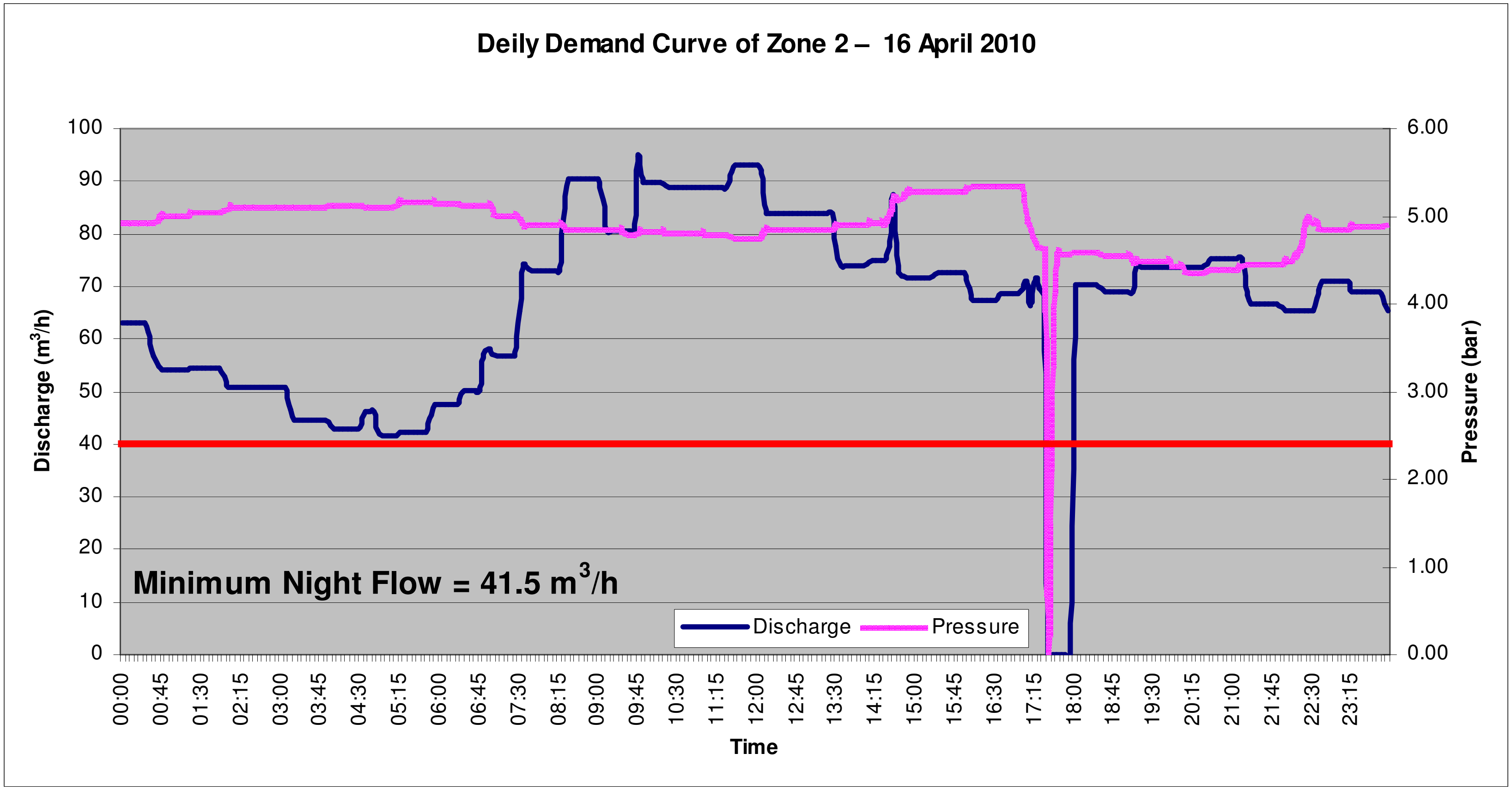


Figure 6.73 Daily Demand Curve of Zone 2 on 16.04.2010

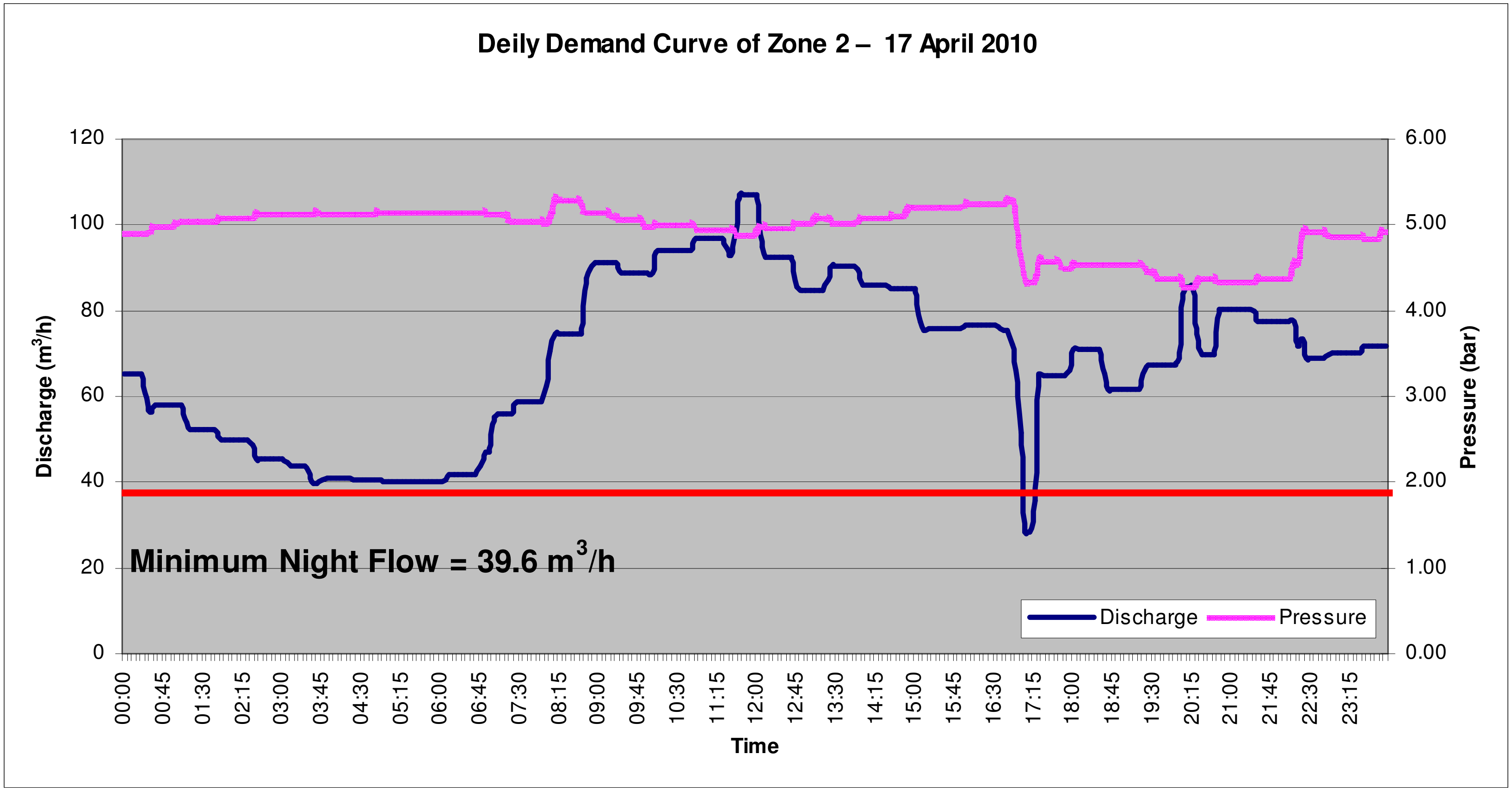


Figure 6.74 Daily Demand Curve of Zone 2 on 17.04.2010

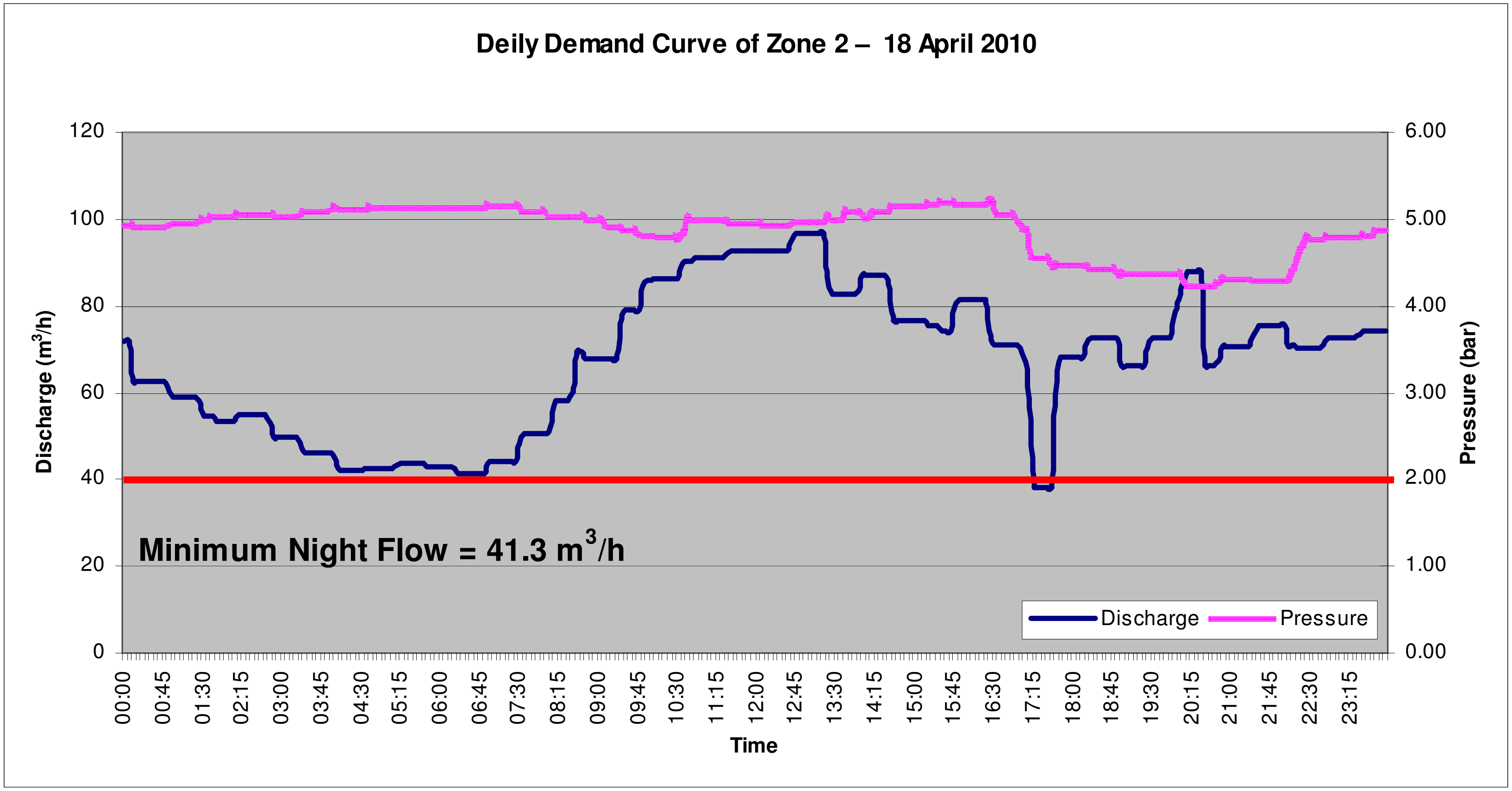


Figure 6.75 Daily Demand Curve of Zone 2 on 18.04.2010

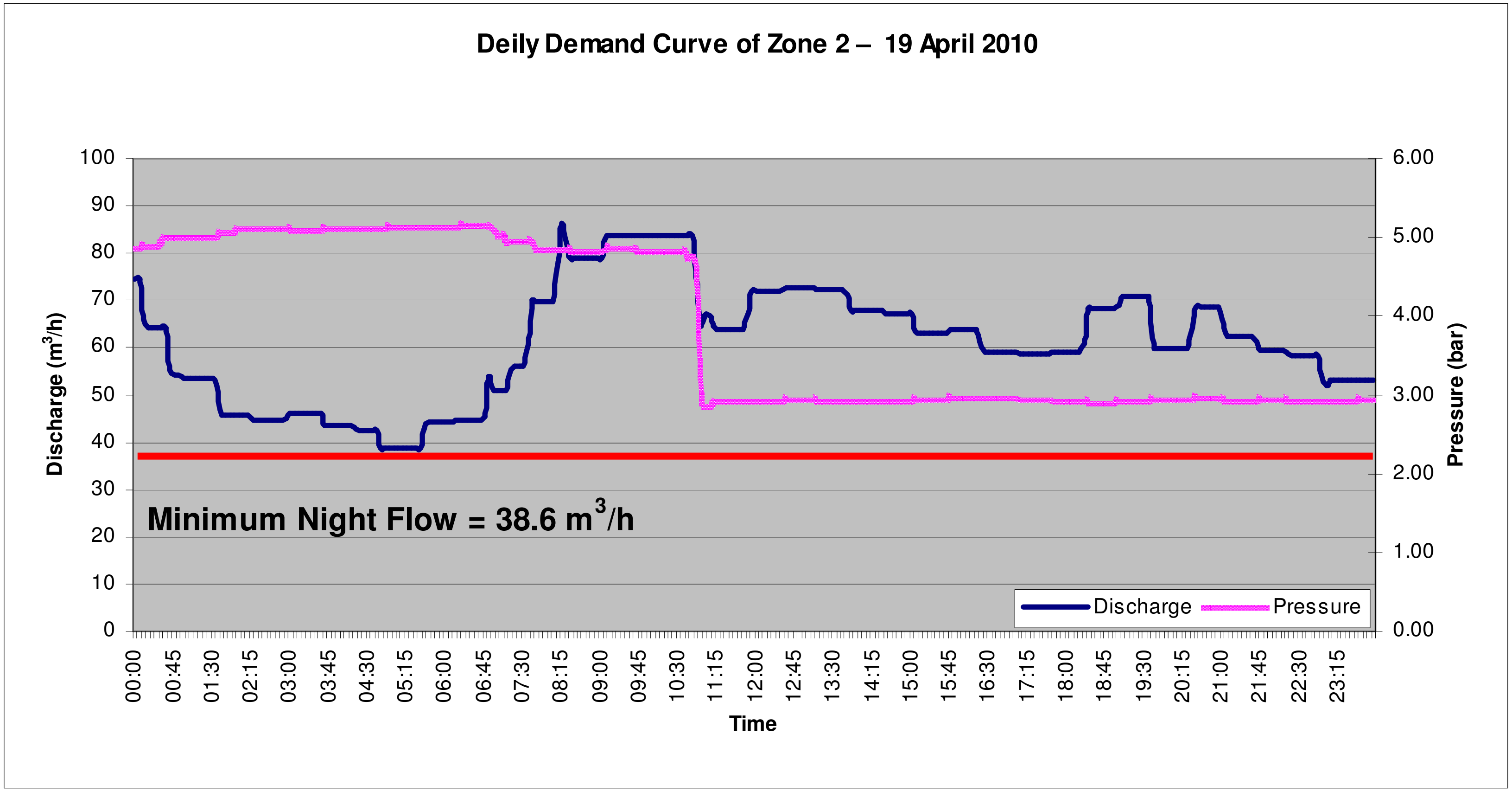


Figure 6.76 Daily Demand Curve of Zone 2 on 19.04.2010

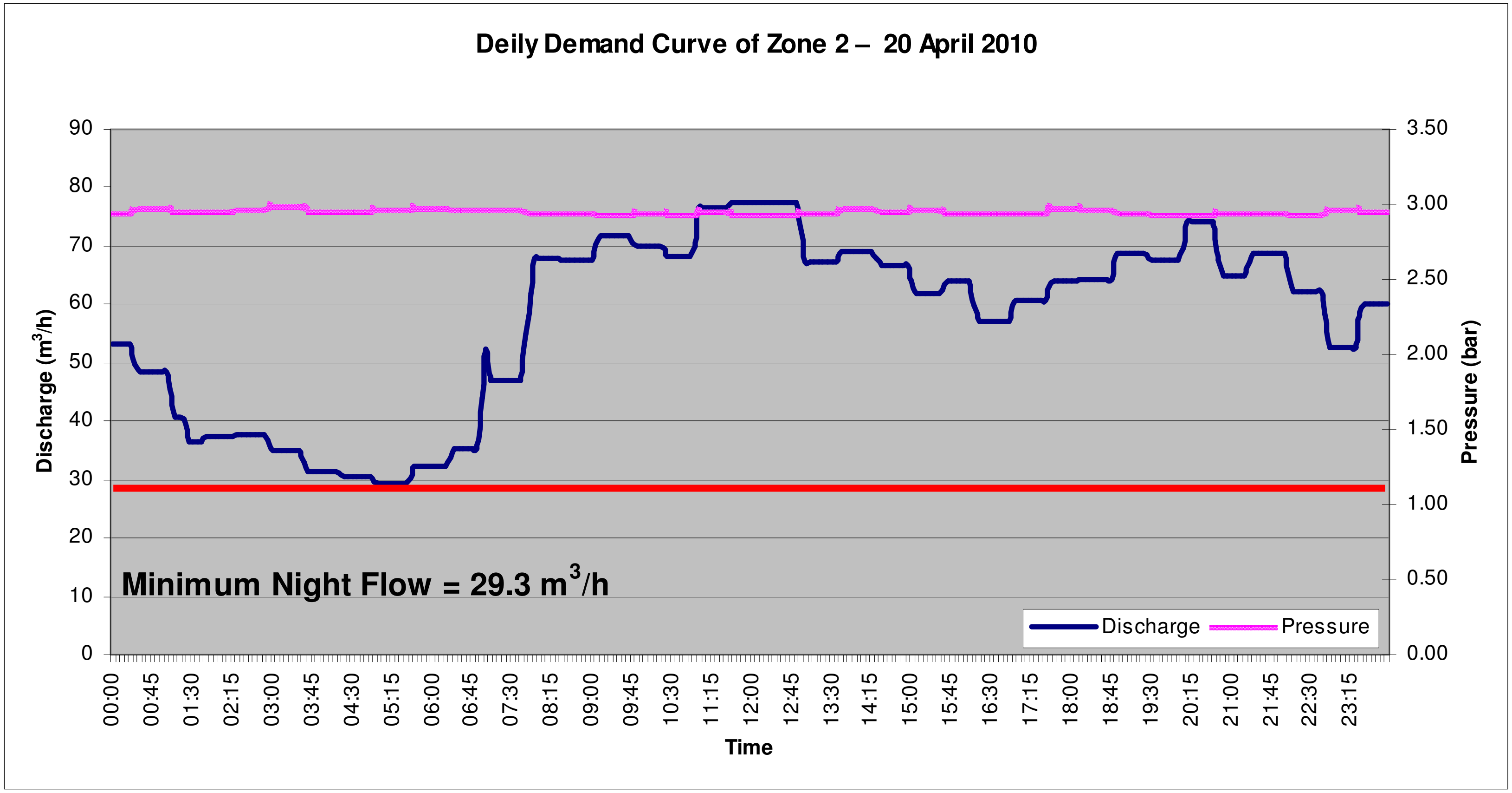


Figure 6.77 Daily Demand Curve of Zone 2 on 20.04.2010

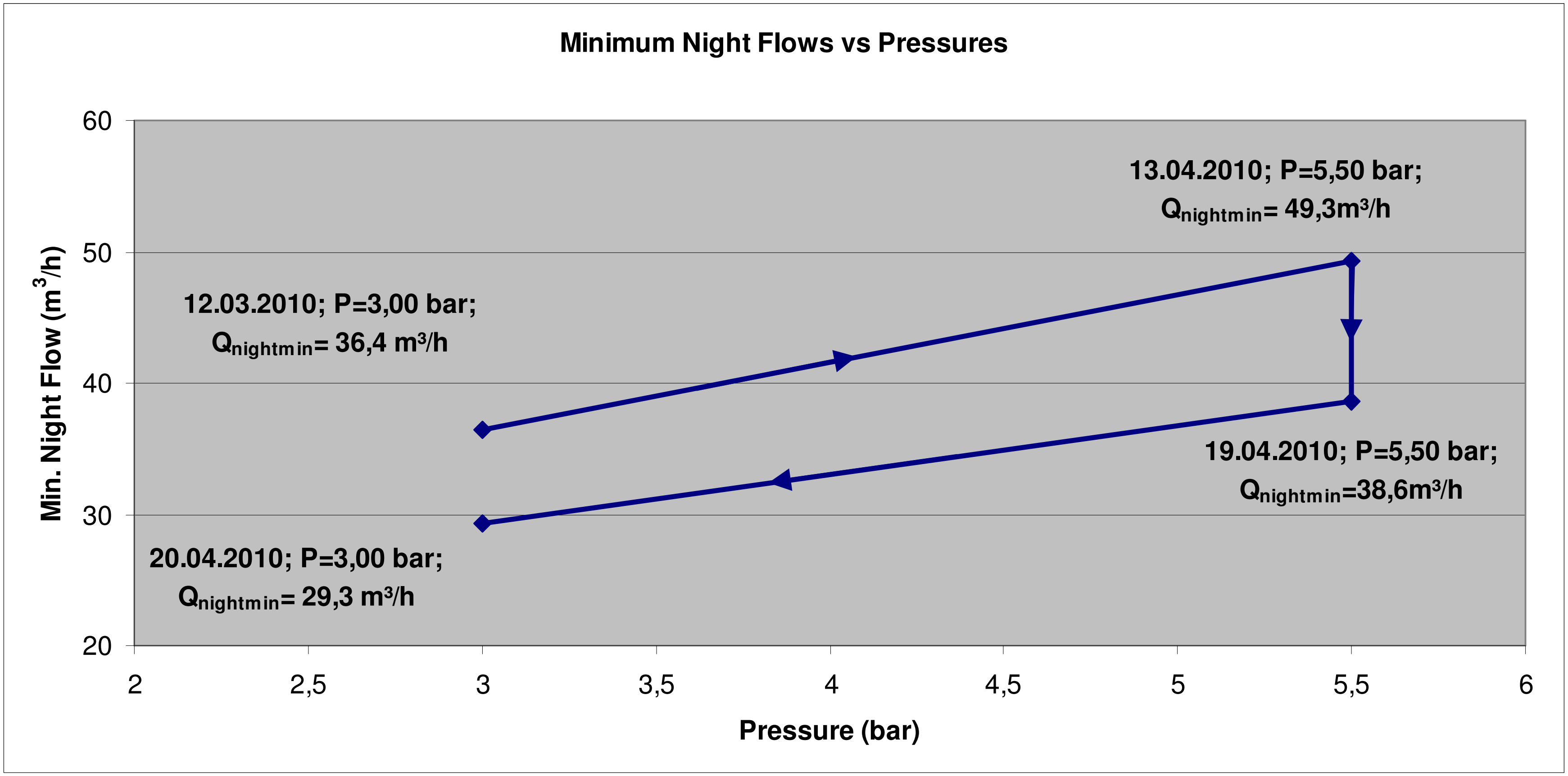


Figure 6.78 Minimum Night Flows vs. Pressures in Zone 2 before and after the Field Studies

Considering the values in Figure 6.78, 12.9 m^3/h loss is prevented just by reducing pressure. That is a drop of 26%. With the leaks fixed only, a drop of 10.7 m^3/h is achieved in minimum night flows. That is a drop of 21.7%. With the actions done together, a drop of 7.1 m^3/h is obtained from 36.4 m^3/h value at the 3 bar level. That corresponds to a drop of 19.5%. To examine day-by-day changes in minimum night flows and total water entering to the zone, Table 6.20 is given below.

Table 6.20 SCADA Summary Table for Zone 2

Date	Days	Water Entering to Zone 6 (m^3)	Minimum Night Flow (m^3/h)	Minimum Flow Time	Total Lost Water (m^3)	Water Loss / Total Flow (%)
01.03.10	Mon	1370	32,9	03:05	789,61	57,636
02.03.10	Tue	1330	31,8	05:20	762,42	57,325
03.03.10	Wed	1388	32,1	05:05	771,09	55,554
04.03.10	Thu	1362	34,7	02:25	833,67	61,209
05.03.10	Fri	1310	32,6	05:25	782,81	59,757
06.03.10	Sat	1410	31,9	05:05	766,41	54,355
07.03.10	Sun	1390	34,9	05:35	838,13	60,297
08.03.10	Mon	1340	33,3	04:50	799,69	59,678
09.03.10	Tue	1400	32,1	04:30	769,92	54,994
10.03.10	Wed	1400	32,1	05:05	770,39	55,028
11.03.10	Thu	1418	33,7	04:45	809,77	57,106
12.03.10	Fri	1482	33,7	05:20	809,53	54,624
13.03.10	Sat	1400	31,4	04:50	754,22	53,873
14.03.10	Sun	1360	29,5	04:50	707,58	52,028
15.03.10	Mon	1390	30,9	04:30	742,73	53,434
16.03.10	Tue	1400	34,9	04:20	838,59	59,900
17.03.10	Wed	1370	32,2	05:20	772,97	56,421
18.03.10	Thu	1380	31,8	05:05	762,66	55,265
19.03.10	Fri	1400	31,9	04:50	765,00	54,643
20.03.10	Sat	1420	31,1	04:35	746,95	52,602
21.03.10	Sun	1410	32,4	04:35	777,19	55,120
22.03.10	Mon	1370	32,8	04:45	787,27	57,465
23.03.10	Tue	1400	32,7	02:40	783,75	55,982
24.03.10	Wed	1400	34,2	02:30	819,84	58,560
25.03.10	Thu	1400	31,9	04:15	765,94	54,710
26.03.10	Fri	1455	34,7	03:10	833,44	57,281
27.03.10	Sat	1445	32,4	03:45	777,19	53,785
28.03.10	Sun	1330	34,7	06:35	832,73	62,612
29.03.10	Mon	1420	31,6	04:10	757,50	53,345
30.03.10	Tue	1400	30,3	05:25	726,33	51,881
31.03.10	Wed	1400	32,3	04:45	775,03	55,359
01.04.10	Thu	1427	33,3	05:45	799,22	56,007
02.04.10	Fri	1433	33,4	04:20	800,86	55,887
03.04.10	Sat	1460	31,9	05:40	766,64	52,510
04.04.10	Sun	1530	34,6	04:35	830,63	54,289
05.04.10	Mon	1510	33,9	04:15	814,69	53,953

Table 6.20 Continued

06.04.10	Tue	1440	32,2	04:50	772,73	53,662
07.04.10	Wed	1400	31,9	05:15	766,41	54,743
08.04.10	Thu	1480	33,3	05:15	800,39	54,080
09.04.10	Fri	1467	33,2	04:45	797,34	54,352
10.04.10	Sat	1463	34,2	04:20	820,31	56,071
11.04.10	Sun	1422	36,1	03:55	865,31	60,852
12.04.10	Mon	1644	36,4	05:20	872,81	53,091
13.04.10	Tue	1774	49,3	05:00	1182,66	66,666
14.04.10	Wed	1660	49,0	05:00	1176,47	70,872
15.04.10	Thu	1690	47,6	03:55	1143,52	67,664
16.04.10	Fri	1630	41,5	04:55	996,33	61,124
17.04.10	Sat	1630	39,6	03:35	950,63	58,321
18.04.10	Sun	1640	41,3	06:20	990,70	60,409
19.04.10	Mon	1500	38,6	04:45	926,25	61,750
20.04.10	Tue	1350	29,3	05:00	702,66	52,049
21.04.10	Wed	1360	28,3	05:45	680,39	50,029
22.04.10	Thu	1400	30,9	05:00	742,50	53,036
23.04.10	Fri	1500	30,7	05:40	736,88	49,125
24.04.10	Sat	1490	35,4	03:55	848,91	56,974
25.04.10	Sun	1450	31,6	05:40	757,27	52,225
26.04.10	Mon	1388	29,7	04:10	712,03	51,299
27.04.10	Tue	1362	29,7	05:05	712,97	52,347
28.04.10	Wed	1400	26,9	04:50	645,70	46,122
29.04.10	Thu	1370	31,8	05:05	762,66	55,668
30.04.10	Fri	1322	31,1	05:15	746,02	56,431
01.05.10	Sat	1358	28,0	04:40	673,13	49,567
02.05.10	Sun	1450	32,1	05:10	770,86	53,163
03.05.10	Mon	1450	30,9	05:10	742,03	51,175
04.05.10	Tue	1430	30,3	04:45	726,56	50,809
05.05.10	Wed	1420	29,7	04:50	711,80	50,127
06.05.10	Thu	1400	30,9	04:50	741,56	52,969
07.05.10	Fri	1380	31,6	04:15	757,97	54,925
08.05.10	Sat	1390	28,5	04:40	685,08	49,286
09.05.10	Sun	1380	28,9	04:40	693,28	50,238
10.05.10	Mon	1464	29,6	04:35	710,86	48,556
11.05.10	Tue	1536	33,7	04:50	809,06	52,673
12.05.10	Wed	1570	32,3	04:55	774,84	49,353
13.05.10	Thu	1530	34,7	04:50	832,73	54,427
14.05.10	Fri	1550	32,5	04:40	779,30	50,277
15.05.10	Sat	1510	33,1	05:30	794,40	52,609
16.05.10	Sun	1494	33,1	04:40	793,36	53,103
17.05.10	Mon	1516	33,2	05:00	796,41	52,533
18.05.10	Tue	1380	32,5	04:40	781,03	56,596
19.05.10	Wed	1430	30,5	04:35	731,95	51,186
20.05.10	Thu	1420	30,7	03:15	736,64	51,876
21.05.10	Fri	1400	31,1	05:30	746,95	53,354
22.05.10	Sat	1360	29,5	05:35	708,98	52,131
23.05.10	Sun	1360	31,2	04:25	748,59	55,044
24.05.10	Mon	1450	30,2	05:35	723,75	49,914
25.05.10	Tue	1390	30,8	06:05	738,28	53,114

Table 6.20 Continued

26.05.10	Wed	1408	29,3	04:45	703,36	49,955
27.05.10	Thu	1405	29,4	04:40	704,53	50,145
28.05.10	Fri	1477	26,1	04:30	625,55	42,353
29.05.10	Sat	1520	30,5	06:05	732,19	48,170
30.05.10	Sun	1480	31,4	05:35	754,22	50,961
31.05.10	Mon	1450	32,8	03:30	787,27	54,294

In Figure 6.79 below daily total water entering to zone 2 and minimum night flows for each day are plotted. It is seen that with the increasing pressure, the values show a great increase for one week. The decrease in minimum night flows from 30 – 35 m^3/h level to 25 – 30 m^3/h level is seen in the graph too.

Figure 6.80 describes better the decrease in water loss percentages. Before this study, the water loss percentages were at a range of 55% – 60 %. During the study week, it is seen as high as 70%. After fixing the leaks and reducing the pressure, the leak percentages drop down to 50% – 55%. That is a drop of 5% showing the effect of active studies.

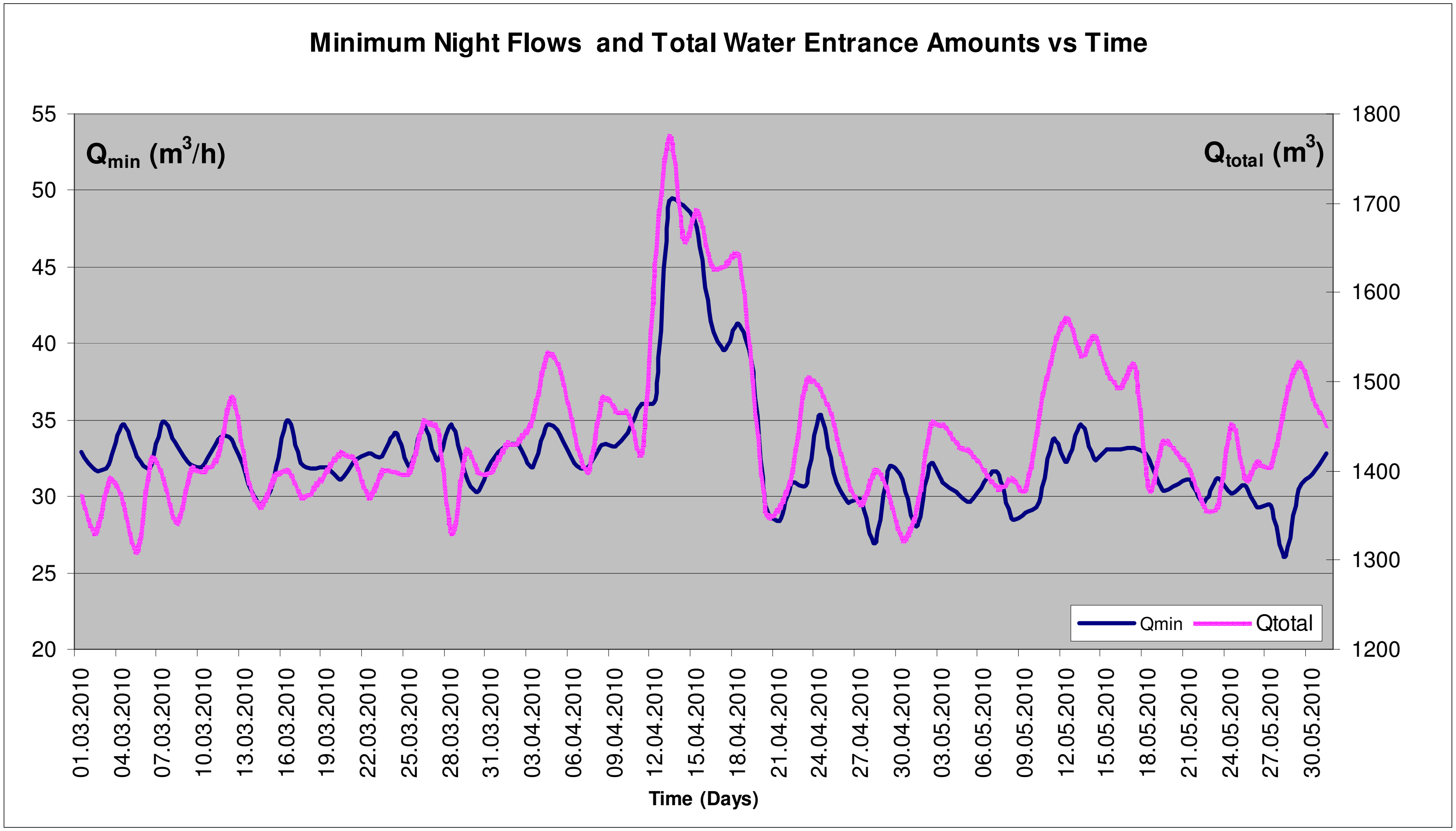


Figure 6.79 Total Water Entering and Minimum Night Flow Values vs. Days

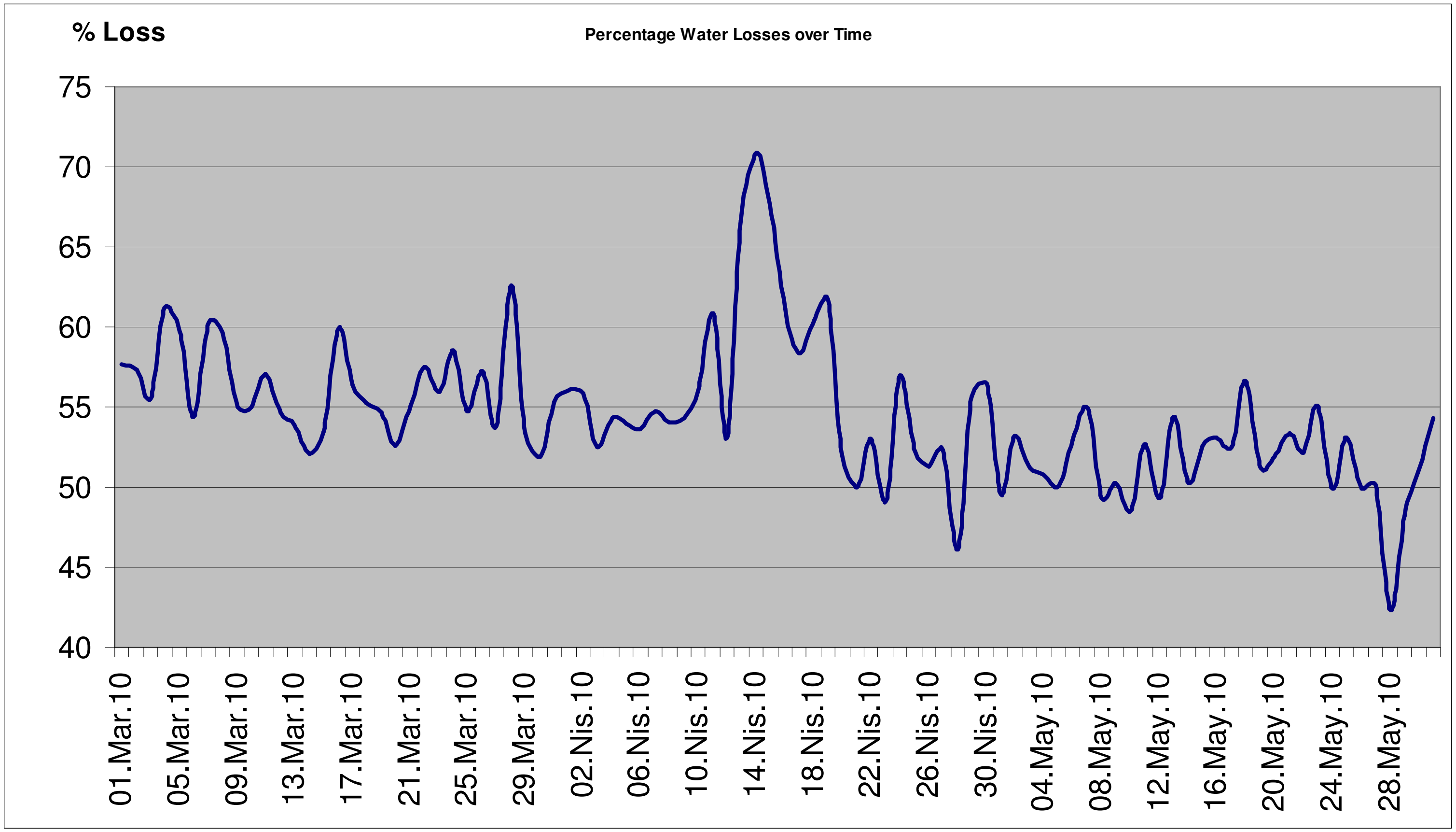


Figure 6.80 Water Loss Percentages vs. Days

To check the revenue ratios, Table 6.21 and Figure 6.81 are given below. When the table is examined, the pressure regulation in 2009 can be seen clearly on August and September months. Revenue percentages increased from 55% level up to 70% level by pressure reduction. Also daily average water entering to the zone decreased from 2000 m^3/day level down to 1500 m^3/day level. However, the effects of active leak detection studies are not so distinct in both the table and the graph. An increase of 3.64% from 2010/4 period to 2010/5 period may indicate the leak detection studies. But the previous period does show an opposite reaction which is a 3% decrease from 2010/3 period to 2010/4 period. This may be because; active leak detection studies are performed in mid April. Therefore the effects of them can only be seen in the second half of April consumptions which may not be visible in 2010/4 period.

Table 6.21 Monthly Revenue Percentages

SCADA DATA				CIS DATA			Monthly Revenue Percentages (%)
Dates	Days	Water Entering to Zone 6 (m^3)	Average Daily Water Entering to Zone 6 (m^3)	Period	Period's Total Revenue (m^3)	Daily Average Revenue (m^3)	
A	*B*	*C*	*D = C / B*	*E*	*F*	*G*	*H = 100xG/D*
01.06.09 - 30.06.09	30	57700	**1923,33**	2009/6	31865	**1036,30**	**53,88**
01.07.09 - 31.07.09	31	67750	**2185,48**	2009/7	36597	**1206,64**	**55,21**
01.08.09 - 31.08.09	31	59240	**1910,97**	2009/8	47333	**1312,67**	**68,69**
01.09.09 - 30.09.09	30	49360	**1645,33**	2009/9	29740	**1168,73**	**71,03**
01.10.09 - 31.10.09	31	47508	**1532,52**	2009/10	31947	**1089,07**	**71,06**
01.11.09 - 30.11.09	30	43172	**1439,07**	2009/11	29291	**990,33**	**68,82**
01.12.09 - 31.12.09	31	42770	**1379,68**	2009/12	25952	**845,39**	**61,27**
01.01.10 - 31.01.10	31	41900	**1351,61**	2010/1	27026	**847,94**	**62,74**
01.02.10 - 28.02.10	28	38150	**1362,50**	2010/2	22693	**800,33**	**58,74**
01.03.10 - 31.03.10	31	43150	**1391,94**	2010/3	24003	**860,68**	**61,83**
01.04.10 - 30.04.10	30	44600	**1486,67**	2010/4	28337	**874,41**	**58,82**
01.05.10 - 31.05.10	31	44750	**1443,55**	2010/5	27897	**901,68**	**62,46**
(01.06.09 - 31.05.10)	365	535300	**1466,58**	2009/6 - 2010/5	362681	-	**67.75**

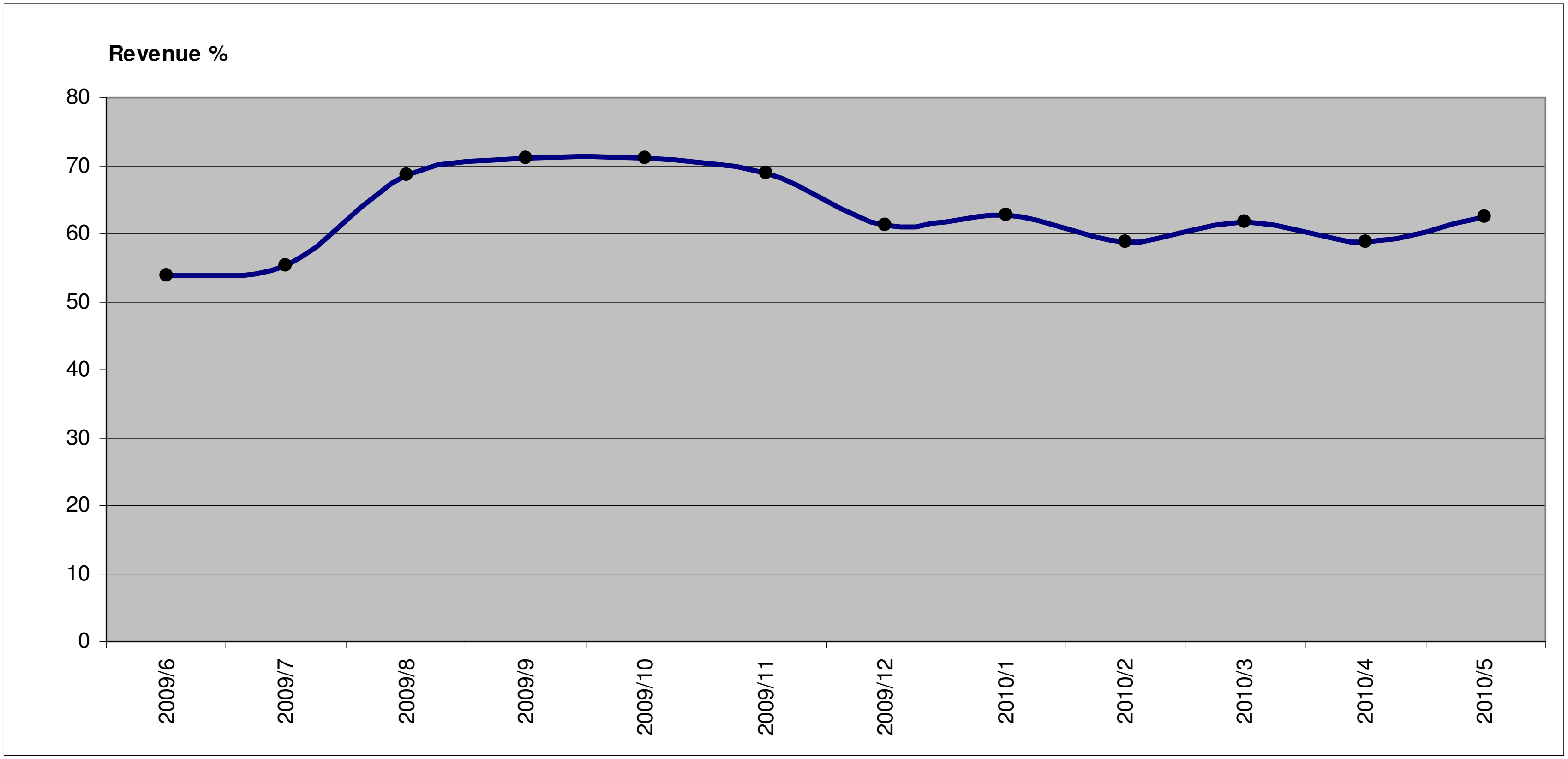


Figure 6.81 Revenue Percentages over Periods

CHAPTER 7

DISCUSSION OF RESULTS

The importance of controlling water losses revealed itself before, during and after the field studies. At the beginning, calculated physical water loss amounts of more than 50% showed the fact that considerable losses (potable water loss, electricity loss, efforts spent for treating water, etc.) do occur. After all, it does not seem reasonable to provide 100 units of water knowing that at least 50 units is being lost and not taking any action against this issue for years.

In order to fight against physical water losses, basically there are two methods. One is to detect point losses using standard procedure(s) and then fixing the leaks. The second is based on pressure management. In fact, these two methods are complementary.

During Antalya case studies, it was possible to make controlled experiments with two networks (subzone 2 and subzone 6 of Konyaaltı pressure zone); the two study areas were similar. The essential difference was that, pressure management was applied only to subzone 2. Certainly, in subzone 2, concerning to reduce physical water losses, more satisfactory results were obtained with respect to subzone 6 where pressure management was not applied.

Table 7.1 summarizes the overall effects of the water leak repairs in both physical water loss aspect (considering minimum night flows obtained from SCADA) and monthly revenue loss percentage aspect (considering both SCADA records and CIS records). According to Table 7.1 in both zones, considerable amounts of reductions are obtained. The values for comparison are selected during the high-pressure periods (which may be considered as the same in both zones). In addition, considering 344 properties in zone 6 and 474 properties in zone 2, minimum night flow values are computed to compare with the UK values supplied by Butler (2000) given in Section 4.4.2.

Considering the values before repairs and after repairs, it can be easily concluded that step testing, forming sub-DMAs and similar preparations lead to a better performance in water leak detection. In zone 6 by making step tests and prioritizing the sub-DMAs, a reduction of 963 l/property/day is achieved; on the other hand, in zone 2 without any step tests and preparations only a reduction of 543 l/property/day is achieved.

In addition, to check the final leak levels obtained after the repairs it is seen that, leak levels in Antalya are too much compared to the UK values. Butler (2000) gave 55 l/property/day as an acceptable level of leakage; however, Antalya values are around 1500 l/property/day and 2000 l/property/day in zones 6 and 2 respectively.

Table 7.1 Overall Summary Table for the Case Studies

	Physical Water Losses		Monthly Revenue Loss Percentages	
	Before Repairs	After Repairs	Before Repairs	After Repairs
Zone 6	34.8 m³/h 68.6% 2428 l/prop/day (06.04.2010)	21 m³/h 49.4% 1465 l/prop/day (12.04.2010)	63.66% (2010/02)	52.15% (2010/05)
Zone 2	49.3 m³/h 66.67% 2496 l/prop/day (13.04.2010)	38.6 m³/h 61.75% 1954 l/prop/day (19.04.2010)	38.17% (2010/03)	37.54% (2010/05)

CHAPTER 8

CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDIES

The importance of Information Technologies (GIS, SCADA and CIS) concerning the studies for the reduction of physical water losses were brought to light in a detailed manner.

One of the compelling conditions faced during the case studies was the misleading GIS data. Due to lack of attention while generating GIS data, leads field staff to make wrong decisions about the case, and causes to lose considerable amount of time. In zone 6, careless operations of an office personnel lead to digitizing double service connections for a single building. Also there were numerous other mistakes in other layers. Very recent constructed connections and placed valves were not digitized until a request from field staff was delivered. It also shows a miscommunication problem between different units of the administration. To eliminate such problems, all the water loss related departments should be combined under a different organization in the administration so that a good and fast communication between units could be ensured. Especially, to be able to control better the water distribution network and the actions done to it, there should be only one unit in the water authority, which deals with monitoring, detection and repairing of the leaks.

The topic of water losses will gain more importance in the next years. The technological developments allow production of more detailed and better water loss detection equipments. SCADA systems are developing in a positive manner also. With better SCADA systems and computer networks, it can be made possible a low data transmitting tolerance in the SCADA systems. It is possible with today's technology but higher data transmitting tolerances are being preferred in order to save disk space in the computers and to avoid possible radio scrambles. If this issue is solved, then obtaining more precise daily demand curves will be possible. In addition, storage tank elevations will be obtained with better precisions.

Unfortunately, water administrations discover the importance of saving water only whenever a drought season appears. However, saving the tiniest drop of water has a small but meaningful contribution to the valuable water reserves. Administrations then should focus on their customer information systems and keep a GIS integrated customer information database (CIS). Consumptions should be monitored and recorded with the highest accuracy available. Transforming usual water meters into more precise water meters can be a positive move towards gaining more revenue from the customers. Moreover, using new generation water meters that have the ability to log consumption data over time can lead the way of obtaining individual water usage behaviours (and daily demand curves) of customers. With these water meters, it would be possible to eliminate the errors that are faced through this study during the computation of revenue loss amounts.

By applying water distribution system master projects, big amounts of investments are laid under the ground without having precise location information of the infrastructure. To have the maximum benefit from the water distribution system elements, infrastructure knowledge should be reliable. Starting from detection of fittings in the network and then detecting the pipeline routes are a must to deal with water leaks. Geographical information systems provide exactly the needed solution for infrastructure location determination. Water administrations should discover the importance of generating reliable GIS data layers and should keep them up to date. Discovering the whole system at once and keeping it up to date is the easiest solution when compared to having unreliable and out of date GIS data layers.

Pressure management, in summary, seems to be as a very easy and effective solution for water loss controlling. However, it hides the leaks at a certain extent. In zone 2 of Antalya water distribution network, two thirds of it was scanned with ground microphones while pressure management was suspended. This scanning helped pinpointing six leaks. In the remaining one thirds of the network, ground microphoning was applied under reduced pressures. As a result, even one leak point was not detected. It is almost impossible having no leak in that area, as all the conditions were homogenous throughout the zone. Therefore, combined working of active leak detection studies and pressure management is a very powerful method to choose. It should not be forgotten that both methods (fixing point leaks) and pressure management are complementary methods.

REFERENCES

Aronoff, S. (1989) Modeling, Geographic information systems: a management perspective, WDL Publications, Canada.

Bağcı, G., Integration of SCADA with GIS for Water Quality Modeling of Distribution Network, M. Sc. Thesis, METU, Dept. of Env. Eng., 2001.

Bhave, P. R. (1991) Analysis of Flow in Water Distribution Networks, Technomic, UK.

Butler, D. (2000) Leakage Detection and Management, Palmer Environmental, UK.

Cesario, L. (1995) Modeling, Analysis, and Design of Water Distribution Systems, American Water Works Association, USA.

Eker, İ., Analysis of Water Distribution Network Systems Using Information Systems, M. Sc. Thesis, METU, Dept. of Civ. Eng., 1998.

Jones, M. (2006). "With Today's Technology, What Percentage of unaccounted-for water is OK?" American Water Works Association Journal, 98 (2), 32–33.

Hunaidi, O., Chu, W., Wang, A., Guan, W. (2000). "Detecting Leaks in Plastic Pipes." American Water Works Association Journal, 92 (2), 82–94.

Özkan, T., Determination of Leakages in a Water Distribution Network Using SCADA Data, M. Sc. Thesis, METU, Dept. of Civ. Eng., 2001.

Özkan, T., Leakage Control by Optimal Valve Operation, Ph. D. Thesis, METU, Dept. of Civ. Eng., 2008.

Shamsi, U. M. (2005) GIS Applications for Water, Wastewater, and Stormwater Systems, CRC Pres, USA.

Shamsi, U. M. (2002) GIS Tools for Water, Wastewater, and Stormwater Systems, American Society of Civil Engineers, USA.

Summers, P. (2001). “Finding Your Way” American Water Works Association Journal, 93 (11), 58–61.

Thornton, J. (2002) Water Loss Control Manual, McGraw-Hill, USA.

Walski, T. M., Barnard, T. E., Durrans, S. R., Meadows, M. E., (2004) Computer Applications in Hydraulic Engineering, Haestad Press, USA.

Walski, T. M., Chase, D. V., Savic, D. A., Grayman, W., Beckwith, S., Koelle, E. (2003) Advanced Water Distribution Modeling and Management, Haestad Press, USA.

Web 1, Turkish Statistical Institute. City Populations of Year 2000. <http://tuikrapor.tuik.gov.tr/reports/rwservlet?nufus2000db2=&ENVID=nufus2000db2Env&report=il_koy_sehir_cinsiyet.RDF&p_kod=1&p_kod=1&desformat=spreadsheet> (May 17, 2010).

Web 2, Turkish Statistical Institute. Konyaaltı Population of Year 2009. <http://report.tuik.gov.tr/reports/rwservlet?adnksdb2=&report=turkiye_ilce_koy_sehir.RDF&p_il1=7&p_ilce1=2038&p_kod=2&p_yil=2009&p_dil=1&desformat=html&ENVID=adnksdb2Env> (May 17, 2010).

Web 3, Hermann Sewerin GmbH. SePem 01 Operating Instructions, <http://www.sewerin.com/download/248.html> (March 20, 2010).

Web 4, Antalya Water and Wastewater Administration. Antalya Su ve Atıksu Bilgi Sistemi. <http://www.asat.gov.tr/index.php?page=pages&PID=601> (May 20, 2010).

Web 5, International Water Association Efficient Operation and Management Specialist Group. The IWA Water Loss Task Force Water 21 – Article No.2 Assessing Non-Revenue Water and its Components – a Practical Approach. <http://www.iwaom.org/datosbda/Descargas/29.pdf> (July 31, 2010).

Web 6, International Water Association Efficient Operation and Management Specialist Group. The IWA Water Loss Task Force Water 21 – Article No.4 Leak Detection Practices & Techniques – A Practical Approach. <http://www.iwaom.org/datosbda/Descargas/30.pdf> (July 31, 2010).

Web 7, International Water Association Efficient Operation and Management Specialist Group. The IWA Water Loss Task Force Water 21 – Article No.5 Managing Leakage by District Metered Areas. <http://www.iwaom.org/datosbda/Descargas/31.pdf> (July 31, 2010).

Web 8, United Nations Population Fund. State of World Population 2009 – Facing a changing world: woman, population and climate. <http://www.unfpa.org/swp/2009/en/pdf/EN_SOWP09.pdf> (August 14, 2010).

Web 9, Cors-TR System. Ulusal Cors Sisteminin Kurulması ve Datum Dönüşümü Projesi. <http://cors-tr.iku.edu.tr/> (May 1, 2010).

Web 10, Hermann Sewerin GmbH. Aquaph6on A 100 Operating Instructions, <http://www.sewerin.com/download/211.html> (March 20, 2010).