Título del Trabajo Fin de Máster:

Non-Revenue Water Mathematical Model as a tool for the establishment of water losses management in utilities in developing areas. Application in Batumi Tskali (Batumi, Georgia).

Intensificación:

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Fecha: **SEPTIEMBRE de 2014**

UNIVERSIDAD POLITECNICA DE VALENCIA

máster en ingeniería hidráulica y medio ambiente mihma

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Resumen:

La empresa pública de abastecimiento de agua "Batumi Tskali" en la ciudad de Batumi, en Georgia, había estado experimentando la pérdida de agua de hasta un 85% debido al deterioro de la red, que se ha estado utilizando desde la década de 1800. Además, durante la era soviética no se realizó ningún tipo de mantenimiento, lo que contribuyó al deterioro de las tuberías e demás infraestructura hidráulica. En 2006, Batumi Tskali fue liquidado para formar una nueva empresa municipal del agua, con el apoyo de la consultora alemana MACS Energy and Water, que fiscaliza el programa en curso de rehabilitación de las infraestructuras con fondos del Banco Alemán para el desarrollo y los programas de rehabilitación (KfW).
Una de las herramientas más importantes para hacer frente al problema de las pérdidas de agua y establecer una gestión adecuada es el modelo matemático de la red.
La intención principal de la tesina es presentar la metodología seguida para implementar un programa de reducción de pérdidas de agua en la empresa pública suministradora utilizando las diferentes etapas y los datos necesarios en la construcción del modelo matemático del sistema rehabilitado. Por otra parte, el objetivo principal es la construcción de un modelo matemático de agua no facturada, donde incluir el modelado de las pérdidas de agua.

Abstract:

Georgian water utility "Batumi Tskali" had been experiencing water loss of up to 85% from its deteriorating network, some of which that has been in place since the 1800s, with poor maintenance during the Soviet era contributing to pipe deterioration. In 2006, Batumi Tskali was liquidated to form a new municipal water utility, with support from German consultancy MACS Energy and Water, leading to the implementation of an ongoing infrastructure rehabilitation program borne by KfW (German Bank for developing and rehabilitation programs).

One of the most important tools to cope with the problem of water losses and establish a proper management is the Mathematical Model of the network.

The aim of the Master thesis is to present the followed methodology to implement a water losses reduction program at the water utility using the different stages and data needed when building the Mathematical Model of the rehabilitated system. Furthermore, the main objective is to build a Non-revenue model where include the modeling of the water losses.

Resum:

L'empresa pública d'abastiment d'aigua "Batumi Tskali" a la ciutat de Batumi, a Geòrgia, havia estat experimentant la pèrdua d'aigua de fins a un 85% a causa del deteriorament de la xarxa, que s'ha estat utilitzant des de la dècada de 1800. A més, durant l'era soviètica no es va realitzar cap tipus de manteniment, el que va contribuir al deteriorament de les canonades i altres infraestructures hidràuliques. El 2006, Batumi Tskali va ser liquidat per formar una nova empresa municipal d'aigua, amb el suport de la consultora alemanya MACS Energy and Water, que fiscalitza el programa en curs de rehabilitació de les infraestructures amb fons del Banc Alemany per al desenvolupament i els programes de rehabilitació (KfW).

Una de les eines més importants per fer front al problema de les pèrdues d'aigua i establir una gestió adequada és el model matemàtic de la xarxa.

La intenció principal de la tesina és presentar la metodologia seguida per implementar un programa de reducció de pèrdues d'aigua a l'empresa pública subministradora utilitzant les diferents etapes i les dades necessàries en la construcció del model matemàtic del sistema rehabilitat. D'altra banda, l'objectiu principal és la construcció d'un model matemàtic d'aigua no facturada, on incloure el modelatge de les pèrdues d'aigua.

Palabras clave: ***Agua no facturada, modelo matemático, fugas, balance hídrico, distritos de medición***

Key words: ***Non-revenue water, mathematical model, leakage, water balance, district metering areas***

Paraules Claus: ***Aigua no facturada, model matemàtic, fugues, balanç hídric, districtes de medició***

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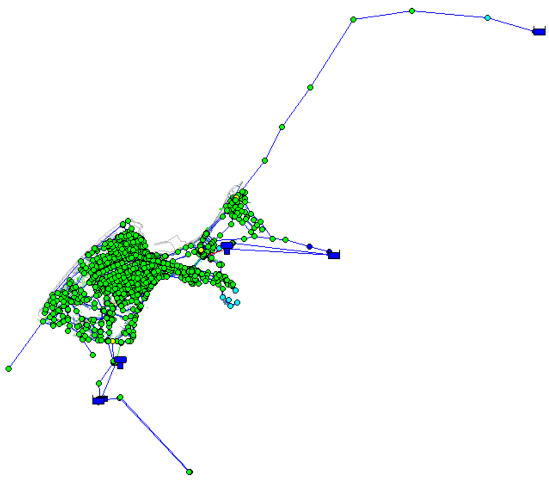

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Als meus pares

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მინდა მადლობა მოვახსენო ბატონ ჯანსუღ ვარშალომიძეს (გენერალური დირექტორი), ბატონ თეიმურაზ ბედინაძეს (ფინანსური დირექტორი), ბატონ ალექსანდრე მიქელაძეს (ტექნიკური დირექტორი), არაშემოსავლიანი წყლის ჯგუფის წევრებს - ზურას, ნუგზარს, გიორგის და შპს." ბათუმის წყალის" ყველა თანამშრომელს, ასევე ბატონ ზაურ ფატლაძეს და ბატონ ჯაბა ტუღუშს (პასი) ჩემი ბათუმში ყოფნის და მუშაობის დროს გაწეული უდიდესი დახმარებისთვის. ასევე გულწრფელი მადლობა მინდა გადავუხადო ჩემს მაქსის ბათუმის ოფისის თანამშრომლებს: ლია დავითაძეს, ნანა მაზმიშვილს, ანჟელა და სირა ოვანესიანებს, დიანას, ლევან სარჯველაძეს, მატიას ჰითცელს და ჰარალდ ვალდიქსს მხარდაჭერისთვის და თანადგომისთვის

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1 BLACKGROUND

Georgia is a country in the Caucasus region of Eurasia. Located at the crossroads of Western Asia and Eastern Europe, it is bounded to the west by the Black Sea, to the north by Russia, to the south by Turkey and Armenia, and to the southeast by Azerbaijan. The capital and largest city is Tbilisi. Georgia covers a territory of 69,700 square kilometers, and its population is almost 5 million. Georgia is a unitary, semi-presidential republic, with the government elected through a representative democracy.

(Source: Wikipedia)

Figure 1: Georgia location

During the classical era, independent kingdoms became established in what is now Georgia. The kingdoms of Colchis and Iberia adopted Christianity in the early 4th century. A unified Kingdom of Georgia reached the peak of its political and economic strength during the reign of King David IV and Queen Tamar in the 11th–12th centuries. After this the area was dominated by various large Empires, including the Safavids, Afsharids, and Qajar Persians. In the late 18th century the kingdom of Kartli-Kakheti forged an alliance with the Russian Empire, and the area was annexed by Russia in 1801. After a brief period of independence following the Russian Revolution of 1917, Georgia was occupied by Soviet Russia in 1921, becoming the Georgian Soviet Socialist Republic and part of the Soviet Union. After independence in 1991, post-communist Georgia suffered from civil unrest and economic crisis for most of the 1990s. This lasted until the Rose Revolution of 2003, after which the new government introduced democratic and economic reforms.

Georgia is a member of the Council of Europe and the GUAM Organization for Democracy and Economic Development. It contains two de facto independent regions, Abkhazia and South Ossetia, which gained limited international recognition after the 2008 Russo-Georgian War. Georgia and a major part of the international community consider the regions to be part of Georgia's sovereign territory under Russian military occupation.

Batumi is a seaside city on the Black Sea coast and capital of Adjara, an autonomous republic in southwest Georgia. With a population of 190.000 (2013 census) being the third biggest city in the country, Batumi serves as an important port and a commercial center. It is situated in a subtropical zone, rich in agricultural produce such as citrus fruit and tea. While industries of the city include shipbuilding, food processing, and light manufacturing, most of its economy revolves around tourism. Since 2010, the face of the city has been transformed by the construction of new high-rise landmark buildings and the renovation of the Old Town.

(Source: Wikipedia)

Figure 2: Batumi location in Georgia and Adjara

In the framework of German – Georgian Financial Cooperation, the Program for Rehabilitation of Municipal Infrastructure in Batumi aims to achieve a stable and demand oriented water supply as well as ecologically sound disposal and treatment of the wastewater for the population of Batumi.

In three independent Program phases the water and wastewater infrastructure is to be rehabilitated. In order to strengthen the institutional and personnel capacities in the Project Executing Agency (PEA), the Municipality of Batumi – and particularly the PEA Working Group, an Accompanying Training Program has been foreseen. This training program also includes assistance and training for the management and staff of the Municipal Water and Wastewater Utility Batumi Tskali in order to manage the ongoing transformation and commercialization. Nowadays the third and last phase of the rehabilitation is ongoing, which a special focus on the establishment of a water losses control program at the water utility, Batumi Tskali.

2 INTRODUCTION

2.1 Water losses in developing areas: the case of Batumi, Georgia

Georgian water utility "Batumi Tskali" had been experiencing water loss of up to 85% from its deteriorating network, some of which that has been in place since the 1800s, with poor maintenance during the Soviet era contributing to pipe deterioration.

Furthermore, the absence of awareness of the cost and value of water had complicated the implementation of a proper water losses program in the utility.

In 2006, Batumi Tskali was liquidated to form a new municipal water utility, with support from consultancy MACS Energy and Water, leading to the implementation of an ongoing infrastructure rehabilitation program borne by KfW.

The technical support which is being given to Batumi Tskali focuses on the establishment of water loses control program.

On that framework, the main idea of this Master Thesis was using the process needed to build the mathematical model of the system to introduce in the utility a strategy to control the non-revenue water (NRW).

The NRW control program is based on the IWA methodology and nowadays is still an ongoing process. However, the main steps have been made on almost the entire network.

On the next chapters we will define the system and present the steps to implement the water losses control program from the beginning 2 years ago until now.

It is needed to understand that we are presenting and on-going process not yet finished and also think about the system improvement progression, which was formed by two completely different parts when we arrived (old and new network). These parts were treated separately for calculations, as we will present on the chapter regarding the system definition and concept.

2.2 Objectives

The main objectives and contributions we expect to reach with the thesis are the following:

- NRW mathematical model of the system: water losses modelling and simulation.

-Obtaining a procedure to consider the NRW mathematical model as a tool for implement a water losses control management program in water utilities in developing areas.

2.3 State of the art

The control of the non-revenue water (NRW) is one of the most important issues that need to be managed in developing areas. It would be possible to use the process to build a NRW mathematical model in one developing area as a tool for achieving a correct water losses management, and link each step of the procedure with the reduction in NRW observed. Some of the methods for leakage control which are mentioned in the article “Methods and Tools for Managing Losses in Water Distribution Systems” (Harrison E. Mutikanga et al. 2013) have been consulted, in order to know the existing leakage control methods and its results. One of the conclusions of that research paper states that solving problems in water distribution systems in developing countries demand unique tools and methods for water loss control that require further research, due to its peculiar technical characteristics. Additionally, another conclusion reports that whereas the IWA/AWWA performance indicators provide a good foundation, they are insufficient for international water loss benchmarking (McKenzie et al. 2007) and not directly applicable to most water distribution systems in developing countries.

The quantity of water lost, or NRW, is a measure of the operational efficiency of a water distribution system (Wallace 1987), and high levels of NRW are indicative of poor governance (McIntosh 2003) and poor physical condition of the water distribution system (Male et al. 1985). Regarding this fact, tools and methods have been developed to implement losses control programs in the water utilities. Hydraulic simulation models can be used to evaluate leakages in water distribution networks. Cheung and Girol (2009) in Brazil studied that night flow analysis, coupled with leakage hydraulic analysis, has proven to be a valuable tool for leakage estimation even in networks of irregular water supply, which could be the case of networks in developing areas. The network hydraulic model has been well developed and applied to water distribution system analysis in the last three decades (AWWA 2005). For leakage management, the hydraulic model can be used for many purposes, including network zoning (Awad et al. 2009; Sempewo et al. 2008), pressure managing planning for leakage control (Burrows et al. 2003; Tabesh et al. 2009; Ulanicki et al. 2000) and leakage modeling as pressure-dependent demand (Almandoz et al. 2005; Germanopoulos 1985; Giustolisi et al. 2008; Wu et al. 2010). Furthermore, there are some research papers focusing on the non-physical water losses. The Asian Development Bank (ADB) estimates that 50-65% of NRW in Asian water utilities is due to apparent losses (McIntosh 2003). To minimize these losses, many researchers have developed tools and methodologies for water meter replacement based on meter testing, economic optimization, and operational research techniques (Arregui et al. 2011; Lund 1988; Noss et al. 1987; Yee 1999). Arregui et al. (2006) stated that metering inaccuracies could be minimized by integrated meter management policies and strategies. Moreover the high unauthorized water consumption, that is common in developing areas, requires not only engineering solutions but sociocultural approaches, which have been reported as the major drivers in reducing NRW in some Asian cities (Luczon and Ramos 2012). Regarding the importance of the water utilities management performance, benchmarking studies on water loss management using partial methods have been reported in various countries (South Africa, Seago et al. 2004; Austria, Koelbl et al. 2009b; Portugal, Marques and Monteiro 2003).

2.4 General overview

The following flow chart presents the overview of the process with the aim of giving a general idea about the methodology.

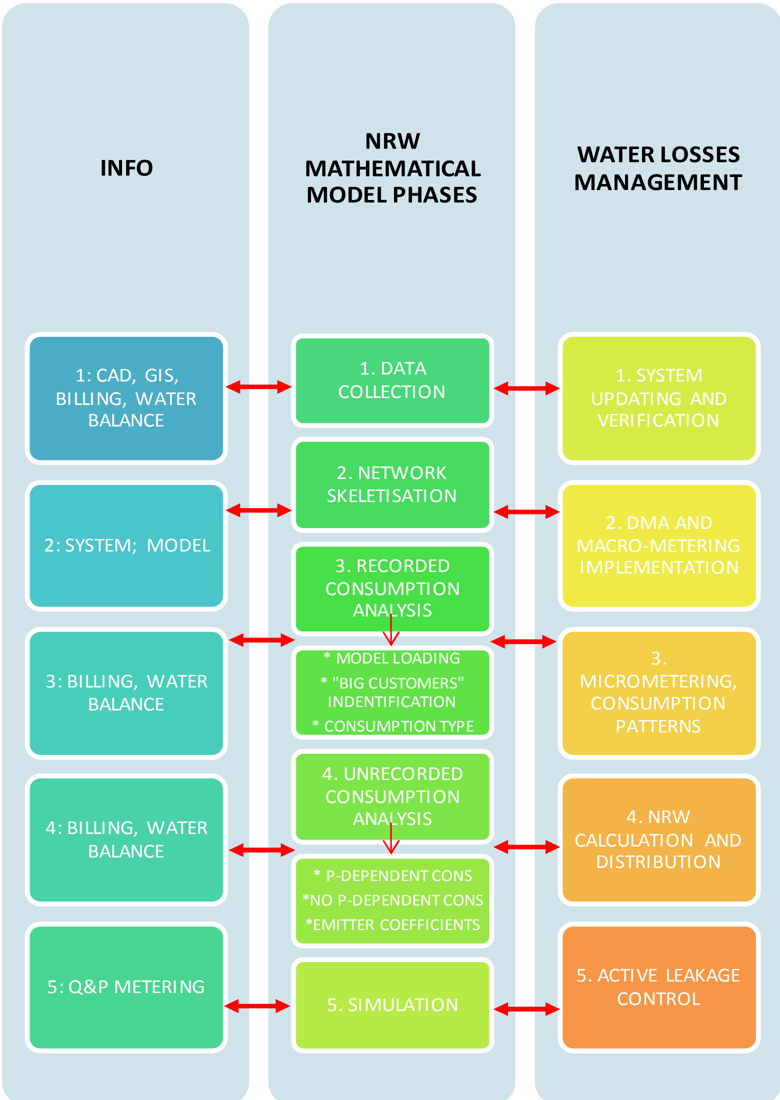


Figure 3: Methodology overview

3 MATERIAL AND METHODS

3.1 Batumi water system

The aim of this chapter is to explain what the situation of the water system in Batumi was from the beginning of the project until the last agreed update to implement the DMAs as a part of the losses control program.

3.1.1 Introduction

As explained at the introduction of this document, the project is still on-going and nowadays the scope of work is to finish with the establishment of the DMAs and with the installation of individual water meters.

On the other hand, the network on some parts of the city, less inhabited, are still under reconstruction. It will be finished with the last phase of the project. Anyway, those areas are already included into the losses control program.

In order to have a better idea of the project, we will summarize the different rehabilitation project phases to make it clear.

On the next sub-chapters the existing situation at the beginning and the new system design will be presented.

Furthermore, the agreed network division into DMAs concept will be also explained and detailed.

3.1.2 Existing situation at the beginning of the project

3.1.2.1 General layout

The general layout of the Batumi water supply system was a result of historical development, changing decision criteria; changing strategies between surface water supplied by gravity and pumped well field water. The distribution system had a total official length of 300 km, however according to the drawings available, the Consultant found the complete system's length with 201 km including transmission mains, and a length of 153 km without TMs.

The water from the two main sources, Chakvi and Chaisubani, enters from the east and feeds directly into the distribution system. There is no reservoir volume available to buffer demand peaks, which depend rather on operation hours and capacities of the individual booster pumps than on consumption patterns.

3.1.2.2 Valves and hydrants

The total number of line valves was unknown, most of the visible line valves were leaking. However, in some areas Batumi Tskali operated line valves to open distribution to specific areas during the night only, and closed these connections in the morning.

The number of hydrants varied according to different sources between 80 (Batumi Tskali) and 68 (fire brigade). The specific hydrant density was thus about 0.4 hydrants per km of the distribution system.

3.1.2.3 Pipe material and age

The material consisted mainly of steel pipes and cast iron pipes. The oldest parts were constructed around 1908 and the newest parts from 1970 to 1980.

Materials like HDPE were so far just used in a few extensions and for private house connections. Also GAZ pipes were used for this purpose.

3.1.2.4 Service connections

Officially there were 18.750 registered service connections. In fact there were many more connections to main pipes, since numerous apartments had ‘private connections’, equipped with booster pumps connected somehow to the distribution system. These connections were not registered as they were installed privately without following any standards or regulations.

Almost 100 percent of the service connections were made of steel pipes. Physical connections to the main pipes are made by welding, threading and a variety of improvised methods.

3.1.2.5 Booster pumping

There were 215 “official booster” pumping stations installed in the distribution system. The purpose was to increase the operational pressure in the service connections. Batumi Tskali was responsible for operating, maintaining and paying electricity bills for these “official booster pumping stations”. In general these BPS were in a very poor condition and subjected to frequent repairs. Operating time was usually 12 hours per day, in the morning between 8 and 12 hours, and in the afternoon/evening between 15 and 23 hours.

These BPS were connected directly to the distribution system using the network as a suction tank (the network volume is about 35.600 m3) and directly delivered into the house installation. Typically neither pressure surge tanks were installed nor any kind of operation control. Only very few buildings were equipped with roof tanks.

3.1.2.6 Consumption metering

Batumi Tskali reported approximately 1.000 working water meters; all of them installed for legal entities. There was no metering on private consumption at all.

Given the official figure of 18.750 service connections only 5% of the connections were metered, all others were calculated according to the pertinent standard consumption per user group.

3.1.2.7 Present service conditions

A pressure monitoring program recording service pressure for at least 24 hours was carried out by installing automatic pressure loggers equally distributed over the system. The results can be summarized as follows:

- ⇒ Maximum pressure was around 2 bar, only in one point a pressure of up to 4 bar was measured
- ⇒ Minimum pressure in all districts was below 0.5 bar, even negative pressures were measured (created by the booster pumps)
- ⇒ The pressure ranged in all districts most of the time below 0,7 bar

3.1.2.8 Present operation and maintenance of the system

Maintenance of the system was limited to emergency repairs on main pipes and service connections. Batumi Tskali staff had been trained on leak detection and basic leak repair and tried to keep up with repairing detected leaks.

3.1.2.9 Detailed inventory of the existing distribution system

A detailed inventory of the existing distribution system was carried out, based on the existing GIS system as well as on own field assessments. The complete first design of the system had been divided into 4 zones, which are foreseen to be rehabilitated in 3 phases. The inventory of the existing system had been divided into those 4 zones accordingly. These zones respectively phasing is shown in the map below.

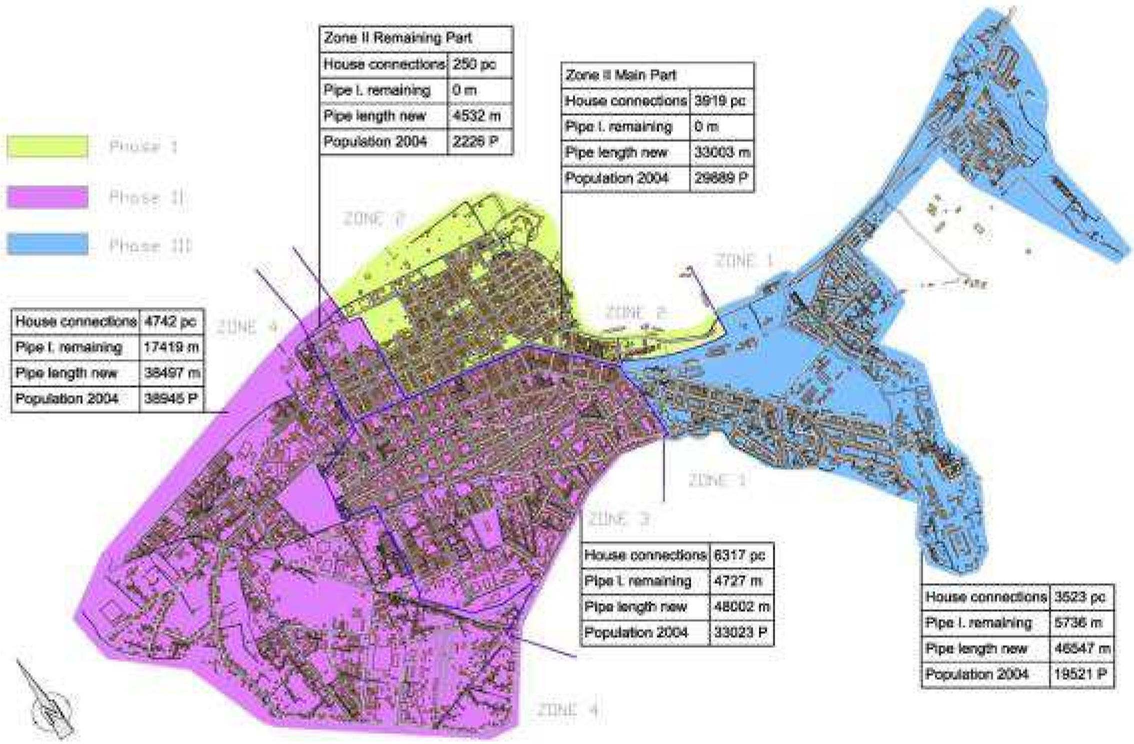


Figure 4: Existing system and rehabilitation phases

3.1.2.10 House installations

House installations in apartment blocks followed the Russian design standards. Every apartment had up to four vertical pipes supplying kitchen, toilet and bathrooms separately. Horizontal rings in the apartments were very rare. All house installations were made of steel pipes and leaking rising mains were found seldom. Household taps and sanitary appliances were normally in poor condition and leaking, not closing properly and some older toilet bowl models need repeated flushing to finally discharge. All this contributed to the high specific consumption.

3.1.3 New system design

3.1.3.1 Project target for the new water supply system

The targets for rehabilitation of the system including house connections can be summarized as follows:

All buildings shall be connected to a functioning water supply network, providing:

- ⇒ 24 h continuous supply
- ⇒ Sufficient water quantity for the 2025 demand, at an assumed max. per capita domestic specific demand of 120 l/c·d, and an overall per capita demand of 313 l/c·d
- ⇒ Sufficient service pressure to operate the system without booster pumps up to the 9th floor
- ⇒ Water in quality in line with Georgian Standards

Further,

- ⇒ All house connections shall allow metered water billing (condominium based)
- ⇒ The loss level in the system shall be below 20%
- ⇒ The system shall be compatible with the future overall layout of the entire city system, which requires at this stage already dimensioning of the entire future city system

For balancing the demand, two news reservoirs will be constructed at Salibauri and Injalo hills.

3.1.3.2 General design

On the next image we will be able to see the initial idea of the new network design. The network was divided into 4 different areas as explained, to build one behind the other, disconnecting the customers from the old system and supplying each area from the built new system.

The rehabilitation is being done in three phases, nowadays the phase III is on the tender review stage. Under phase III will be built the network on some less inhabited areas at the moment, but with prevision of growing up in a short time.

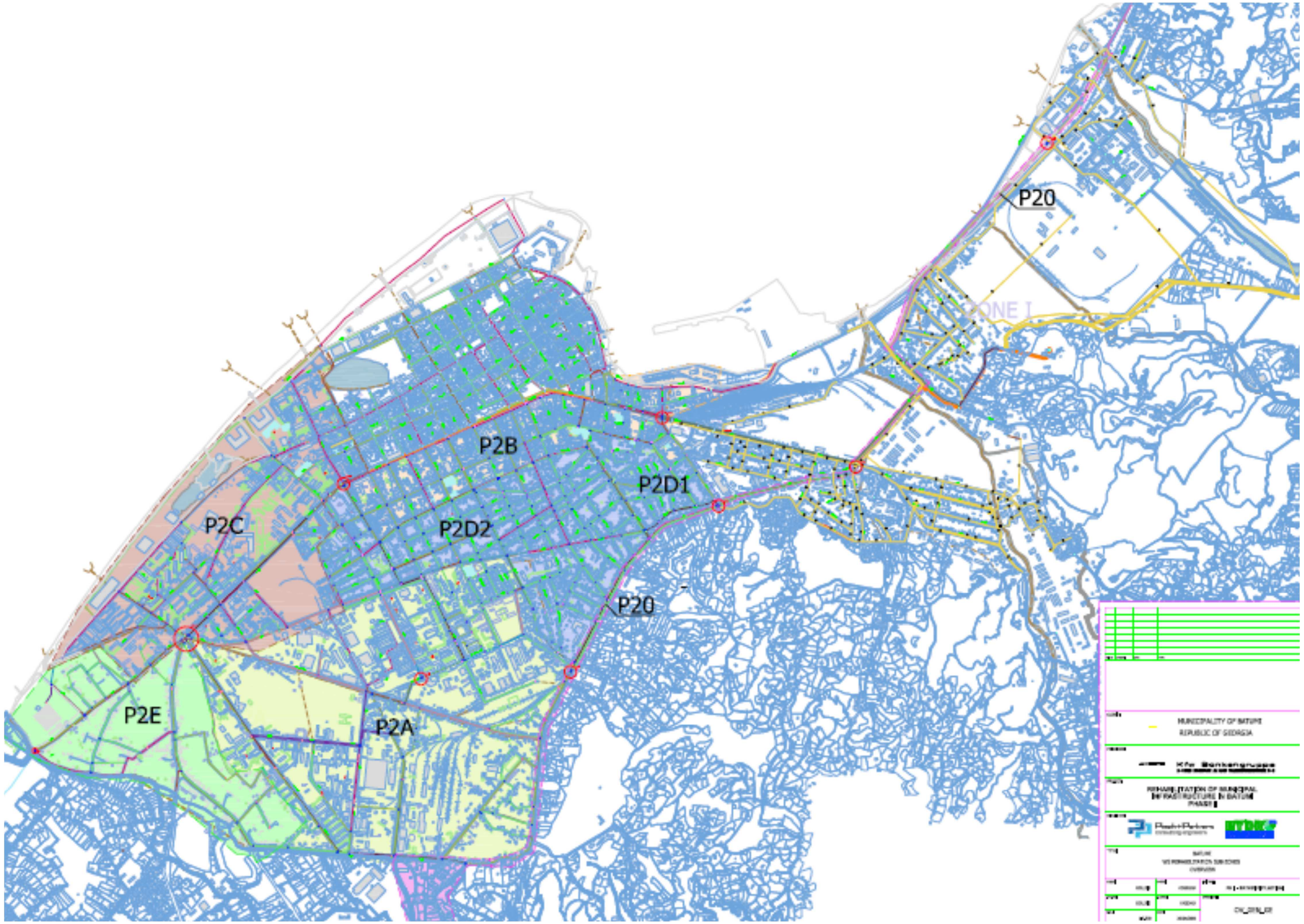


Figure 5: General design new system

3.1.3.3 New water supplying system

Following a schematic chart is presented in order to define each element which forms part of the new water supplying system.

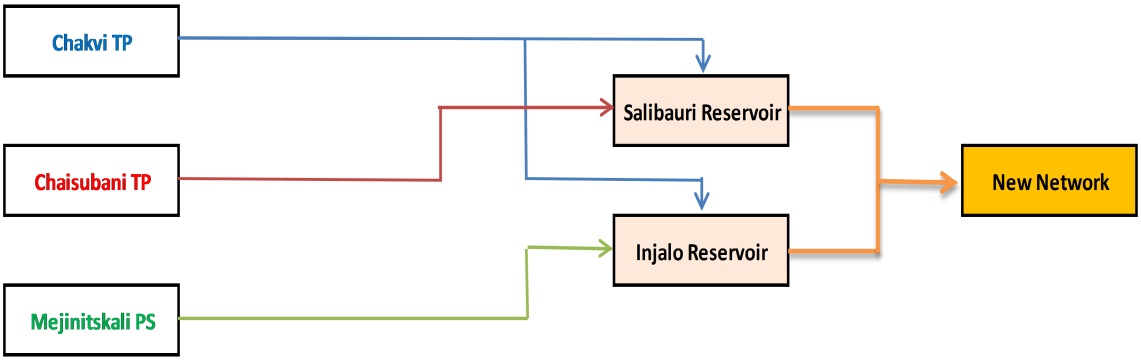


Figure 6: New system scheme

As we can see on the figure, the system is being supplied by three water sources:

- ⇒ Chakvi Treatment Plant: this plant takes the water from the river Chakvi and feeds the system by gravity. It is possible to feed both reservoirs by Chakvi line, which is the main transmission pipe crossing all the city and villages from Chakvi treatment plant.
- ⇒ Chaisubani Treatment Plant: in this case the plant takes water from the river Chaisubani feeding the system also by gravity. Normally supplying Salibauri reservoir.
- ⇒ Mejinistkali Pumping Station: this is a yield with several wells situated on the bottom of the city. Normally supplying Injalo reservoir by pumping (some hours).
- ⇒ Salibauri reservoir: inflows from Chakvi or from Chaisubani treatment plants.
- ⇒ Injalo reservoir: inflows from Chakvi TP and from Mejinistkali PS.

Both reservoirs are situated on hills which have the same height, so being Batumi a flat city each area of the system supplied by one or by the other reservoirs has the same pressure.

3.1.4 Network division into district metered areas

3.1.4.1 Introduction

In order to implement correctly the control losses program based on IWA methodology, the new network was divided into District Metering Areas (DMAs) in based on the former Billing Areas (BA) which Batumi Tskali was operating at that moment.

Each DMA should be monitored through monthly measurements of inflows and outflows in comparison with the billing to calculate the amount of NRW at the DMA.

The collected data will allow Batumi Tskali management to set priorities for detailed inspections identifying real losses (leakages) and to find apparent losses (unauthorized consumption, data handling errors and metering inaccuracies). In this way, involved staff and technical resources will be used in the most efficient way.

Originally, as seen on the previous point, the new water supply network was divided into only 4 water supply areas (DMAs) for all Batumi. Each of these DMAs embraced approximately 10.000 house connections. An optimal DMA should have not more than approximately 3.000 connections (according to technical literature), so the DMA structure was adjusted.

Therefore our concept defined an adequate number of DMAs to match the BAs. The concept and the process to design the DMAs are presented on the next point.

3.1.4.2 DMA design

After studying other possibilities such as equal consumption areas or pressure areas, it was agreed that the best option for Batumi was to divide the network following the existing billing areas. Two main reasons were the responsible for that agreement:

- ⇒ Batumi is a flat city and the new built reservoirs are at the same height, so the network does not have different pressure areas.
- ⇒ As originally the network was designed to have 4 different areas organized on billing areas, the easier way to design DMAs not changing the billing structure was to follow that structure joining billing areas if needed into one only DMA.

The next maps show the final division of the network into 18 DMAs and a schema of the supplying and measurements points.

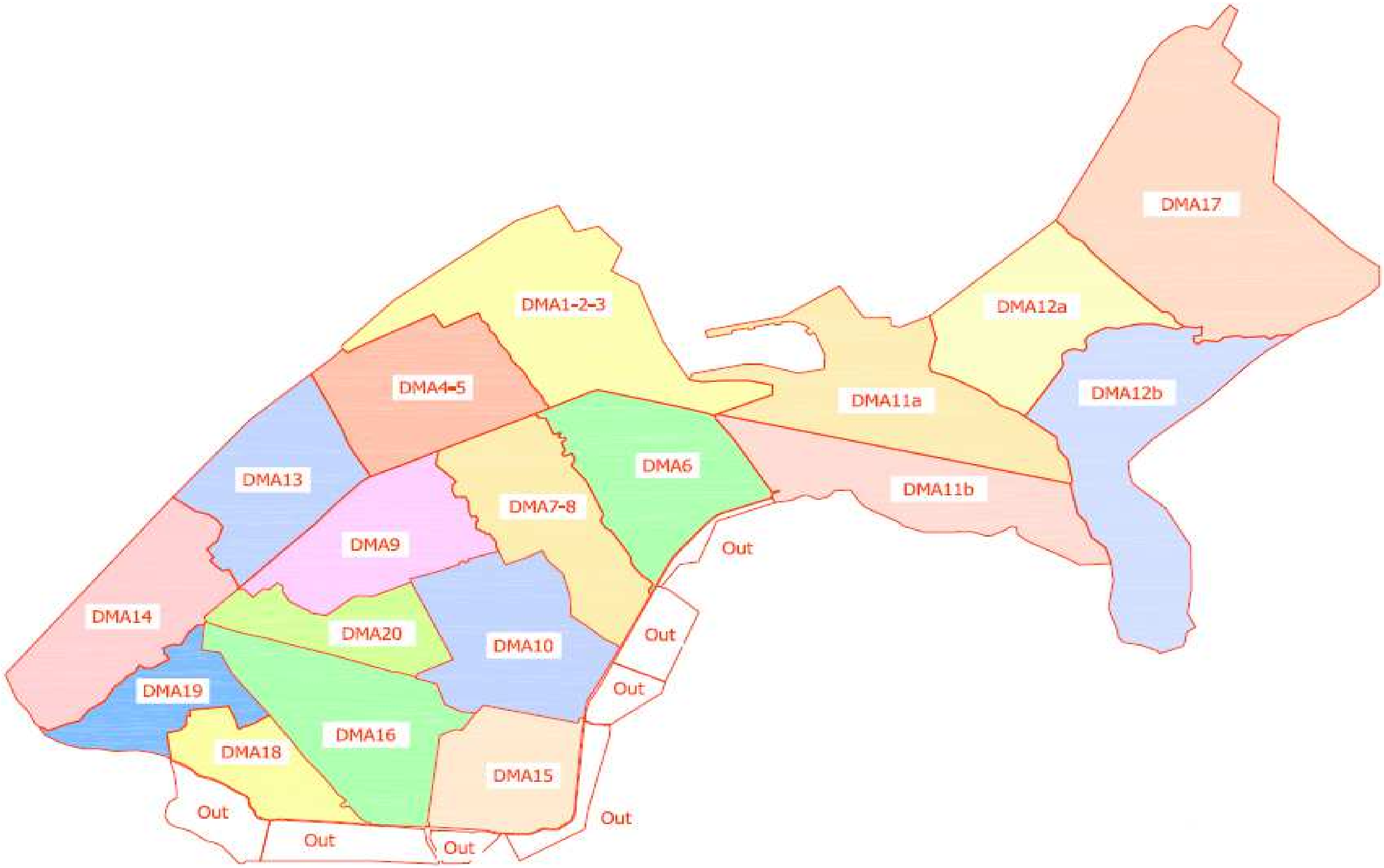


Figure 7: Optimized DMAs map

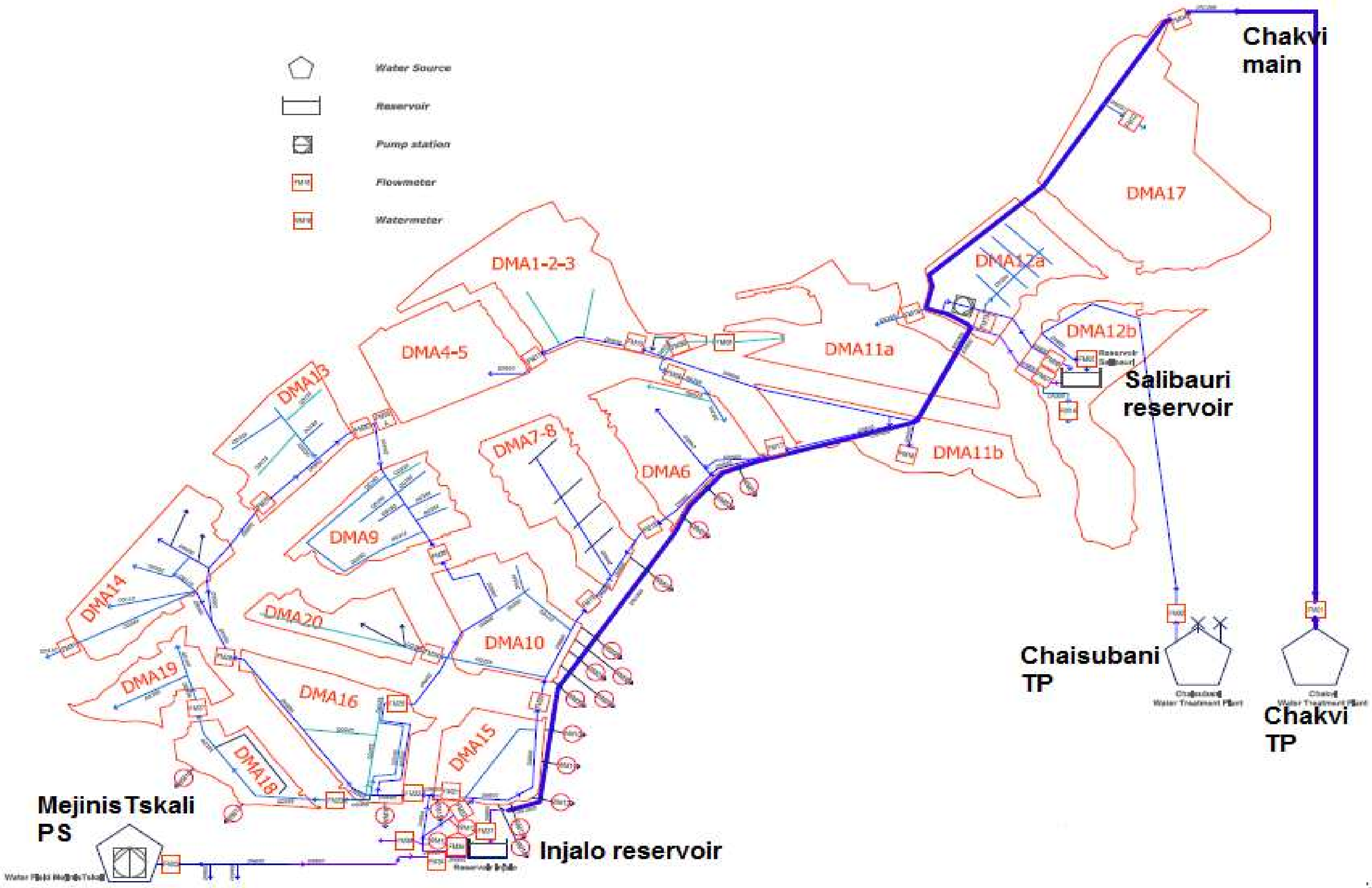


Figure 8: DMA measurements points and supplying schema

Later, on chapter 2.5 DMAs implementation, we will describe the strategy to achieve the isolation and also will comment some tests and studies which were done to train the staff and to check the total closing of the districts.

3.2 Initial audit and work plan

3.2.1 Introduction

In this chapter we analyse the state of the water supplying when arriving at the place, like 2 years ago. At that moment there was some rehabilitated areas supplied by the new network and other ones not rehabilitated supplied by the old system.

At the same time, we tried to collect all available information regarding the network mathematical model used for design.

That first moment was the beginning of the implementation of the methodology to get the data for building the mathematical model. The first step was to do an audit of the supply concept and available data.

The audit of information was done by studying the project drafts, visiting each facility in order to investigate and check how the network supply worked.

3.2.2 Water balance

In any water supply should be considered a balance between the volume of water injected into the network and the subsequent use made of that water. For this it is necessary to know accurately the water inlets to the system and its final destination, i.e. the classification of consumption according to their specific end and use.

Any design or analysis of a hydraulic system should be based on the above information, which can be considered basic and fundamental.

The flow introduced into the network must be measured and recorded continuously as precisely as possible. Their knowledge is essential for network's design and diagnostic. This value allows to plan and to operate properly the water supply. In addition, knowledge of the minimum flow consumed by the night allows an estimation of leakages.

However, a balance that differs only consumed water and leaks, disregarding all potential terms that fit in it, is both simple and wrong.

The diagram below includes, despite its simplicity, all suggested terms in the technical literature. The four represented criteria (represented in red) are increasingly restrictive, so that a higher level is always more general than the lower.

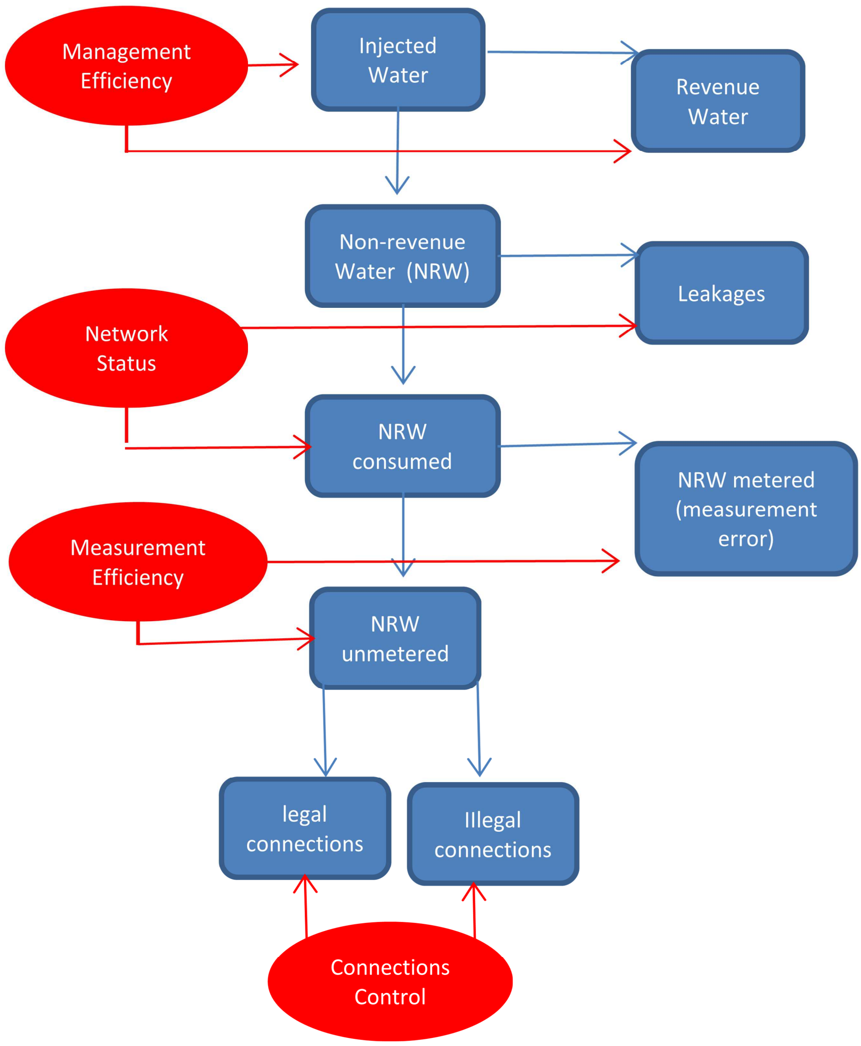


Figure 9: Water Balance

3.2.2.1 Auditing data

Water balance was being made in a spreadsheet called Comprehensive Overview. The periodicity of the calculation was 1 month.

Every month inflows measurements were being read from the water sources and outflows measurements were being read from 4 measurement points (48 hours per month) along the main pipe supplying the old network. Furthermore, information from the Billing Department was available each month.

In the following flow chart we can see how and where the water inflows/outflows were obtained. The notation that we used in the chart is as follows.

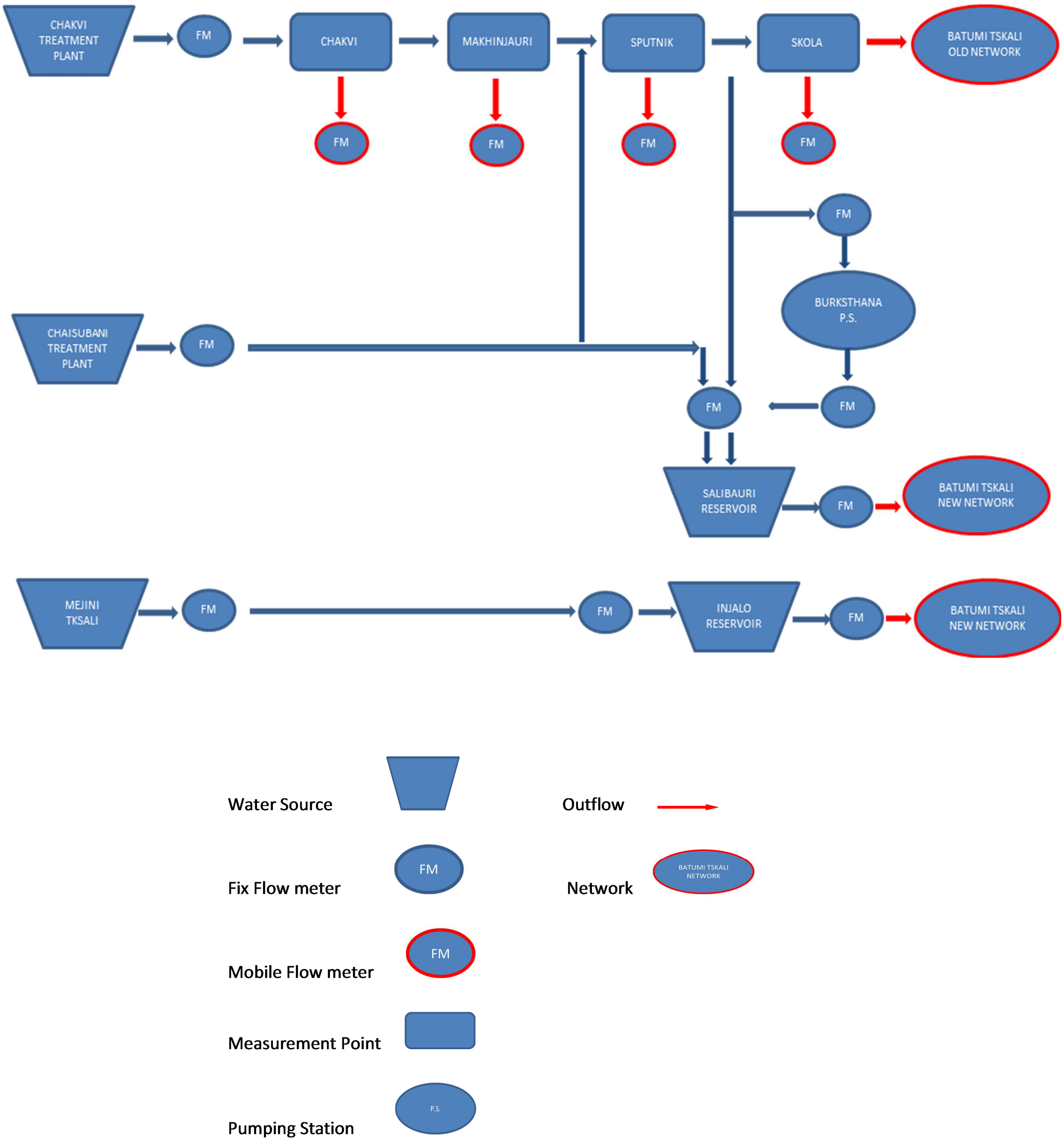


Figure 10: Supplying scheme during network works

On the other hand, the Billing Department of the water company was asked to start dividing the customers into the following categories shown on the table.

CATEGORIES	
Customers with/without Water Meter	Total Householders (Domestic)
	Smaller Legal Entities (Commercial)
	Largeger Legal Entities (Industrial)
	Public entities

Table 1: Data Billing Area.

It is needed to explain a bit how the situation was at that moment. As Georgia was a soviet republic not long ago, they were not used to pay for water. Due to this, water consumption was not metered when speaking about micro-metering and badly the macro-metering.

When the water infrastructure rehabilitation project started, after the soviet era, the Utility divided the city into Billing Areas, and the Billing Department started charging the equivalent of a consumption of 120 L/capita/day. This was planned to be provisional while building the new network and installing water meters to each customer.

The true is that the real consumption per capita was at that moment around 700-800 L/cap/day.

This issue is better explained when speaking about the IWA water balance implementation through the monthly comprehensive overviews.

In order to plan the measurements to implement the water balance the new network was divided into DMAs. As Batumi is a flat city, it was agreed to follow the structure of billing areas to convert those areas in District Metered Areas like showed on the table.

The DMA implementation will be widely explained on the correspondent chapter.

<table>
<tr><th>Billing Area (BA)</th><th>DMA</th><th>Billing Area (BA)</th><th>DMA</th></tr>
<tr><td>BA 1</td><td rowspan="3">DMA 1-2-3</td><td rowspan="2">BA 11</td><td>DMA 11a</td></tr>
<tr><td>BA 2</td><td>DMA 11b</td></tr>
<tr><td>BA 3</td><td rowspan="2">BA 12</td><td>DMA 12a</td></tr>
<tr><td>BA 4</td><td rowspan="2">DMA 4-5</td><td>DMA 12b</td></tr>
<tr><td>BA 5</td><td>BA 13</td><td>DMA 13</td></tr>
<tr><td>BA 6</td><td>DMA 6</td><td>BA 14</td><td>DMA 14</td></tr>
<tr><td>BA 7</td><td rowspan="2">DMA 7-8</td><td>BA 15</td><td>DMA 15</td></tr>
<tr><td>BA 8</td><td rowspan="4">BA 16</td><td>DMA 16</td></tr>
<tr><td>BA 9</td><td>DMA 9</td><td>DMA 18</td></tr>
<tr><td>BA 10</td><td>DMA 10</td><td>DMA 19</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>DMA 20</td></tr>
<tr><td>BA 17</td><td>DMA 17</td></tr>
</table>

Table 2: Correspondence BA-DMA

3.2.2.2 Working plan

In order to be able to improve the input data to be used for the water balance, it was planned to work on the next points:

⇒ **Flow meters installation at each inflow point**:

We needed to know the inflow water in the system from Chakvi, Chaisubani and Mejini Tskali. At that moment there were installed flow meters in Chakvi and Mejini Tskali, but inflow from Chaisubani was estimated. We could also obtain flow measurements from the reservoirs, Salibauri and Injalo, in order to know which part of the water from Chakvi, Chaisubani and Mejini Tskali supplied the reservoirs and which part was consumed by villages and settlements or consumed by old network illegal connections, or also lost by leakages.

⇒ **Each water use must have a water meter/ flow meter installed:**

This point was really difficult to reach, although the more new network built the more water meters installed. At that moment the system outflows measurements from Chakvi main were being made by 48 hours per month and that results were extrapolated to the entire month. The optimum would be measure it continuously to be able to improve the water balance and use it to know the Modulation Curves.

⇒ **Consumption Modulation Curves:**

Obviously, the consumption in a water supply is not constant throughout the day. The next image shows as an example a possible flow evolution curve, injected in a water supply over 24 hours a day.

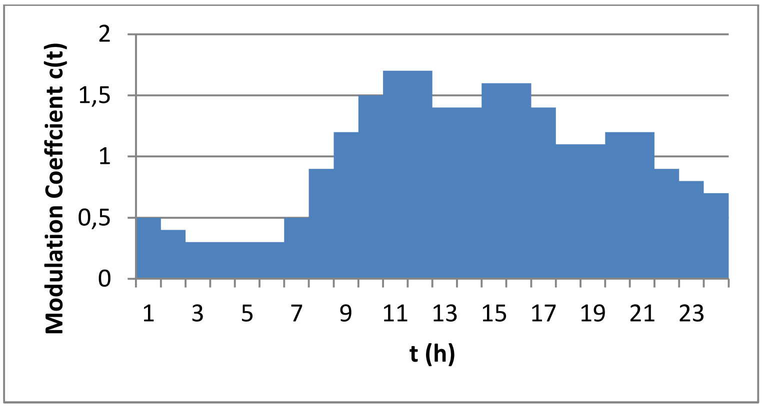


Figure 11: Modulation Curve

The curve represents the Modulation Coefficient c (t), i.e. the relationship between average flow of each time of day, Q (t), and the average daily flow, Qad:

$$c(t) = \frac{Q(t)}{Qad}$$

This modulation curve will change from day to day (it is not the same a Tuesday than a Saturday) and it will also change throughout the year (it's not the same a July day than a February day).

In an existing network must be measured every injected or consumed flow (not just billed). With all this information we can establish average water provision, peak ratios, night flow and modulation curves for any day of the year. The more the infrastructure in water meters or flow meters, the more information is available.

Analysis of these data is a prerequisite for using the mathematical model and obtains interesting results. The more reliable the input data are, the better the results. In order to start having more reliable data, a measurement plan was agreed and implemented while the works on the network continued.

The initial plan is presented on the next page. These initial results were very useful to calibrate the first version of the mathematical model and also to start knowing consumption patterns and improving the water balance accuracy.

FLOW MEASUREMENTS PLAN OLD NETWORK					
INFLOW BATUMI TSKALI NETWORK	***MEDITION***	***PERIODICITY***	***OUTFLOW BATUMI TSKALI NETWORK***	***MEDITION***	***PERIODICITY***
CHAKVI	*FFM*	*CONTINUOSLY*	*MAKHINJAURI*	*MFM*	*1 WEEK PER MONTH (7 DAYS)*
CHAISUBANI:			*SPUTNIK*	*MFM*	*1 WEEK PER MONTH (7 DAYS)*
PIPE 600	*MFM*	*1 WEEK PER MONTH (7 DAYS)*	*SKOLA*	*MFM*	*1 WEEK PER MONTH (7 DAYS)*
PIPE 400	*MFM*	*1 WEEK PER MONTH (7 DAYS)*	*OTHER CONNECTIONS OLD NETWORK*	*MFM*	*1 WEEK PER MONTH (7 DAYS)*
PIPE 350	*MFM*	*1 WEEK PER MONTH (7 DAYS)*			
BARTSKHANA P.S. (input)	*FFM*	*CONTINUOSLY*			
FLOW MEASUREMENTS PLAN NEW NETWORK					
INFLOW BATUMI TSKALI NETWORK	***MEDITION***	***PERIODICITY***	***OUTFLOW BATUMI TSKALI NETWORK***	***MEDITION***	***PERIODICITY***
SALIBAURI (input)	*FFM*	*CONTINUOSLY*	*DMA's*	*FFM*	*CONTINUOSLY*
SALIBAURI (output)	*FFM*	*CONTINUOSLY*	*SUBSCRIBERS*	*WM*	*CONTINUOSLY*
CHAISUBANI:					
PIPE 600	*MFM*	*1 WEEK PER MONTH (7 DAYS)*			
MEJINI TSKALI	*FFM*	*CONTINUOSLY*			
INJALO (input)	*FFM*	*CONTINUOSLY*		*FFM*	*Fix Flow Meter*
INJALO (output)	*FFM*	*CONTINUOSLY*		*MFM*	*Mobile Flow Meter*
BARTSKHANA P.S. (output)	*FFM*	*CONTINUOSLY*		*WM*	*Water Meter*

Table 3: Flow measurements plan

PRESSURE MEASUREMENTS PLAN					
OLD NETWORK	MEDITION	PERIODICITY	NEW NETWORK	MEDITION	PERIODICITY
BARTSKHANA P.S.	*MPDL*	*1 WEEK PER MONTH (7 DAYS)*	*DMA's*	*FPDL*	*CONTINUOSLY*
SKOLA	*MPDL*	*1 WEEK PER MONTH (7 DAYS)*	*SALIBAURI*	*FPDL*	*CONTINUOSLY*
MPDL *Mobile Pressure Data Logger*			*INJALO*	*FPDL*	*CONTINUOSLY*
FPDL *Fix Pressure Data Logger*			*BARTSKHANA P.S.*	*FPDL*	*CONTINUOSLY*

Table 4: Pressure measurements plan

3.2.3 Measurement plan

3.2.3.1 Introduction

As we explained above, the measurements plan was created at the beginning of the losses control program implementation because the necessity to have a more accurate water balance to build and calibrate the mathematical model.

It is worth to say that the metering points have changed along with the construction of the network and with the connection of the rehabilitated areas to the new supplying system.

In each time we adjust the measurements to we need at that moment. At the beginning we had to divide the system into two: old system (the old areas supplied by Chakvi main, with lots of leakages and illegal connections) and the new one with the customers connected to the new system.

Later, with most of the city connected to the new system and with the ongoing installation of individual water meters, we left the old system out of our water balance.

From that moment, Chakvi main started to be rehabilitated to cut the leakages and also to disconnect from the system the illegal connections. Onwards, Chakvi main will only be used to supply the reservoirs with flow from Chakvi treatment plant.

That situation will arrive when finishing the phase III, as nowadays a few DMAs are still connected to Chakvi main and supplied directly from Chakvi treatment plant and not from the reservoirs. In any case, those areas which will be rehabilitated under phase III have not so much connections nowadays.

We are presenting the results of the measurements plan in our monthly and quarterly reports, and using it to calculate the water balance and calibrate the model. So, we think that the best option to show the results we are obtaining is to present the measurements of the last quarterly report before writing this Master Thesis.

3.2.3.2 Flow measurements

At this stage of the program, we are using flow data from the following metering points:

- ⇒ Outflow meters of the reservoirs.
- ⇒ DMAs flow meters.

We also know the water produced each month and have it online, as we will explain later when presenting the Managing Information System (MIS).

Regarding the water consumption, the next results from the reservoirs were observed during the last quarter.

In first place the results of Salibauri reservoir.

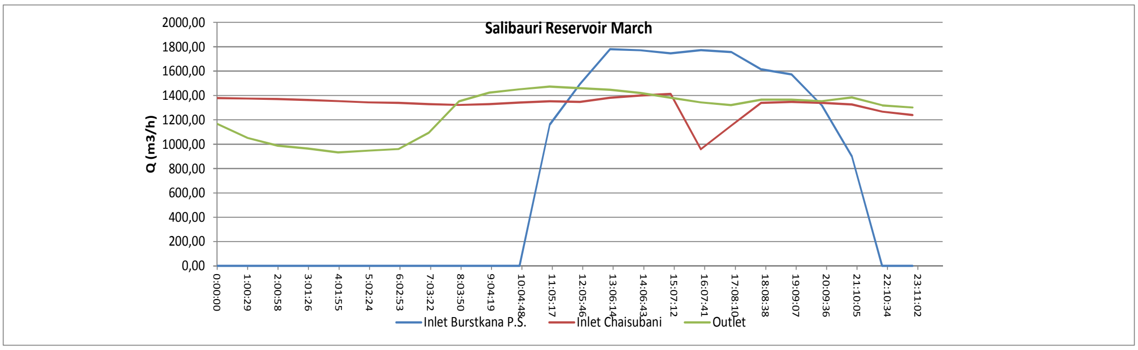


Figure 12: Salibauri average 24 h flow evolution in March

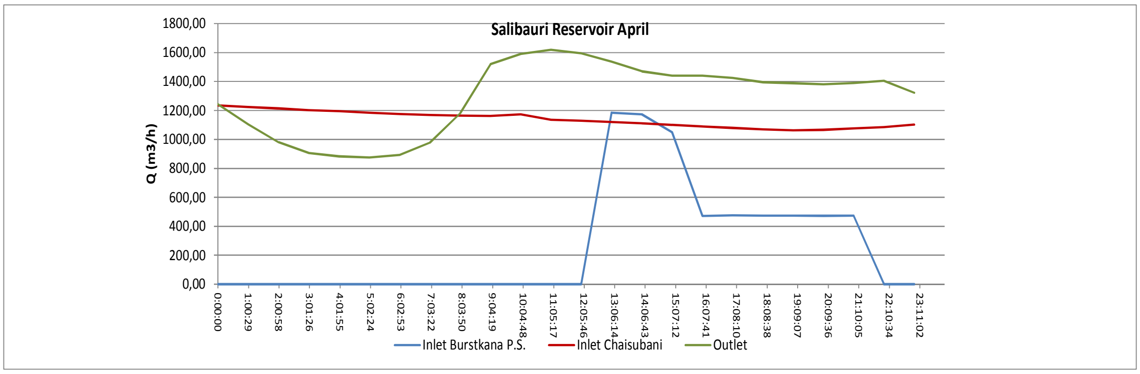


Figure 13: Salibauri average 24 h flow evolution in April

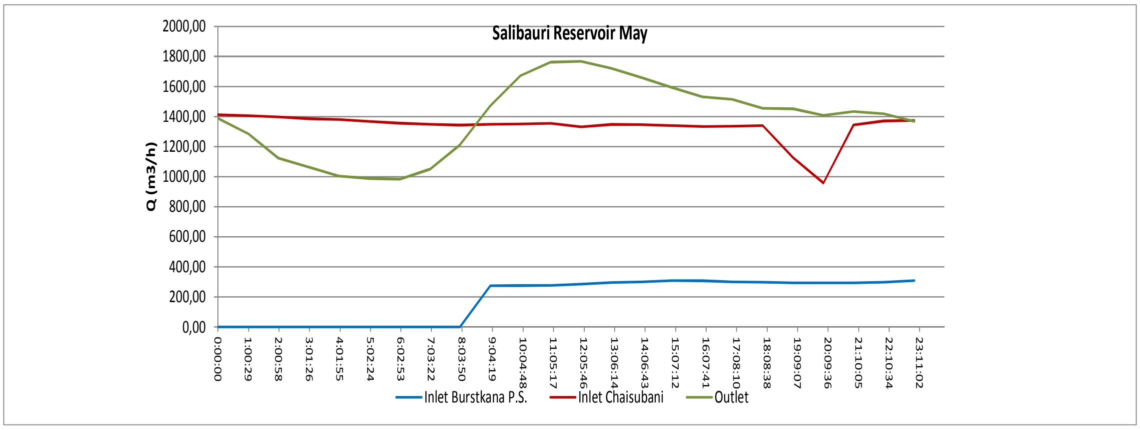


Figure 14: Salibauri average 24 h flow evolution in May

As we can see on the charts, the minimum consumption occurs during night time with a value around 1.000 m3/h (still high) and the maximum is growing each month from 1.400 m3/h in March until 1.800 m3/h in May.

The inlet from Chaisubani oscillates between 1.200 and 1.400 m3/h and the inlet from Burthkana pumping station is variable according with the water height in Chakvi. In any case this is less important than Chaisubani inlet to Salibauri.

On the other hand, the difference between the night time consumption and the day time one, in comparison with the average consumption, is starting to be different, broking the observed tendency last months. This is a good signal of NRW reduction because DMAs isolation.

The consumption patterns observed each month and the average are presented as follows.

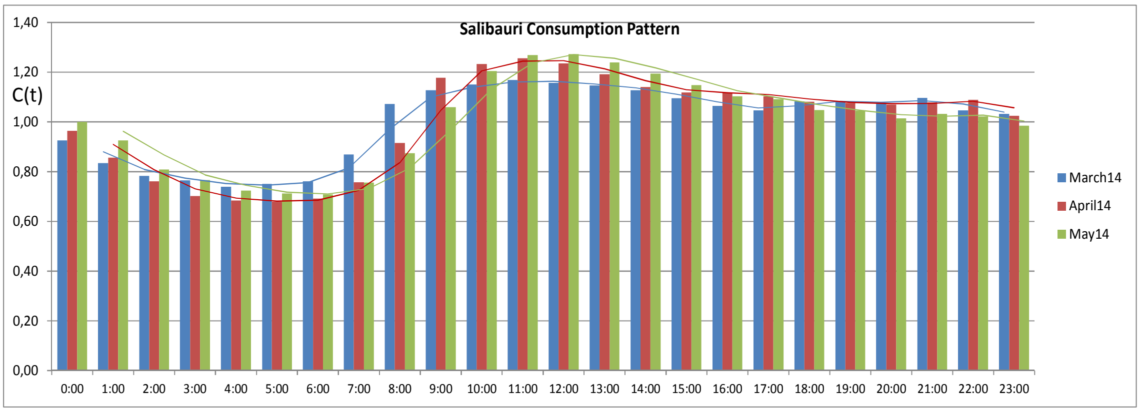


Figure 15: Salibauri consumption pattern during the quarter

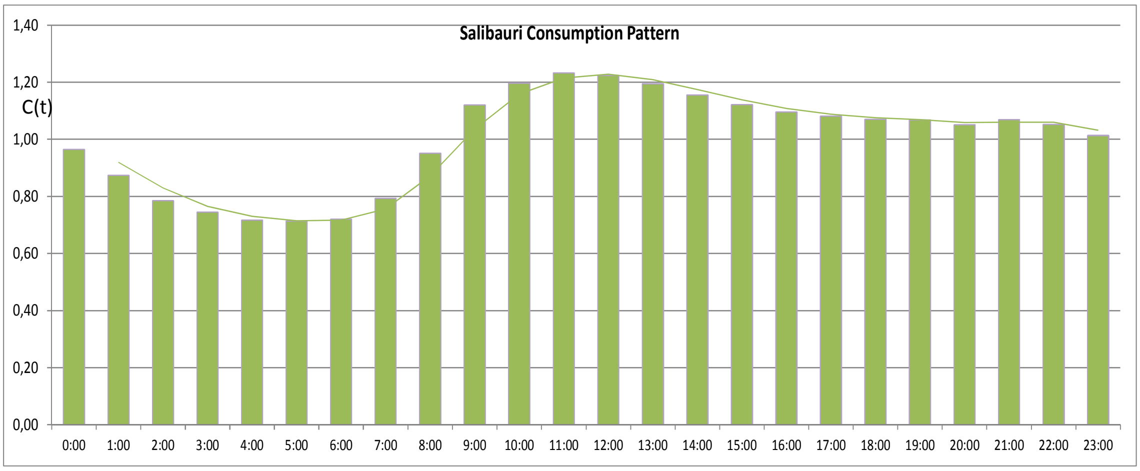


Figure 16: Salibauri consumption pattern in average

As we have commented above, the consumption pattern slightly has broken the usual shape we are observing along the last months. Maximums consumption peaks are 20% higher than the average consumption and minimums ones are 30% lower.

In second place, the presentation of Injalo reservoir results.

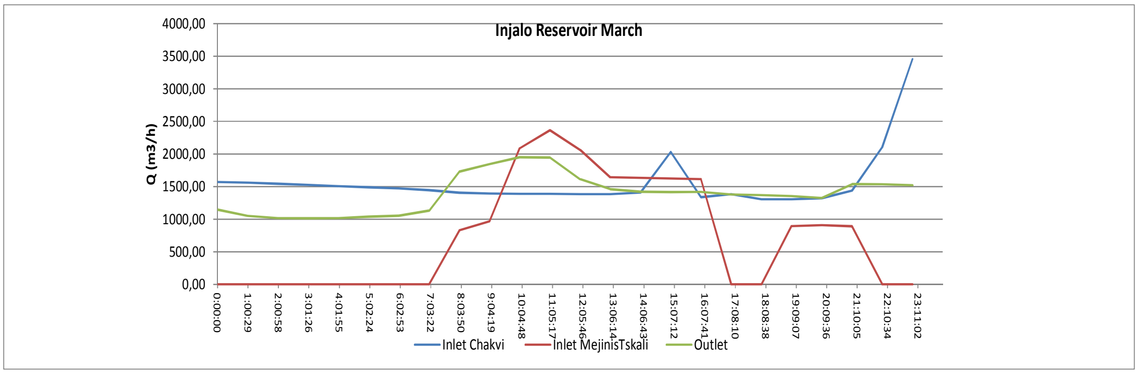


Figure 17: Injalo average 24 h consumption in March

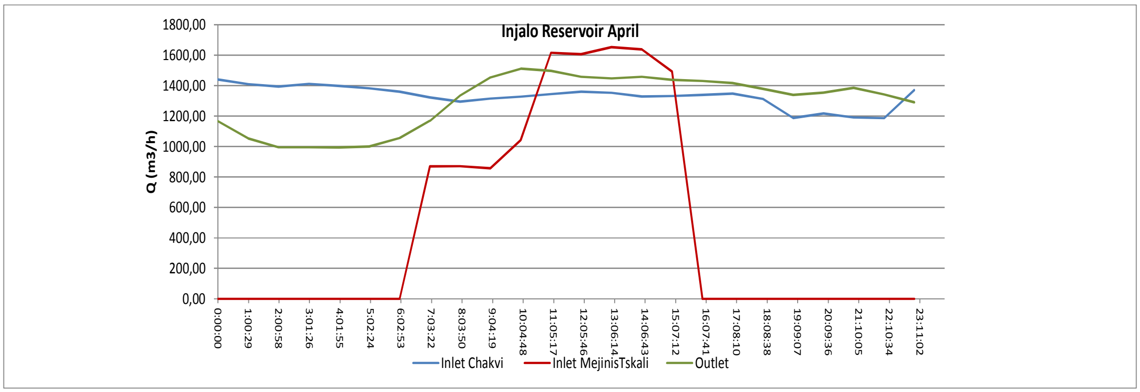


Figure 18: Injalo average 24 h consumption in April

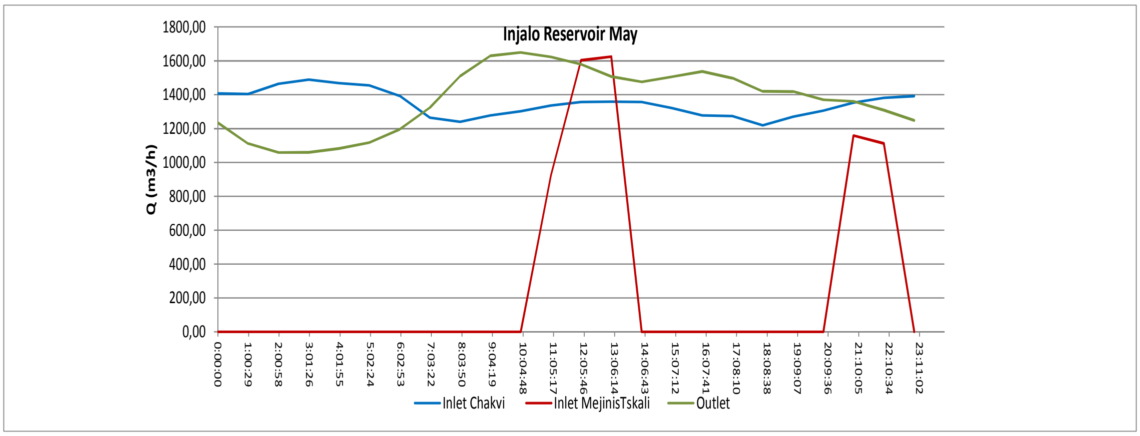


Figure 19: Injalo average 24 h consumption in May

In the case of Injalo, the minimum consumption occurs during night time with a value around 1.000 m^3/h as in Salibauri and the maximum is higher in March with around 2.000 m^3/h. So, during March Injalo was supplying the network more than Salibauri. The other months, April and May, the maximums were similar to Salibauri.

The inlet from Chakvi oscillates between 1.400 and 1.500 m3/h (the chart of March is registering one mistake at the end of the month) and the inlet from Mejinistkali presented values between 1.600 – 2.000 m3/h.

Respecting consumption patterns, we can see the increase on the maximum during March. Regarding the value of the minimum is similar to past periods.

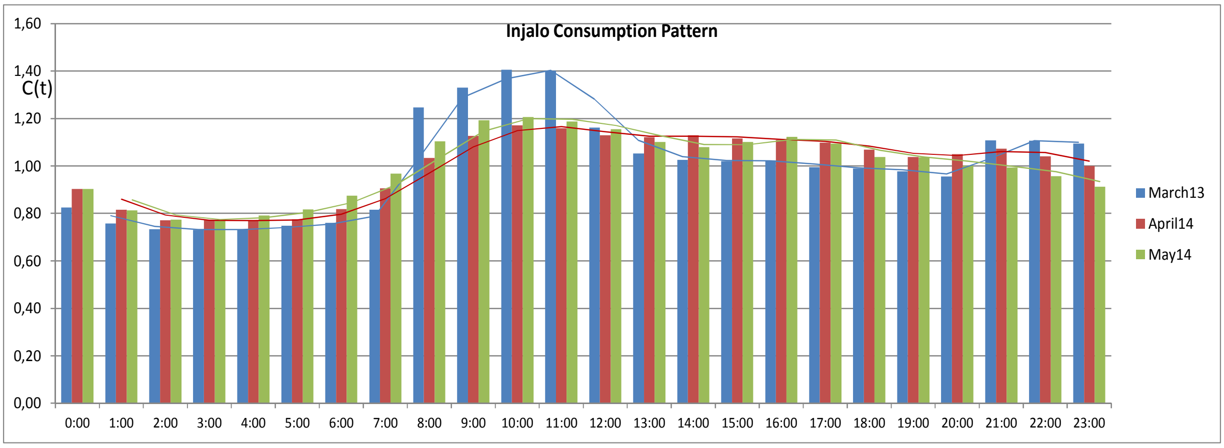


Figure 20: Injalo consumption pattern during the quarter

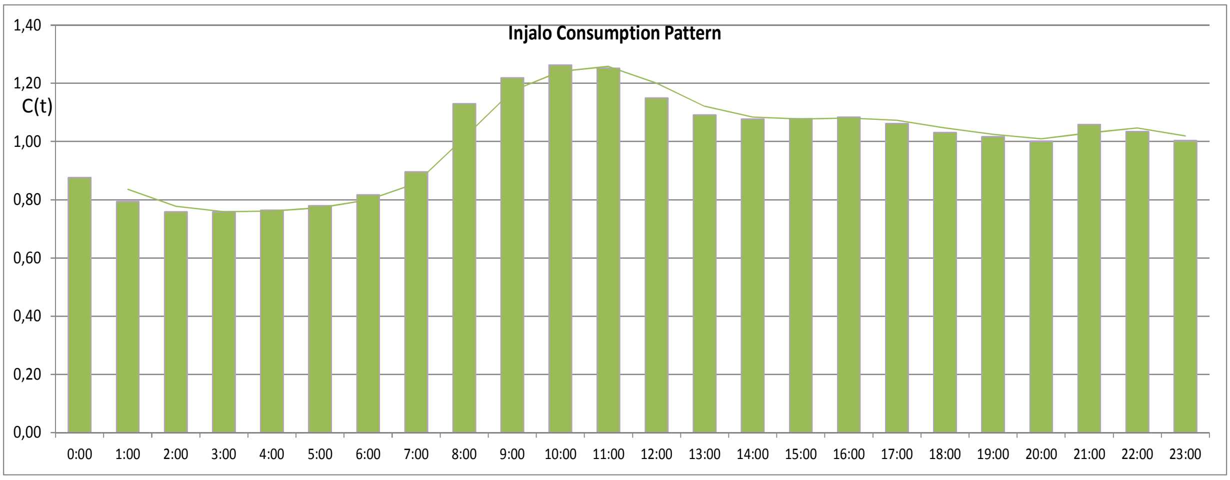


Figure 21: Injalo consumption pattern in average

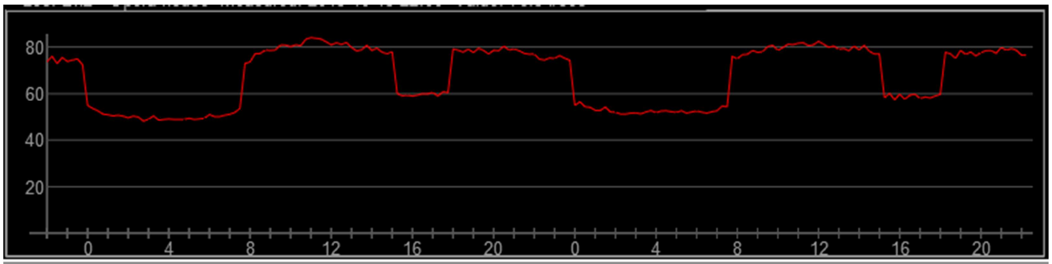
Finally, the flow measurements at the DMAs are being done by flow meters installed as showed on the design map. As it will be presented later when speaking about DMA implementation and about the MIS, each flow meter has installed a transmitter which sends the flow data each 15 minutes to the water utility server.

Due to this, we can know the flow in each device consulting the MIS on the website. On the other hand, we implemented on the MIS the calculation of the monthly flows in each flow meter in order to collect automatically the data.

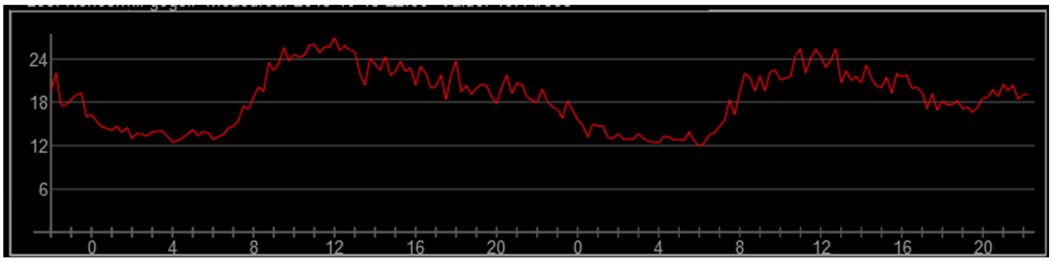
As having electricity cuts is still quite likely, the NRW team (water utility staff trained by us on NRW issues) is also getting the data from the flow meters via usb each month.

Following, examples of some flow meters data.

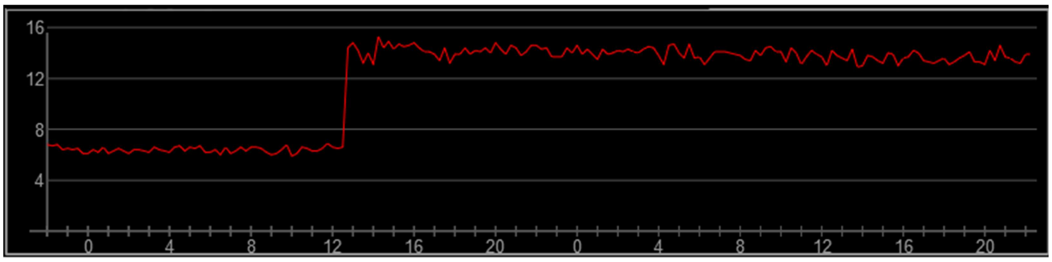
DMA 17



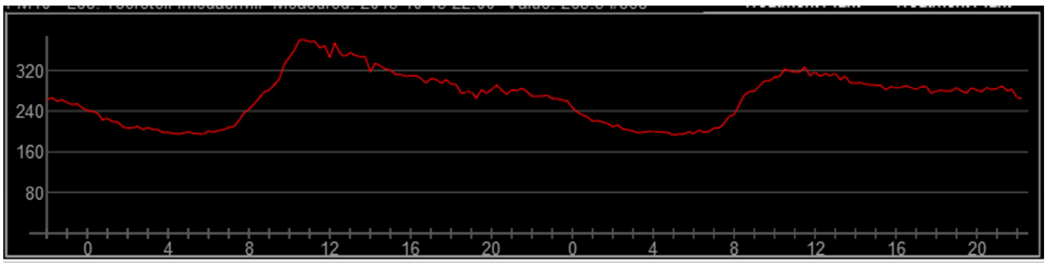
DMA 13



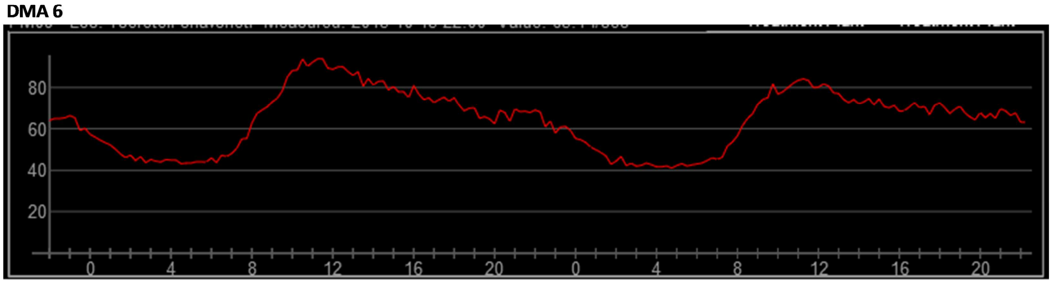
DMA 11a



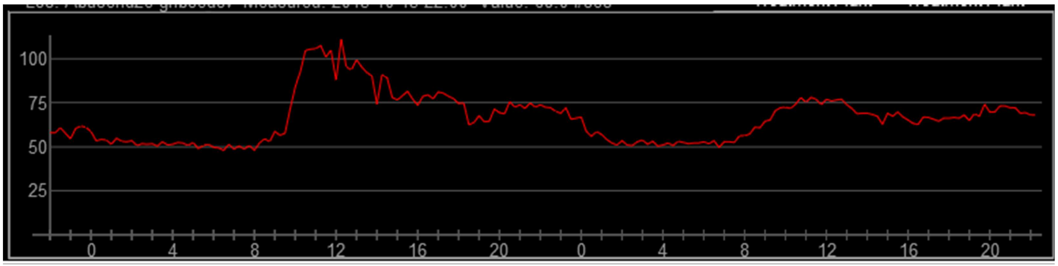
DMA 10



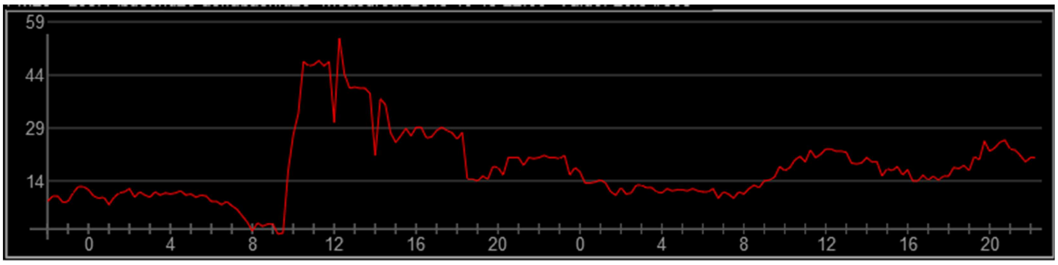
DMA 6



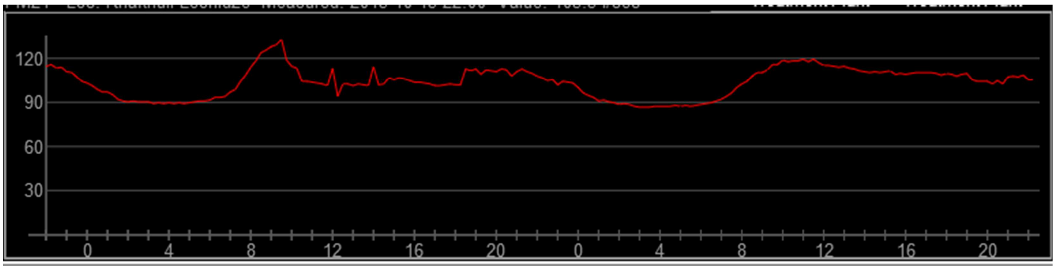
DMA 9



DMA 13



DMA 20



DMA 16

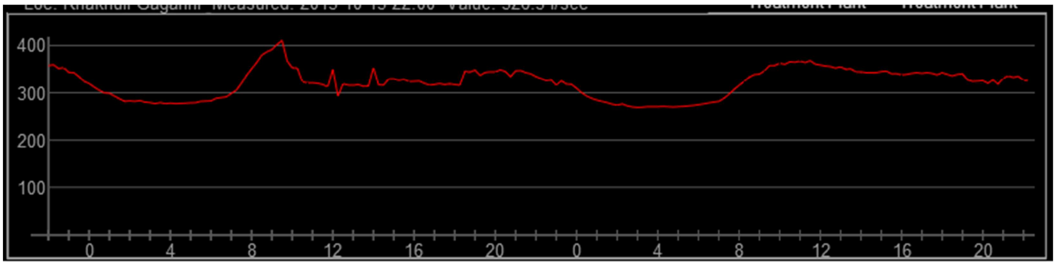


Figure 22: DMAs flow meters registers

The graphs of the most isolated DMAs, or with less inter-connection or less flow from one DMA to other, represent a similar shape as the consumption charts of the reservoirs.

In the case of the first one, DMA 17 which is connected to Chakvi line, the shape of the consumption pattern is different to the typical domestic one. It shows two cycles of consumption, as if it were working shifts in one large factory for instance. In fact, in this DMA is situated the Oil Terminal, identified as the largest customer there.

The consumption pattern of DMA 11a is also different to most of them. This DMA is still connected to Chakvi line, and present several illegal connections and leakages.

3.2.3.3 Pressure measurements

In this section we are presenting the evolution of the pressure during the reported quarter. As we know, DMAs under phase III are still connected to Chakvi line then there is a different tendency on the pressure between these areas and the other supplied by the new network.

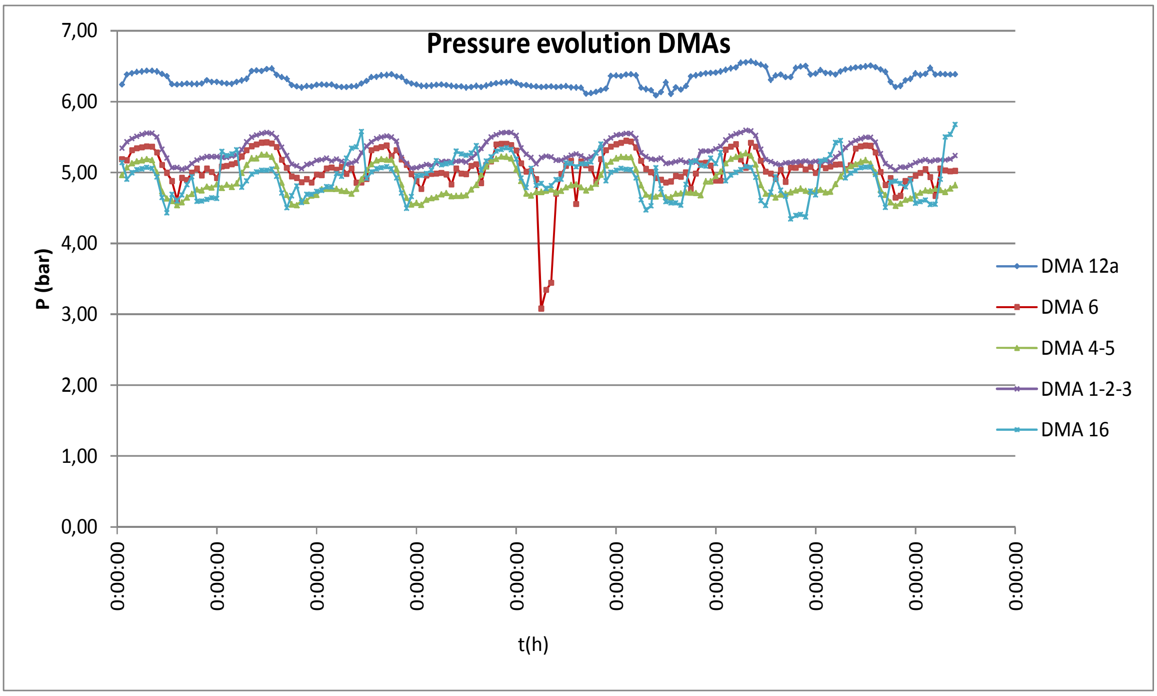


Figure 23: DMAs weekly (average) P evolution

As we can see on the chart and as usual, DMAs supplied by the reservoirs (all of them less 12a) have similar pressure values. These values have an oscillation between 4,5 and 5,5 bar approximately. Highest pressure peaks correspond to the lowest consumption hours (during night time) and vice versa.

The shape of the pressure evolution in those DMAs connected to the new system follow a domestic shape (as the consumption patterns).

On the other hand, DMA 12a is supplied directly from Chakvi line. In this case the oscillation of pressure is higher (6 – 6,5 bar) than the observed on the other areas, and also higher than the value observed the last period in this DMA. As we can notice, in the case of DMA connected to Chakvi line there are not significant differences between the pressure values during day or night time.

The fact of having high pressures during night time is one of the factors which explain the large amount of NRW registered in those DMAs still connected to Chakvi line.

3.2.4 Mathematical model

The mathematical model is the basis used in the hydraulic calculation to simulate different states that occur in the distribution network without having to physically get to experience them. In our case the chosen program to build the mathematical model is EPANET.

EPANET is software that models water distribution piping systems developed by EPA (United States Environmental Protection Agency). EPANET is public domain software that may be freely copied and distributed. It is a Windows 95/98/NT/XP program. EPANET performs extended period simulation of the water movement and quality behaviour within pressurized pipe networks.

Pipe networks consist of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks:

- the flow of water in each pipe,
- the pressure at each node,
- the height of the water in each tank,
- the type of chemical concentration throughout the network during a simulation period, water age, source, and tracing.

By the results of such simulations are then extracted consequences that will be used to planning and network management.

If we know the network data and state of consumption the problem of analysis is now solved because powerful calculation programs are available.

The process of developing a mathematical model is to collect all the network existing information and treat it to be assimilated by the analysis and simulation programs.

The objective of any mathematical model is reproduce by a computer, as accurately as possible, the actual behaviour of the physical system it represents.

The mathematical model of the distribution network will consist of a set of lines and nodes that represent pipes, pumps and pumping stations, and automatic control valves, tanks and reservoirs, and the consumption or injection points that form the network.

3.2.4.1 Auditing data

When starting our scope of work with the water utility it was decided to build a new mathematical model with the intention of modeling and include the leakages on the simulations.

The mathematical model that we need to those proposals is a Detailed Model. A Detailed Model should include most network elements. It is used to control the daily operations and regulation of the network, manoeuvring manage, leakage detection, remote control, pressure regulation and others.

To develop a Detailed Model we tried to make simplifications in the network, but including all the lines that are significant, meaning those with transport capacity on the network.

The information about the topology of the network was available in AutoCAD format, even it was detailed each network element, such as valves, pumps, tanks, etc. Regarding the implementation of DMAs, its design was an ongoing process at that moment.

3.2.4.2 Working plan

The development of the mathematical model was performed following this series of stages:

⇒ **Collection of information.**

⇒ **Skeletisation of the network:**

It consists in the real network's simplification, it will be done studying available information and as a Detailed Model. The isolation of each DMA as an independent unit is also needed.

⇒ **Analysis and assignment of recorded consumption:**

We have to assign the recorded demands in the consumption points of the model. By water balance and Billing Department information we will be able to divide the demand flow between the different consumption points in each DMA.

⇒ **Analysis and assignment of unrecorded consumption:**

Study and distribution of unaccounted consumption: leaks, meter errors, illegal connections, etc.

Following these stages we'll have a first model without validation. The following stages are focused on the correction and adjustment of network parameters so that the model will be able to simulate the system with certain reliability.

⇒ **Pressure and flow measures:**

We will make a series of measures in some parts of the network, for different charge states, which serve as the setting value in the next stage.

⇒ **Fitting the model:**

The Model reproduces by simulation the loading of the measurements. It is compared the values of pressure and flow measured in the network, with the results of the model, and adjusted the parameters searching that the ones match the others.

It would be needed a better database of customers, with the characteristics of the water meters (type, age and characteristic curve) and the characteristics of their consumption.

Using the water meters data already mentioned, we will be able to further adjust the value of NRW due to water consumed but not registered by measurement error [NRW metered (measurement error) in the balance]. This point will be possible by setting the Water Meters Error Curve.

As mentioned above, by using the customers consumption characteristics we can make different consumption patterns and their modulation curves. In every Mathematical Model's node we will be able to charge different modulation curves as consumption patterns exist (domestic, commercial, industrial, official, etc.).

By the Measurements Plan, we have increasingly significant values to load the model again. We can thus say that the development of the model is done by successive approximations, each one more accurate than the previous.

Later on chapter 2.4, we will present the NRW modeling and simulation.

3.3 Water balance

3.3.1 Introduction

Accordingly with the ongoing works rehabilitating the system, the water balance has been updated each time we had the possibility, gaining accuracy.

On this chapter we will present how we are managing the information related to water production, consumption and billing updating a monthly file which allows us to calculate the water balance.

That file is called Comprehensive Overview and will be explained below.

3.3.2 Comprehensive Overview

This monthly-updated Excel file is nowadays divided by DMAs despite we are on the process of isolation and also some of them are under phase III rehabilitation as explained.

The structure of the Excel sheet is organized in different areas representing each inflow and outflow of the system, and its distribution structure.

The file calculates automatically the amounts of consumption and NRW taking into account different scenarios, after updating some data on enabled cells.

At the end of the sheet, the IWA water balance is calculated with the updated data each month being useful to calibrate the model and simulate the system.

Bellow the comprehensive overview is presented, in this case the last available one, June 2014. After the presentation each one of the parts is defined.

1)

Input Data		
Outlet Chakvi TP	m^3	2.704.689
Outlet Chaisubani TP	m^3	498.720
Outlet Mejinistskali	m^3	354.187
Outlet Salibauri	m^3	972.265
Outlet Injalo	m^3	1.007.998

Distribution Water Balance		
Water Production	m^3	3.557.596
Inlet reservoirs	m^3	1.980.263
Inlet DMA17	m^3	191.029
Consumption+ Leakages	m^3	**1.386.304**
	%	**39%**

2)

Inlet Salibauri		
Chakvi Inlet	m^3	392.069
Chaisubani Inlet	m^3	728.064
Total	m^3	**1.120.133**

Inlet Injalo		
Chakvi Inlet	m^3	884.297
MejiniTskali	m^3	354.187
Total	m^3	**1.238.484**

DMAs Water Balance

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b
FM measuring DMA Inflows	ID	FM36;FM10	FM11	FM09;**FM16A;FM17**	FM18;FM19	FM26;FM30A	FM20;FM25	**FM08**;FM15	**FM16**
FM measuring DMA Outflows	ID	**FM08**;FM11	FM30A	FM18			FM19;FM24;**FM26**		**FM16A**;**FM17**
Inflow metered	m^3	651.337	429.411	63.746	142.159	365.017	120.705	20.041	
Outflow metered	m^3	429.411	186.384	65.382			76.777		
Input Volume per DMA	m^3	**221.926**	**243.026**	**-1.636**	**142.159**	**365.017**	**43.928**	**20.041**	

DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
FM13		FM29;FM30	**FM28**	FM21	FM22	FM12	FM23	**FM27**	FM24
			FM31;FM29	FM20	FM23;**FM28**; FM25		**FM27**		
51.831		224.687		66.009	946.373	191.029	56.474		
			43.576	59.866	117.313				
51.831		**224.687**	**-43.576**	**6.143**	**829.060**	**191.029**	**56.474**		

3)

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA9	DMA 10	DMA 11a	DMA 11b	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
Population - Capita - Inhabitants																			
Single	No.	372	658	2230	1713	967	332	17	1406	828	36	4	59		17	134			127
Italian	No.	5273	2798	2315	1338	874	99	55	735	404	483	299	15			383			151
Block	No.	3694	7926	2157	2829	4509	4892	95	1391	1417	430	4269	4898		9210	4208			2185
Total Householders (Domestic)	No.	**9.339**	**11.382**	**6.702**	**5.880**	**6.350**	**5.323**	**167**	**3.532**	**2.649**	**949**	**4.572**	**4.972**		**9.227**	**4.725**			**2.463**

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA9	DMA 10	DMA 11a	DMA 11b	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
Number of Customers																			
Single	No.	234	340	1167	917	477	258	7	775	429	15	4	46	283	140	88	107	92	76
Italian	No.	3074	1631	1447	846	502	109	25	367	290	178	192	6	67	73	152	14	6	140
Block	No.	2418	5091	1353	1772	2440	2456	30	640	630	189	3110	4672		3696	1934	121		929
Total Householders (Domestic)	No.	**5.726**	**7.062**	**3.967**	**3.535**	**3.419**	**2.823**	**62**	**1.782**	**1.349**	**382**	**3.306**	**4.724**	**350**	**3.909**	**2.174**	**242**	**98**	**1.145**
Smaller Legal Entities (Commercial)	No.	739	499	257	173	161	83	2	98	29	2	96	45	13	145	47	3		45
Bigger Legal Entities (Industrial)	No.	3				2		3	2	1						1			
Public entities	No.	29	26	7	9	3	1	1	4	3	1	17	3		6	7	1		9
Total=H+C+I+P	No.	**6.497**	**7.587**	**4.231**	**3.717**	**3.585**	**2.907**	**68**	**1.886**	**1.382**	**385**	**3.419**	**4.772**	**363**	**4.060**	**2.229**	**246**	**98**	**1.199**

Number of Customers Watermeters									
Single	No.	231	363	1348	1041	555	276	1	36
Italian	No.	2507	1230	1182	732	299	66		63
Block	No.	935	1715	452	611	366	373		60
Total Householders (Domestic)	No.	**3.673**	**3.308**	**2.982**	**2.384**	**1.220**	**715**	**1**	**159**
Smaller Legal Entities (Commercial)	No.	737	498	256	173	161	83	2	96
Bigger Legal Entities (Industrial)	No.	3				2		3	2
Public entities	No.	29	25	7	9	3	1	1	4
Total=H+C+I+P	No.	**4.442**	**3.831**	**3.245**	**2.566**	**1.386**	**799**	**7**	**261**

427		1	138	295	132	1	107	90	87
159		195	166	43	63	13	14	6	77
337		1224	2068		162	47	119		254
923		**1.420**	**2.372**	**338**	**357**	**61**	**240**	**96**	**418**
29	2	96	44	13	144	47	3		45
1						1			
3	1	16	3		6	7	1		9
956	**3**	**1.532**	**2.419**	**351**	**507**	**116**	**244**	**96**	**472**

DMA	DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA9	DMA 10	DMA 11a	DMA 11b

Billed Metered Consumption									
Single	m^3	3019	6805	32802	23100	15470	6735	16	994
Italian	m^3	28474	17122	17940	10629	4807	1250		767
Block	m^3	9492	16447	5231	7821	4572	3370		402
Total Householders (Domestic)	m^3	**40.985**	**40.374**	**55.973**	**41.549**	**24.849**	**11.355**	**16**	**2.163**
Smaller Legal Entities (Commercial)	m^3	25122	14407	3378	5097	5320	1521	114	1556
Bigger Legal Entities (Industrial)	m^3	15340				2063		581	2563
Public entities	m^3	2386	2485	1388	1878	752	84	111	51
Total=H+C+I+P	m^3	**83.834**	**57.266**	**60.739**	**48.525**	**32.984**	**12.960**	**822**	**6.333**

DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
9384			2082	7671	2917	4	3081	3337	2053
3357		2302	1951	995	980	203	228	150	1459
4101		6588	8214		1260	253	1341		2879
16.842		**8.890**	**12.247**	**8.666**	**5.157**	**460**	**4.650**	**3.487**	**6.391**
616	7	5293	2498	490	4907	2586	50		2845
51						325			
193	275	1600	968		812	986	16		466
17.702	**282**	**15.783**	**15.713**	**9.156**	**10.875**	**4.357**	**4.716**	**3.487**	**9.702**

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA9	DMA 10	DMA 11a	DMA 11b
SCENARIO 1									
Billed Unmetered Consumption	**(120 L/capita/day)**								
Single	m^3	43	230	259	166	338	54	61	6812
Italian	m^3	1458	1346	565	86	803		126	2556
Block	m^3	7394	22864	4766	6847	14602	16279	342	4399
Total Householders (Domestic)	m^3	**8.896**	**24.440**	**12.679**	**7.099**	**15.743**	**16.333**	**529**	**13.767**
Smaller Legal Entities (Commercial)	m^3	40	52	4					650
Bigger Legal Entities (Industrial)	m^3								
Public entities	m^3		33						
Total=H+C+I+P	m^3	**8.936**	**24.525**	**12.683**	**7.099**	**15.743**	**16.333**	**529**	**14.417**

DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
695	76	14	7		14	792			104
551	900	601				1512			324
2311	1397	12776	17172		32202	15030			6469
3.557	**2.372**	**13.392**	**17.179**		**32.216**	**17.334**			**6.898**
			6		6				
		129							
3.557	**2.372**	**13.521**	**17.185**		**32.223**	**17.334**			**6.898**

4)

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
SCENARIO 2				**Scenario 2**	**L/cap/day=**	**700**	**120**	**5,83**	**<---ratio**										
Billed Unmetered Consumption	**(700 L/capita/day)**																		
Single	m³	252	1344	1512	966	1974	315	357	39737	4053	441	84	42		84	4620			609
Italian	m³	8505	7854	3297	504	4683		735	14910	3213	5250	3507				8820			1890
Block	m³	43134	133371	27804	39942	85176	94962	1995	25662	13482	8148	74529	100170		187845	87675			37737
Total Householders (Domestic)	m³	**51.891**	**142.569**	**32.613**	**41.412**	**91.833**	**95.277**	**3.087**	**80.309**	**20.748**	**13.839**	**78.120**	**100.212**		**187.929**	**101.115**			**40.236**
Smaller Legal Entities (Commercial)	m³	233	303	23					3792				36		36				
Bigger Legal Entities (Industrial)	m³																		
Public entities	m³		193									750							
Total=H+C+I+P	m³	**52.124**	**143.065**	**32.636**	**41.412**	**91.833**	**95.277**	**3.087**	**84.100**	**20.748**	**13.839**	**78.870**	**100.248**		**187.965**	**101.115**			**40.236**

5)

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b
Total Consumption = Revenue Water	**(120 L/capita/day)**								
Single	m³	3062	7035	33061	23266	15808	6789	77	7806
Italian	m³	29932	18469	18505	10715	5610	1250	126	3323
Block	m³	16886	39310	9997	14668	19174	19649	342	4801
Total Householders (Domestic)	m³	**49.881**	**64.814**	**61.564**	**48.649**	**40.592**	**27.688**	**545**	**15.930**
Smaller Legal Entities (Commercial)	m³	25162	14459	3382	5097	5320	1521	114	2206
Bigger Legal Entities (Industrial)	m³	15340				2063		581	2563
Public entities	m³	2386	2518	1388	1878	752	84	111	51
Total=H+C+I+P	m³	**92.769**	**81.791**	**66.333**	**55.624**	**48.727**	**29.293**	**1.351**	**20.750**

DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
10079	76	14	2089	7671	2931	796	3081	3337	2157
3908	900	2903	1951	995	980	1715	228	150	1783
6412	1397	19364	25386		33462	15283	1341		9348
20.399	**2.372**	**22.282**	**29.426**	**8.666**	**37.373**	**17.794**	**4.650**	**3.487**	**13.289**
616	7	5293	2504	490	4913	2586	50		2845
51						325			
193	275	1729	968		812	986	16		466
21.259	**2.654**	**29.304**	**32.898**	**9.156**	**43.098**	**21.691**	**4.716**	**3.487**	**16.600**

DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA9	DMA 10	DMA 11a	DMA 11b
Total Consumption = Revenue Water	**(700 L/capita/day)**								
Single	m^3	3271	8149	34314	24066	17444	7050	373	40730
Italian	m^3	36979	24976	21237	11133	9490	1250	735	15677
Block	m^3	52626	149818	33035	47763	89748	98332	1995	26064
Total Householders (Domestic)	m^3	**92.876**	**182.943**	**88.586**	**82.961**	**116.682**	**106.632**	**3.103**	**82.471**
Smaller Legal Entities (Commercial)	m^3	25355	14710	3401	5097	5320	1521	114	5348
Bigger Legal Entities (Industrial)	m^3	15340				2063		581	2563
Public entities	m^3	2386	2678	1388	1878	752	84	111	51
Total=H+C+I+P	m^3	**135.958**	**200.331**	**93.375**	**89.937**	**124.817**	**108.237**	**3.909**	**90.433**

DMA 11b	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
40730	13437	441	84	2124	7671	3001	4624	3081	3337	2662
15677	6570	5250	5809	1951	995	980	9023	228	150	3349
26064	17583	8148	81117	108384		189105	87928	1341		40616
82.471	**37.590**	**13.839**	**87.010**	**112.459**	**8.666**	**193.086**	**101.575**	**4.650**	**3.487**	**46.627**
5348	616	7	5293	2534	490	4943	2586	50		2845
2563	51						325			
51	193	275	2350	968		812	986	16		466
90.433	**38.450**	**14.121**	**94.653**	**115.961**	**9.156**	**198.841**	**105.472**	**4.716**	**3.487**	**49.938**

6)

Inflows and Outflows										
DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b
FM measuring DMA Inflows	ID	FM36;FM10	FM11	FM09;FM16A; FM17	FM18;FM19	FM26;FM30A	FM20;FM25	FM08;FM15	FM16
FM measuring DMA Outflows	ID	FM08;FM11	FM30A	FM18			FM19;FM24;FM26		FM16A;FM17
Inflow metered	m^3	651.337	429.411	63.746	142.159	365.017	120.705	20.041	
Outflow metered	m^3	429.411	186.384	65.382			76.777		
Input Volume per DMA	m^3	**221.926**	**243.026**	**-1.636**	**142.159**	**365.017**	**43.928**	**20.041**	

DMA	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
FM measuring DMA Inflows	FM13		FM29;FM30	FM28	FM21	FM22	FM12	FM23	FM27	FM24
FM measuring DMA Outflows				FM31;FM29	FM20	FM23;FM28; FM25		FM27		
Inflow metered	51.831		224.687		66.009	946.373	191.029	56.474		
Outflow metered				43.576	59.866	117.313				
Input Volume per DMA	**51.831**		**224.687**	**-43.576**	**6.143**	**829.060**	**191.029**	**56.474**		

7)

SCENARIO 1

Non-Revenue Water = Input Volume - Revenue Water (120 L/capita/day)									
DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b
Total Revenue Water	m^3	92.769	81.791	66.333	55.624	48.727	29.293	1.351	20.750
% Revenue Water	%	41,80%	33,66%	-4054%	39%	13%	67%	7%	#DIV/0!
Total Non-Revenue Water	m^3	129.157	161.235	-67.970	86.535	316.290	14.635	18.690	-20.750
% Non-Revenue Water	%	58,20%	66,34%	4154%	61%	87%	33%	93%	#DIV/0!

DMA	DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
Total Revenue Water	21.259	2.654	29.304	32.898	9.156	43.098	21.691	4.716	3.487	16600
% Revenue Water	41%	#DIV/0!	13%	-75%	149%	5%	11%	8%	#DIV/0!	#DIV/0!
Total Non-Revenue Water	30.572	-2.654	195.384	-76.474	-3.013	785.962	169.338	51.758	-3.487	-16.600
% Non-Revenue Water	59%	#DIV/0!	87%	175%	-49%	95%	89%		#DIV/0!	#DIV/0!

SCENARIO 2

Non-Revenue Water = Input Volume - Revenue Water (700 L/capita/day)										
DMA		DMA 1-2-3	DMA 4-5	DMA 6	DMA 7-8	DMA 9	DMA 10	DMA 11a	DMA 11b
Total Revenue Water	m³	135.958	200.331	93.375	89.937	124.817	108.237	3.909	90.433
% Revenue Water	%	61,26%	82,43%	-5706%	63%	34%	246%	20%	#DIV/0!
Total Non-Revenue Water	m³	85.968	42.696	-95011,20185	52.223	240.200	-64.309	16.132	-90.433
% Non-Revenue Water	%	38,74%	17,57%	5806%	37%	66%	-146%	80%	#DIV/0!

DMA 12a	DMA 12b	DMA 13	DMA 14	DMA 15	DMA 16	DMA 17	DMA 18	DMA 19	DMA 20
38.450	14.121	94.653	115.961	9.156	198.841	105.472	4.716	3.487	49.938
74%	#DIV/0!	42%	-266%	149%	24%	55%	8%	#DIV/0!	#DIV/0!
13.381	-14.121	130.034	-159.537	-3.013	630.219	85.557	51.758	-3.487	-49.938
26%	#DIV/0!	58%	366%	-49%	76%	45%	92%	#DIV/0!	#DIV/0!

Comprehensive overview structure (only green cells are available to input data):

1) Water production data, network distribution and reservoirs inlets.
2) DMAs water balance: flow meters readings.
3) Billing data: population, customer type*, nº customers/DMA, nº customers with water meter/DMA, billed metered consumption, billed unmetered consumption (scenario 1).
4) Billed unmetered consumption (calculation scenario 2).
5) Total consumption: revenue water per DMA (both scenarios).
6) DMA inflows and outflows (from point 2).
7) Non-revenue water per DMA (both scenarios).

*Customer type: householders (domestic consumption) are divided in single houses, blocks (apartment buildings) and Italian yards (typical houses disposition around a common courtyard).

The reason to use two scenarios is because nowadays the billing of the customers without water meter is not representing the reality of the consumption. Then, the Scenario 1 is calculated with the assumption of consumption of 120 L/cap/day which the water utility is billing to the customers. The Scenario 2 tries to represent the real consumption, taking into account some measurements done for example at the multi-apartment buildings which have not individual water meters at this moment. On those measurements we can notice the reality of the large consumption and calculate the Scenario 2 accordingly.

3.3.3 IWA Water Balance

The last part of the comprehensive overview uses the data from Scenario 1 and Scenario 2 to calculate the IWA water balance of the entire system.

Despite we are implementing the DMAs as explained before, it is not possible at the moment to calculate the IWA water balance per DMA, which is our next target. So, at the moment, we are calculating it for the system as a whole.

Below we are presenting the balance as it appears on the comprehensive overviews, in this case calculated for Scenario 2.

Finally, for the terms which form the non-revenue water, we are trying to accurate them increasingly. At the moment we are calculating some of them by random measurements and estimating the others.

Sistem Input Volume=Inflow from Reservoirs Salibauri and Injalo	m^3	2.171.292
Billed Metered Consumption = Sum of Billed Metered Consumption per DMA	m^3	395.233
Billed Unmetered Consumption = Sum of Billed Unmetered Consumption per DMA	m^3	1.086.557
Revenue Water = Sum of Billed Metered Consumption per DMA + Sum of Billed Unmetered Consumption per DMA = Billed Authorized Consumption	m^3	1.481.790
Non-revenue Water = SIV - RW	m^3	689.502
unbilled Metered Consumption	m^3	34.475
unbilled Unmetered Consumption	m^3	68.950
unbilled Authorized Consumption = unbilled Met.Cons + unbilled Unmet.Cons.	m^3	103.425
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	1.585.215
Water Losses = Sistem Input Volume - Authorized Consumption	m^3	586.077
Unauthorized consumption	m^3	275.801
Metering Inaccuracies and Data Handling Errors	m^3	89.635
Leakage on Transmission and/or Distribution Mains	m^3	13.790
Leakage and Overflow s at Utility's Storage Tanks	m^3	68.950
Leakage on Service Connections up to Point of Customer Metering	m^3	137.900
Real Loses=Leakage on Transmission+ Leakage and Overflow s at Tanks + Leakage on Service Connection	m^3	220.640
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	365.436

Lm = Length of mains	km	9
Nc = Number of service connections, Nc>5000	No.	42968
Lp = Total length of private pipe, property line to customer meter (km)	km	201
DC = Density of connections / km mains, DC> 20	No./km	4774
P = Average Pressure, P>25m	m	55
Unavoidable Annual Real Losses (UARL) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P	L/day	2.175.877
Real Losses = CARL = Water Losses - Apparent Losses	m^3	163.588
% Non-Revenue Water	%	23,5%
Infrastructure Leakage Index = ILI = CARL / UARL		0,075

System input volume 2.171.292 100%	Authorized Consumption 773.123 36%	Billed Authorized Consumption 526.387 24%	Billed Metered Consumption 363.738 17%	Revenue Water 526.387 24%
			Billed Unmetered Consumption 162.649 7%	
		Unbilled Authorized Consumption 246.736 11%	Unbilled Metered Consumption 82.245 4%	Non Revenue Water 1.644.906 76%
			Unbilled Unmetered Consumption 164.491 8%	
	Water Losses 1.398.170 64%	Apparent Losses 871.800 40%	Unauthorized Consumption 657.962 30%	
			Metering Inaccuracies and Data Handling Errors 213.838 10%	
		Real Losses 526.370 24%	Leakage on Transmission and/or Distribution Mains 32.898 2%	
			Leakage and Overflows at Utility's Storage Tanks 164.491 8%	
			Leakage on Service Connections up to Point of Customer Metering 328.981 15%	

Figure 24: IWA water balance

3.4 NRW Mathematical Model

3.4.1 Introduction

The aim of this chapter is to present the results obtained after the first simulation done to calibrate the NRW Mathematical Model. The simulation was based on 24 h.

At the moment of this first simulation, the DMAs were not completely connected to the new network, and inside the DMAs which were already connected, the customers were not completely metered by water meters. To solve this temporal and on-going situation, we have been considered the following assumptions:

⇒ The base demand applied to the model's consumption nodes has been calculated from the average of the monthly Measurements Plan we had until that moment, dividing the amount of water which supplied the new network on that period between the consumption nodes.

⇒ The demand pattern applied to the model's consumption nodes was the average Consumption Pattern we calculated in Salibauri and Injalo outflows until that moment.

Regarding the NRW modeling, there are three possible methods which are presented as follows and explained on the next point.

⇒ Case 1. Correction of registered demands with a demand factor to compensate volumetric losses.

⇒ Case 2. Interpretation of all volumetric losses as constant and independent of the time instant.

⇒ Case 3. Using emitters to represent leakage. The NRW consumed can be represented either as a second category of demand, as well as a correction factor of demand.

Figure 25: Consumption distribution at 0:00 h

3.4.2 Including NRW in the Mathematical model

The non-revenue water can be defined as follows:

NRW= Macro metering (flow meters at water sources) - Micro metering (water meter customers)

The distribution that NRW follows is summarized on the next table:

NRW DISTRIBUTION	
CONSUMED WATER	***NO CONSUMED WATER***
Unmetered Consumption	Network's leakage
Water meters or measurement error	Network's evaporation
Street cleaning	Overflow
Sewer drains	Cleaning and maintaining the network
Illegal connections	

Table 5: NRW Distribution

The types of consumption that can be modelled in our mathematical model (EPANET) are explained on the followings tables.

<table>
<tr><th colspan="2">USER-DEFINED CONSUMPTION</th><th colspan="2">HYDRAULIC-CALCULATION-DEPENDENT CONSUMPTION</th></tr>
<tr><th>Constant Consumption</th><th>Time-varying Consumption</th><th>Pressure-dependent Consumption</th><th>Calculated Consumption</th></tr>
<tr><td rowspan="3">Are defined by the Basis Demand property in the form of each of the connections.</td><td>They are defined by a Modulation Curve referred to the connections' Basis Demand property.</td><td>They are defined by the use of Emitters.</td><td>They are the contributions or removals of flow that occur in tanks or reservoirs.</td></tr>
<tr><td>Modulation Curve is specified in Demand Pattern property in the form of each connection.</td><td rowspan="2">To define these emitters is used Emitter Coefficient property of each of the connections.</td><td rowspan="2"></td></tr>
<tr><td>The Demand Pattern is published in the Patterns section.</td></tr>
</table>

Table 6: Consumption modelled types by EPANET

BASIS DEMAND	***SIGN CRITERIA***	***WARNINGS***
It is the characteristic property for modeling a constant consumption over time.	Positive: Flow extracted from the network.	The flow rates of the nodes are maintained at all times, including physically impossible operating conditions.
Units: l/s (LPS)	Negative: Flow that is injected into the network.	Possible calculation errors.
		Possible incompatibilities with other elements that regulate the flow of a line (QCV).

Table 7: Constant Consumption modeling

The time-varying consumption at the nodes are modeling using the concept of **Modulation Coefficient** (**Cm**):	**Q(t)=Cm(t)·Qav** **Qav: flow in average**
EPANET performs constant flow during the interval calculation.	

Table 8: Time-Varying Consumption modeling

Using the EPANET's property *Demand Pattern* it is possible to combine in a single consumption node different modulation curves, i.e. different consumption patterns. The parameters of this property are presented in the next table.

PARAMETERS	
BASIS DEMAND	That is the referring flow rate of each type of consumption.
TIME PATTERN	That is the reference to the consumption pattern of each defined consumer type.
CATEGORY	Label to identify a type of consumption.

Table 9: Demand Patterns

For Pressure-Dependent consumption modeling each EPANET node can associate a flow discharge possibility depending on the pressure.

$$Q = EC \cdot \sqrt{P}$$

Each emitter is equivalent to a discharge to a reservoir whose level is the same as the elevation of the node and it supports both discharges as contributions flow.

The properties and the elements modelled by emitters are defined on the next tables.

NODE PROPERTIES ASSOCIATED WITH THE EMITTER	
NODE HEIGHT:	It represents the back pressure discharge.
EMITTER COEFFICIENT (EF):	Discharge characteristic coefficient.

Table 10: Emitter node properties

ELEMENTS MODELED BY EMITTERS	
Any element resistant to atmosphere:	**Any pressure-dependent consumption:**
Sprinklers	Domestic consumption curves
Irrigation or fire hydrants	
Leaks or defects in the system	

Table 11: Elements modelled by emitters

There are three possible methods to include the NRW to the model as we said before.

⇒ Inclusion of the NRW as a *Correction Coefficient of Demand* (assuming a similar behaviour to recorded consumption).

⇒ Inclusion of the NRW as a *Constant Value* over time.

⇒ Inclusion of leakage as emitters (flow dependent pressure). *Emitter Coefficient's determination*.

$$Ec = \frac{Q}{\sqrt{P}}$$

After the NRW distribution we are going to simulate each method with our model.

3.4.3 NRW distribution

In each of the cases mentioned in the previous section, volumetric losses will be distributed as follows, according to the conclusions of the survey of the AEAS (Asociación Española de Abastecimientos y Saneamiento) which we are using as "start point" in Batumi's new network:

- Leakages and Losses= 45%
- Measurement error= 18%
- Illegal connections= 4%
- Other/unknowns= 33%

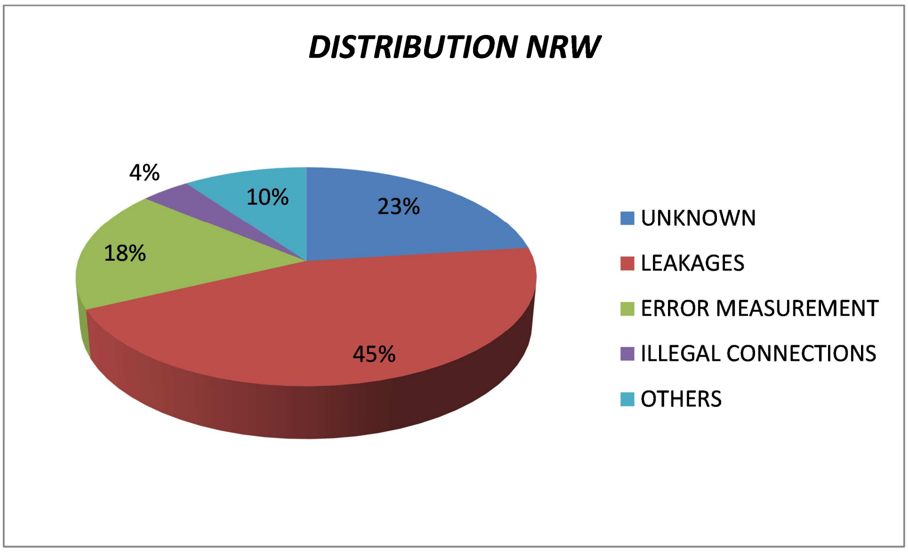


Figure 26: NRW distribution (AEAS)

The first step is to apply these percentages in our system. As we commented previously, these applying will be different depending on the Scenario. However, the volume injected to the network from the reservoirs is the same in both Scenarios.

⇒ Water volume injected in the network.

The volume injected to the network during the period (1 month) according to the model is equal to 915.234 m^3.

Total supplied water from Salibauri reservoir (according to the model) was 445.461 m^3, and Injalo reservoir supplied the network with 469.773 m^3.

As we can see, the model divides the consumption demanded by the network between the two reservoirs (about half and half). To approximate the simulation to the reality, we have evaluated the possibility of supplying the network only with one reservoir. The results are presented later.

Time Hours	Flow LPS
0:00	133,17
1:00	131,61
2:00	130,05
3:00	128,49
4:00	131,85
5:00	136,84
6:00	159,86
7:00	189,44
8:00	204,28
9:00	214,19
10:00	212,63
11:00	207,78
12:00	201,28
13:00	191,52
14:00	185,01
15:00	185,03
16:00	183,56
17:00	178,15
18:00	172,84
19:00	169,28
20:00	167,52
21:00	157,11
22:00	139,42
23:00	123,21

Time Hours	Flow LPS
0:00	135,34
1:00	133,59
2:00	131,83
3:00	130,08
4:00	133,35
5:00	138,31
6:00	161,69
7:00	191,78
8:00	206,78
9:00	216,76
10:00	215,01
11:00	209,91
12:00	203,15
13:00	193,02
14:00	186,27
15:00	186,25
16:00	191,03
17:00	189,81
18:00	188,49
19:00	188,74
20:00	190,50
21:00	184,34
22:00	172,19
23:00	161,88

Figure 27: Flow injection 24 h distribution from Salibauri (left) and Injalo (right)

There is a difference between the amount of water injected in the network calculated by the model and registered by the flow meters in Salibauri and Injalo.

PERIOD FLOW INJECTION (m^3)	
MODEL	915.234
MEASUREMENTS PLAN	874.792
DIFFERENCE	40.442

Table 12: Flow injection difference between Model and Measurements Plan

This difference would decrease in the next simulations due to the calibration of the model. It can be explained as we are using the total inflow divided between the consumption nodes of the model, and in the reality in this moment, the inflow is supplying only some parts of the network, not the entire network.

To calibrate the model, the difference between flow injection metered in the reservoirs in the calculation period and the injected modelled flow will be considered as NRW.

The distribution of the NRW is done like it was explained, as we can see as follows.

NRW DISTRIBUTION (m^3)	
Leakages 45%	18.199
Measurement errors 18%	7.280
Illegal connections 4%	1.618
Unknown 33%	13.346

Table 13: NRW distribution

Once NRW has been distributed, the next step is to apply it to the model using the three methods explained previously.

3.4.4 NRW modeling case 1: correction with a demand factor

With this method we are adjusting the volumetric losses into the registered water, and re-simulating the system. The Demand Factor will be calculated as follows:

$$F_d = \frac{\forall_{registered}}{\forall_{injected}}$$

The next table shows the calculation of the demand factor depending on the scenario.

Fd Calculation	Scenario 2 (300 L/cap/d)
Injected Water (m^3)	915.234
Registered Water (m^3)	874.792
Fd	0,96

Table 14: Demand factor calculation

The simulation with this demand factor affecting to the consumption curve leads to the adjustment between injected and registered water, as expected. However, EPANET presents problems of unbalanced system during some hours of the simulation due to the apparition of negative pressures. The next figure shows the reservoir's outflow distribution in this case.

Salibauri Outflow

Time Hours	Flow LPS
0:00	127.83
1:00	126.36
2:00	124.89
3:00	123.36
4:00	126.60
5:00	131.36
6:00	153.49
7:00	181.89
8:00	196.14
9:00	205.63
10:00	204.14
11:00	199.47
12:00	193.25
13:00	183.86
14:00	177.64
15:00	177.66
16:00	179.27
17:00	171.98
18:00	166.61
19:00	162.98
20:00	161.08
21:00	150.91
22:00	133.75
23:00	117.98

Injalo Outflow

Time Hours	Flow LPS
0:00	129.94
1:00	128.23
2:00	126.52
3:00	124.87
4:00	128.00
5:00	132.78
6:00	155.20
7:00	184.09
8:00	198.48
9:00	208.08
10:00	206.39
11:00	201.51
12:00	195.00
13:00	185.30
14:00	178.79
15:00	178.77
16:00	180.34
17:00	181.27
18:00	180.27
19:00	180.72
20:00	182.62
21:00	176.87
22:00	165.40
23:00	155.71

Figure 28: Reservoirs flow injection 24 h distribution, case 1

The correction between the injected and registered water is done by the application of the factor, as the next table shows.

DEMAND FACTOR CORRECTION (m^3)	
Injected Water (m^3)	878.628
Registered Water (m^3)	874.792
Difference (m^3)	2.354

Table 15: Results demand factor correction

The model calculates the adjustment as a result of the reduction of the peaks of consumption in the nodes due to the consumption pattern. This procedure could reduce the leakages during the night time (higher pressure) but it can also reduce the demanded consumption during day time.

3.4.5 NRW modeling case 2: constant leak flow

In this case we will consider volumetric losses as constants and independent of the time at which they occur. It means that the leak flow will be constant and proportional to the base demand in each node. As we divided the total consumption between the consumption nodes of the model as a first approximation for this simulation, the base demand will be the same in each node, and in consequence, the leak flow will also be the same.

To simulate this case, we have to use a constant modulation curve (same consumption pattern in each hour).

The NRW flow distribution in the model has been done as follows:

CONSTANT LEAK FLOW DISTRIBUTION	
Registered Water (m^3): 874.792	Base Demand: 0,296 L/s
NRW (m^3): 40.442	NRW Flow: 0,014 L/s
Total Demand:	0,309 L/s

Table 16: Constant leak flow distribution

In this case the simulation doesn't present any error message. The outflow distribution by hour from the reservoirs is showed in the next image.

Salibauri Outflow

Time Hours	Flow LPS
0:00	162.22
1:00	162.32
2:00	162.39
3:00	162.51
4:00	162.56
5:00	162.63
6:00	162.70
7:00	162.76
8:00	162.80
9:00	162.88
10:00	162.90
11:00	162.95
12:00	163.01
13:00	163.04
14:00	163.05
15:00	163.12
16:00	163.13
17:00	159.15
18:00	156.86
19:00	154.75
20:00	152.77
21:00	150.93
22:00	149.21
23:00	147.63

Injalo Outflow

Time Hours	Flow LPS
0:00	164.86
1:00	164.76
2:00	164.69
3:00	164.57
4:00	164.52
5:00	164.45
6:00	164.38
7:00	164.32
8:00	164.28
9:00	164.20
10:00	164.18
11:00	164.13
12:00	164.07
13:00	164.04
14:00	164.03
15:00	163.96
16:00	163.95
17:00	167.93
18:00	170.22
19:00	172.33
20:00	174.31
21:00	176.15
22:00	177.87
23:00	179.45

Figure 29: Reservoirs flow injection 24 h distribution, case 2

The results obtained modeling NRW as a constant flow are presented following.

CONSTANT LEAK FLOW (m^3)	
Injected Water (m^3)	876.052
Registered Water (m^3)	874.792
Difference (m^3)	1.259

Table 17: Results demand factor correction

The results show that the adjustment between injected and registered water has been higher than in the previous case. However, this method model NRW as constant during the 24 hours of the day and not depending on the local pressure in the network.

3.4.6 NRW modeling case 3: leak flow using emitters

The last model that we are presenting to model NRW is based in considering part of the leak flow as pressure dependent, and modeling the other part as flow not registered but consumed.

The pressure dependent flow represents the leakages, with different value depending on the time of the day.

The NRW which is not considered as pressure dependent represents the water that is consumed but not metered. This part follows the same consumption pattern as the registered flow.

The leakage flow is divided using emitters at the nodes and calculated at time of lower consumption and higher pressure (night minimum flow). The other part of the flow is assigned constant or proportional to consumption demand in every moment.

In the following table we can observe the distribution of NRW which will be used to calculate the emitters' coefficient, following the AEAS research explained above.

Leakages (m^3/d)	Distribution by AEAS research and allocation (m^3/d)			
1.305	Leakages	45,00%	67,16%	876
	Measurement errors	18,00%	26,87%	350
	Illegal connections	4,00%	5,97%	78
	Unknown	33,00%		

Table 18: Allocation of leakage flow for emitter calculation

The last term is allocated into the first three ones proportionally, to establish the flow values which are not pressure dependent and the dependent ones.

	m3/d	L/s
Leakage Flow	1.305	15,10
Pressure dependent Flow	876	10,14
Non Pressure dependent Flow	428	4,96

Table 19: Pressure dependent and non-dependent flows

The next step is to divide the non-dependent flow proportionally between the consumption nodes of the model. In our case, to make this first simulate, the model's consumption nodes have the same basis demand, so the pressure non-dependent flow will be the same for all nodes.

On the other hand, the pressure dependent flow will be used to calculate the emitter's coefficients, as showed in the next equation.

$$Q = Ec \cdot \sqrt{P}$$

The pressure term is calculated in each node at the instant of lower flow (night time) which presents the higher pressure value.

The following tables show the calculations explained previously applied to one node of each DMA (only to show briefly how it was made because the model has 1105 consumption nodes).

Node	$Q_{BasisDemand}$ (L/s)	$Q_{PressureNon\text{-}dependent}$ (L/s)	Q_{total} (L/s)
DMA1-2-3	0,30	0,0045	0,3045
DMA4-5	0,30	0,0045	0,3045
DMA6	0,30	0,0045	0,3045
DMA7-8	0,30	0,0045	0,3045
DMA9	0,30	0,0045	0,3045
DMA10	0,30	0,0045	0,3045
DMA11a	0,30	0,0045	0,3045
DMA11b	0,30	0,0045	0,3045
DMA12a	0,30	0,0045	0,3045
DMA12b	0,30	0,0045	0,3045
DMA13	0,30	0,0045	0,3045
DMA14	0,30	0,0045	0,3045
DMA15-16	0,30	0,0045	0,3045
DMA17	0,30	0,0045	0,3045
DMA20	0,30	0,0045	0,3045

Table 20: Allocation pressure non-dependent leakages flow

Node	$Q_{Pressure\text{-}dependent}$ (L/s)	P (mca)	$\sqrt{P}$	Ec
DMA1-2-3	0,01	60,44	7,77	0,0012
DMA4-5	0,01	60,50	7,78	0,0012
DMA6	0,01	60,32	7,77	0,0012
DMA7-8	0,01	58,90	7,67	0,0012
DMA9	0,01	60,98	7,81	0,0012
DMA10	0,01	59,96	7,74	0,0012
DMA11a	0,01	60,82	7,80	0,0012
DMA11b	0,01	54,93	7,41	0,0012
DMA12a	0,01	61,93	7,87	0,0012
DMA12b	0,01	50,73	7,12	0,0013
DMA13	0,01	61,15	7,82	0,0012
DMA14	0,01	61,06	7,81	0,0012
DMA15-16	0,01	58,40	7,64	0,0012
DMA17	0,01	54,93	7,41	0,0012
DMA20	0,01	60,63	7,79	0,0012

Table 21: Emitter coefficient calculation

Once obtained the value of the Emitter Coefficient it is updated in each consumption node and the simulation can be done.

The outflow distribution by hour from the reservoirs with this method is showed in the next image.

Outflow Salibauri

Time Hours	Flow LPS
0:00	137.98
1:00	136.44
2:00	134.85
3:00	133.29
4:00	136.64
5:00	141.58
6:00	164.55
7:00	194.04
8:00	208.81
9:00	218.68
10:00	217.09
11:00	212.23
12:00	205.74
13:00	195.96
14:00	189.48
15:00	189.50
16:00	187.28
17:00	182.05
18:00	176.80
19:00	173.36
20:00	171.73
21:00	161.44
22:00	143.90
23:00	127.86

Outflow Injalo

Time Hours	Flow LPS
0:00	140.29
1:00	138.49
2:00	136.75
3:00	134.98
4:00	138.22
5:00	143.17
6:00	166.47
7:00	196.45
8:00	211.40
9:00	221.31
10:00	219.56
11:00	214.46
12:00	207.70
13:00	197.60
14:00	190.82
15:00	190.76
16:00	196.33
17:00	195.00
18:00	193.70
19:00	193.88
20:00	195.57
21:00	189.38
22:00	177.22
23:00	166.86

Figure 30: Reservoirs flow injection 24 h distribution, case 3

The results obtained in this case are presented on the next table.

EMITTER COEFFICIENT (m^3)	
Injected Water (m^3)	940.210
Registered Water (m^3)	874.792
Difference (m^3)	65.418

Table 22: Results emitter coefficient

Although the difference between injected and registered water is higher than the previous methods, in this case the simulation is more realistic. Indeed, it is needed to find the percentages of NRW which are dependent and non-dependent of the pressure. During the next months, when most of the customers will be metered by water meter and the DMAs in use, we will start a campaign to calculate more properly the values of the NRW terms. In this manner the percentage of NRW which is due to leakages could be calculate more accurately.

The calibration of the model and the updated of the consumption nodes with new values of the emitter coefficients will allow reduce each time the observed difference.

At the moment, we are going to increase the percentage of NRW pressure-dependent, in order to reduce the consumption which is non-pressure dependent. This is achieved converting the percentage due to unknown (33%) into leakages (45+33=78%), as the next table shows.

Leakages (m^3/d)			NRW Distribution (m3/d)	
1.305	Leakages	45,00%	78 %	1.018
	Measurement errors	18,00%	18,00%	235
	Illegal connections	4,00%	4,00%	52
	Unknown	33,00%		

Table 23: New NRW distribution for emitter calculation

And the flows calculation is changed due to the new distribution, as follows.

	m3/d	L/s
Leakage Flow	1.305	15,10
Pressure dependent Flow	1.018	11,78
Non Pressure dependent Flow	287	3,32

Table 24: New pressure dependent and non-dependent flows

Following, the tables with the calculations of consumption and emitter coefficient are repeated with the new values.

Node	$Q_{BasisDemand}$ (L/s)	$Q_{PressureNon\text{-}dependent}$ (L/s)	Q_{total} (L/s)
DMA1-2-3	0,30	0,0030	0,3030
DMA4-5	0,30	0,0030	0,3030
DMA6	0,30	0,0030	0,3030
DMA7-8	0,30	0,0030	0,3030
DMA9	0,30	0,0030	0,3030
DMA10	0,30	0,0030	0,3030
DMA11a	0,30	0,0030	0,3030
DMA11b	0,30	0,0030	0,3030
DMA12a	0,30	0,0030	0,3030
DMA12b	0,30	0,0030	0,3030
DMA13	0,30	0,0030	0,3030
DMA14	0,30	0,0030	0,3030
DMA15-16	0,30	0,0030	0,3030
DMA17	0,30	0,0030	0,3030
DMA20	0,30	0,0030	0,3030

Table 25: New allocation pressure non-dependent leakages flow

Node	$Q_{Pressure\text{-}dependent}$ (L/s)	P (mca)	$\sqrt{P}$	Ec
DMA1-2-3	0,0107	60,4400	7,7743	0,001371
DMA4-5	0,0107	60,5000	7,7782	0,001370
DMA6	0,0107	60,3200	7,7666	0,001372
DMA7-8	0,0107	58,9000	7,6746	0,001389
DMA9	0,0107	60,9800	7,8090	0,001365
DMA10	0,0107	59,9600	7,7434	0,001376
DMA11a	0,0107	60,8200	7,7987	0,001367
DMA11b	0,0107	54,9300	7,4115	0,001438
DMA12a	0,0107	61,9300	7,8696	0,001354
DMA12b	0,0107	50,7300	7,1225	0,001496
DMA13	0,0107	61,1500	7,8198	0,001363
DMA14	0,0107	61,0600	7,8141	0,001364
DMA15-16	0,0107	58,4000	7,6420	0,001395
DMA17	0,0107	54,9300	7,4115	0,001438
DMA20	0,0107	60,6300	7,7865	0,001369

Table 26: New emitter coefficient calculation

The simulation with the new values presents a flow distribution from the reservoirs as showed in the next image.

Outflow Salibauri

Time Hours	Flow LPS
0:00	134.48
1:00	133.00
2:00	131.46
3:00	129.92
4:00	133.17
5:00	137.99
6:00	160.21
7:00	188.76
8:00	203.06
9:00	212.60
10:00	211.06
11:00	206.36
12:00	200.07
13:00	190.62
14:00	184.32
15:00	184.36
16:00	182.76
17:00	177.50
18:00	172.34
19:00	168.85
20:00	167.15
21:00	157.07
22:00	139.98
23:00	124.32

Outflow Injalo

Time Hours	Flow LPS
0:00	136.73
1:00	134.98
2:00	133.29
3:00	131.60
4:00	134.73
5:00	139.48
6:00	162.05
7:00	191.08
8:00	205.54
9:00	215.16
10:00	213.45
11:00	208.51
12:00	201.95
13:00	192.16
14:00	185.62
15:00	185.54
16:00	190.33
17:00	189.26
18:00	188.09
19:00	188.44
20:00	190.20
21:00	184.34
22:00	172.69
23:00	162.80

Figure 31: Reservoirs new flow injection 24 h distribution, case 3

The results obtained in this case are presented on the next table.

EMITTER COEFFICIENT (m^3)	
Injected Water (m^3)	887.553
Registered Water (m^3)	874.792
Difference (m^3)	12.761

Table 27: Results emitter coefficient

As we can see, the results got better considering more percentage of pressure-dependent flow. This hypothesis has to be evaluated and estimated in a correct way to achieve the more realistic calibration of the model. Regarding this point, and as we commented various times, during the next months we should elaborate a plan to estimate the different terms which IWA defines as the parts of NRW.

3.4.7 Comparison between the three methods

The next charts show the evolution of the flow (consumption pattern) of both reservoirs in each case (red line represents Salibauri and green one Injalo).

Figure 32: Consumption Pattern method 1

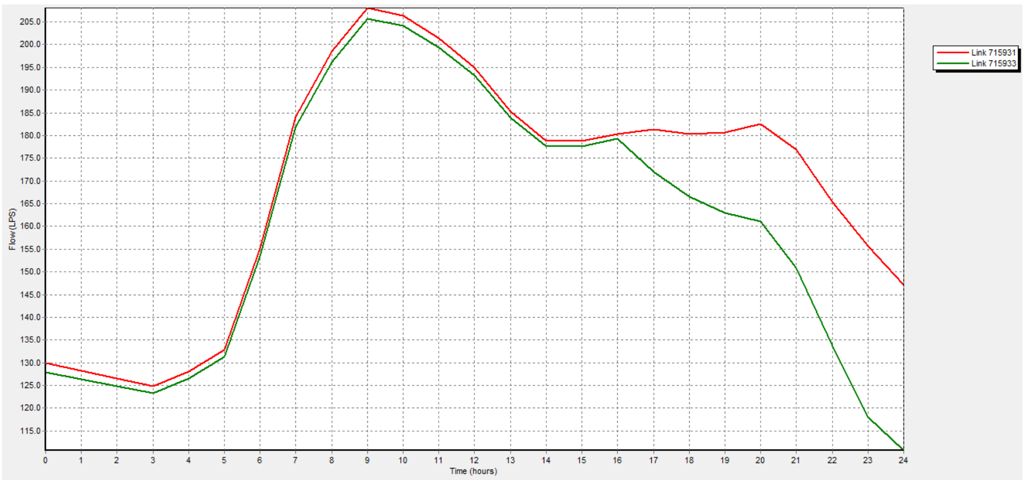


Figure 33: Consumption Pattern method 2

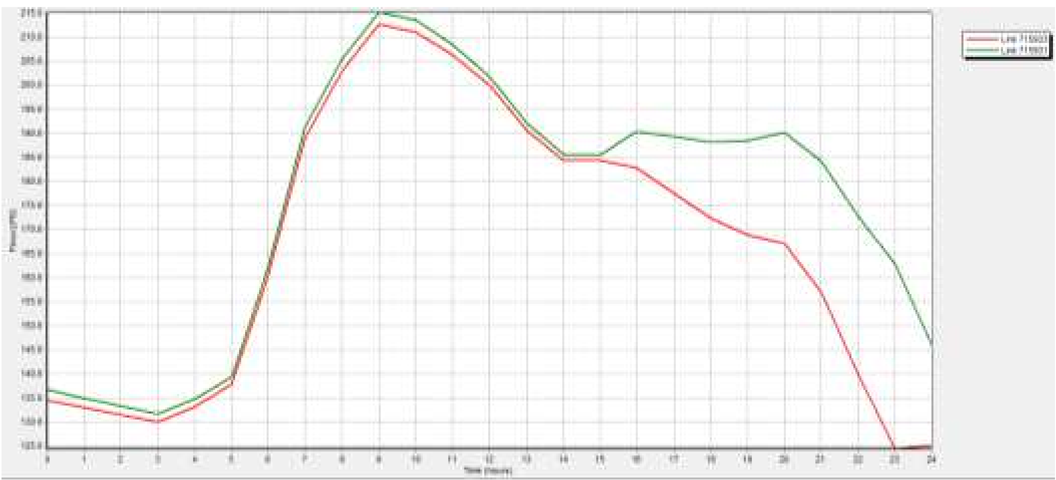


Figure 34: Consumption Pattern method 3

As we can see on the graphs, the 3 methods represented the real shape of the supplying. However, method 1 is only a simulation reducing the peaks of consumption what allows the appearance of negative pressures in the network because during some hours there aren't enough flow to satisfy the demand in the consumption nodes. Regarding method 2, it considers leakage flow independent of the pressure and constant at each time.

Method 3 is the best option to model NRW with a behaviour attached to reality. During the next months we will try to achieve an optimum calibration of the model as we will get more representative data with the on-going process of connecting costumers to new network and metering them with water meters, and with the elaboration of a plan to estimate correctly NRW terms, to identify the proportion of pressure-dependent and non-pressure-dependent flow.

Finally, and as a curiosity of the simulation, we can see in the three cases how since hour 16 to hour 24 the network is supplied in greater extend by Injalo. This happens because in those hours Salibauri is being supplied to avoid getting empty, so the model decrease the flow from this reservoir and increase the flow from Injalo. In this simulation Salibauri is being fed by gravity from Ckavi and Salibauri, and Injalo from Mejinitskali. During those 8 hours the model prefers to supply the network mostly using the pumping than using the gravity flow.

The next chart show the fact explained in the previous paragraph.

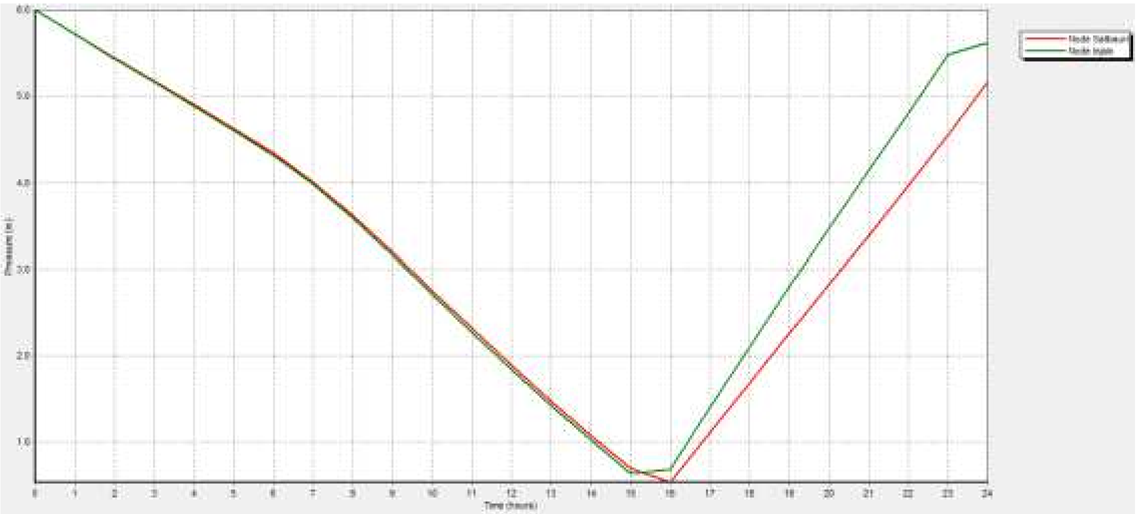


Figure 35: Reservoirs emptying-filling

3.4.8 Supplying from one reservoir hypothesis study

The water network has been designed to satisfy the demands through one only reservoir, in case of necessity. The next two simulations with the model verify this hypothesis.

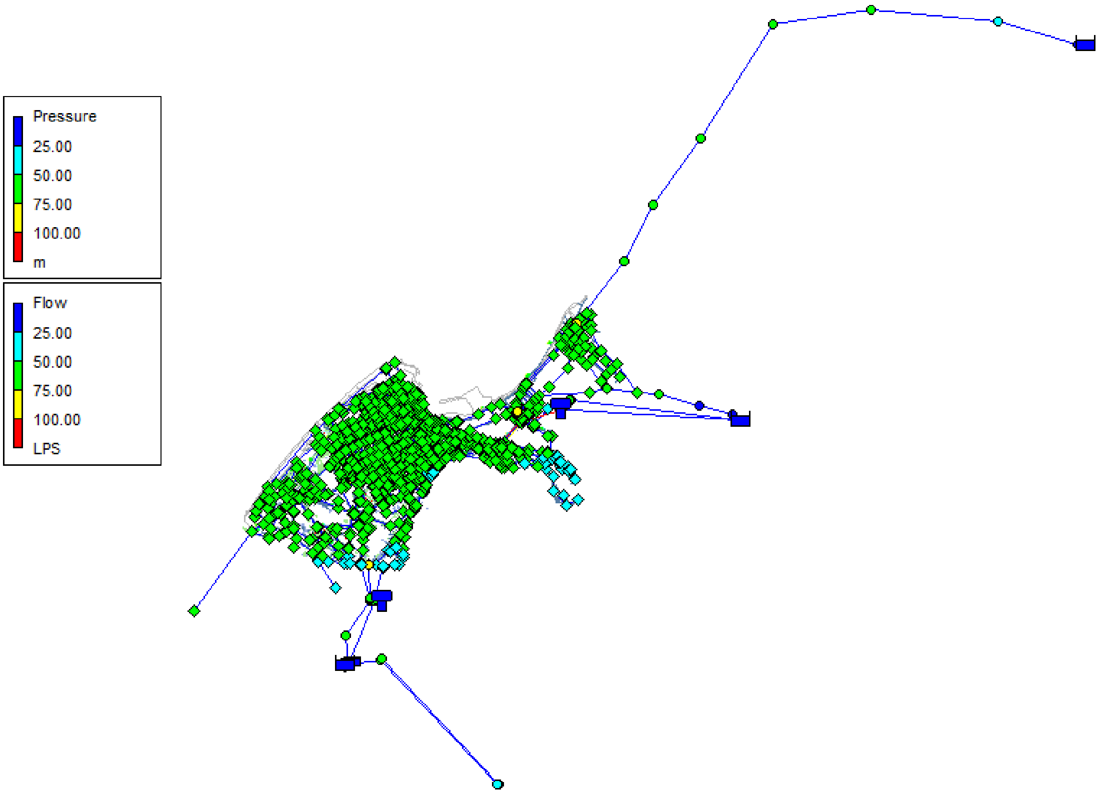


Figure 36: Salibauri supplying network simulation

In this case the values of outflow and pressure are presented in the next images.

Time Hours	Flow LPS
0:00	270.70
1:00	267.39
2:00	264.14
3:00	260.90
4:00	267.21
5:00	276.72
6:00	321.24
7:00	378.41
8:00	406.91
9:00	425.85
10:00	422.68
11:00	413.18
12:00	400.49
13:00	381.45
14:00	368.76
15:00	368.78
16:00	371.98
17:00	365.64
18:00	359.30
19:00	356.14
20:00	356.16
21:00	340.28
22:00	311.66
23:00	286.22

Figure 37: Salibauri supplying network simulation

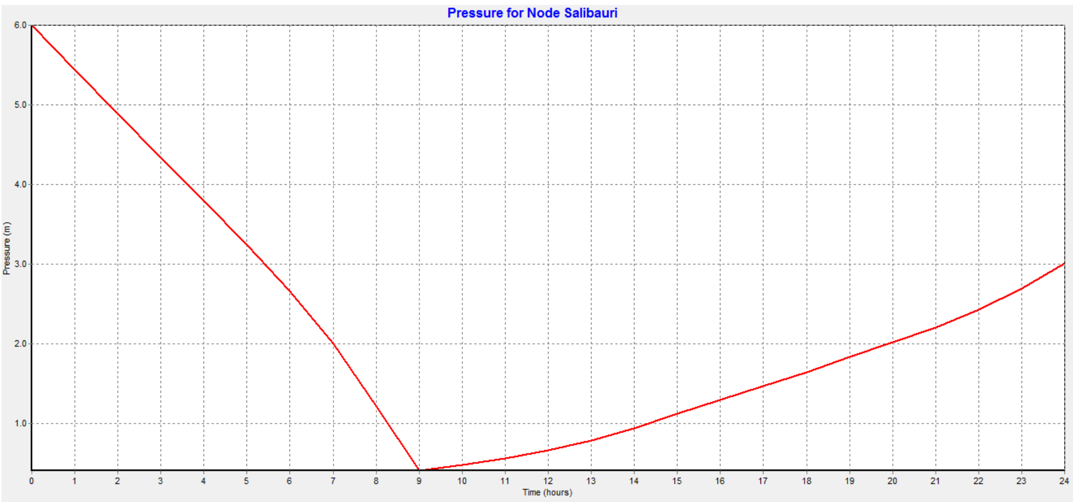


Figure 38: Salibauri pressure evolution

On the other hand, when the network is supplied by Injalo we obtain the next results.

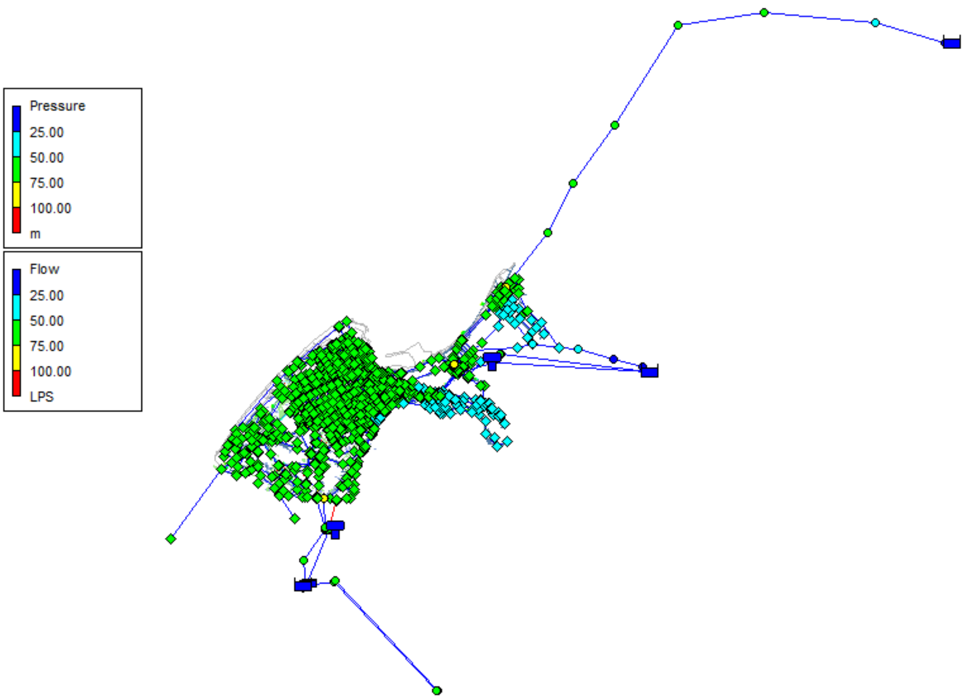


Figure 39: Injalo supplying network simulation

Time Hours	Flow LPS
0:00	270.78
1:00	267.46
2:00	264.21
3:00	260.96
4:00	267.29
5:00	276.79
6:00	321.35
7:00	378.58
8:00	407.11
9:00	426.08
10:00	422.93
11:00	413.42
12:00	400.74
13:00	381.69
14:00	369.00
15:00	369.04
16:00	372.25
17:00	365.92
18:00	359.59
19:00	356.45
20:00	356.48
21:00	340.60
22:00	311.97
23:00	286.51

Figure 40: Injalo Salibauri supplying network simulation

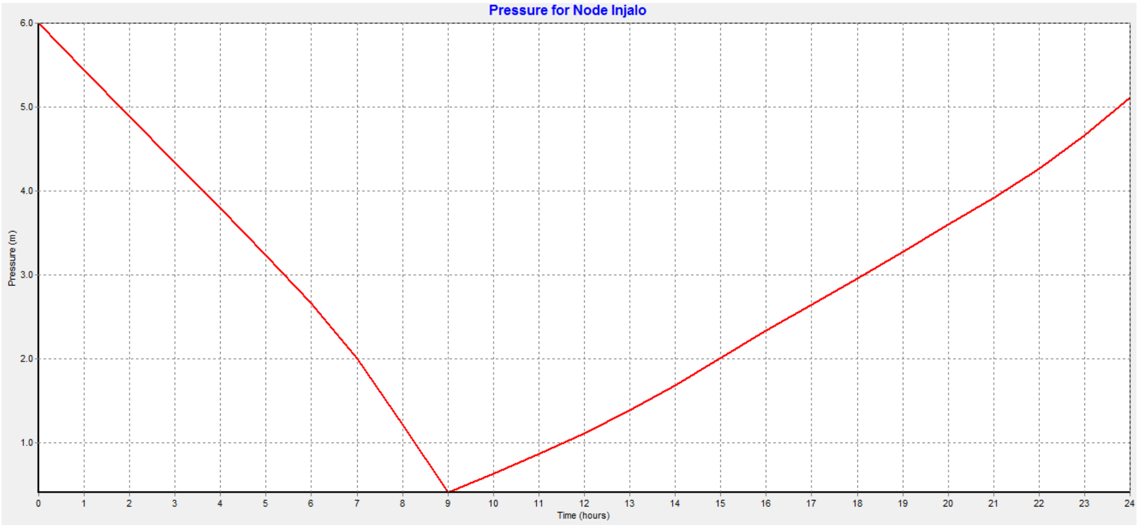


Figure 41: Injalo pressure evolution

As a conclusion of these two simulations we could observe how the outflow of both reservoirs, when the network is being supplied by one or other, is approximately the double than when the network is supplied by the two reservoirs jointly. With regard to the pressure evolution, this is the same in both reservoirs in these simulations. In 9 hours the reservoirs get empty and start to go up the pressure till get the maximum in 15 hours.

3.4.9 Model calibration

The calibration phase is one of the main stages when building a mathematical model cos it should represent the reality as close as possible.

With regards to the calibration, two different studies were done at the beginning of building the model process.

The idea is, as explained for many of the steps taken, to repeat those studies once the implementation of DMAs finishes and we get its total isolation.

The studies were on one hand the daily pressure evolution simulated by the model and compared with the pressure measurements plan at the same measurement points (real and on the model), and on the other hand, a night flow study very useful to calibrate the NRW.

3.4.9.1.1 Pressure evolution study

Regarding the pressure, the model replicate as happens in the reality as we can see in the next chart in comparison with our measurements plan.

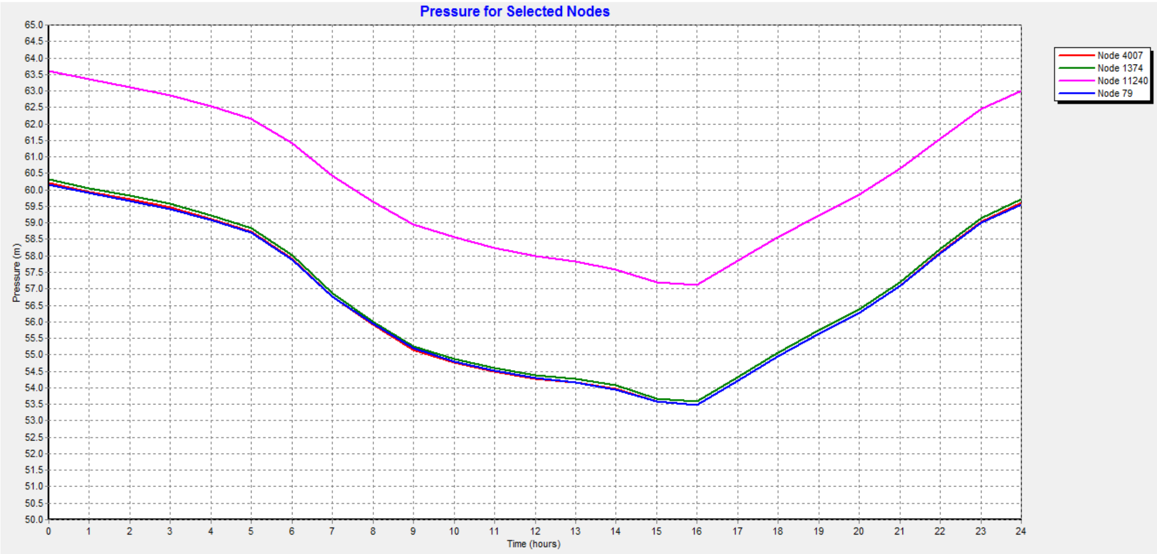


Figure 42: 24 hour pressure evolution in the measuring points

In the graph the 4 points of our measurement plan are represented by model's nodes, as follows:

- Pink line: Varshanidze 54.
- Red line: Theatre.
- Green line: Sheraton.
- Blue line: Pushkini 17.

Pressure values have a maximum during night time (0 to 5 h) and have a minimum during day time when the consumption is high (8 to 18 h).

Night time pressure values are directly related with leakage flows and the knowledge of the minimum flow consumed at night allows estimating losses. Regarding this fact, following we are presenting a brief study which is a useful tool to calibrate the NRW mathematical model.

3.4.9.1.2 Night flow study

Although this method requires having the network divided in DMA's in operation, we are going to present a short study using the information from the flow registered in Salibauri and Injalo by the measurements plan and the flow injected by the model.

During the next months, we will repeat the method applied to isolated DMA's which have metered inflow and customers with water meters.

Following are presented the values of the 24 hour based outflow of Salibauri and Injalo, which were got with the model.

Outflow Salibauri

Time Hours	Flow LPS
0:00	134.48
1:00	133.00
2:00	131.46
3:00	129.92
4:00	133.17
5:00	137.99
6:00	160.21
7:00	188.76
8:00	203.06
9:00	212.60
10:00	211.06
11:00	206.36
12:00	200.07
13:00	190.62
14:00	184.32
15:00	184.36
16:00	182.76
17:00	177.50
18:00	172.34
19:00	168.85
20:00	167.15
21:00	157.07
22:00	139.98
23:00	124.32

Outflow Injalo

Time Hours	Flow LPS
0:00	136.73
1:00	134.98
2:00	133.29
3:00	131.60
4:00	134.73
5:00	139.48
6:00	162.05
7:00	191.08
8:00	205.54
9:00	215.16
10:00	213.45
11:00	208.51
12:00	201.95
13:00	192.16
14:00	185.62
15:00	185.54
16:00	190.33
17:00	189.26
18:00	188.09
19:00	188.44
20:00	190.20
21:00	184.34
22:00	172.69
23:00	162.80

Figure 43: Outflow Salibauri and Injalo

If we pay attention to the hours when the pressure is the maximum which we have already known, 0 to 5 h, the lower consumption is made at 3:00 h.

On the other hand, the consumption pattern which is applied to the basis demand in the model presents the next shape.

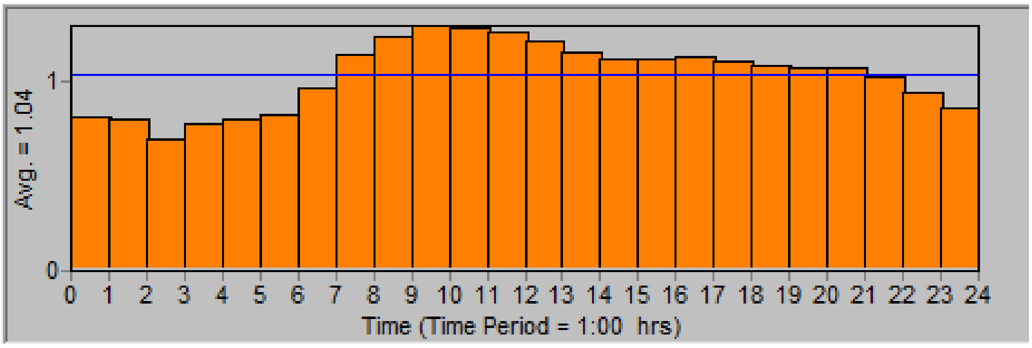


Figure 44: Consumption pattern

Using average measurements plan data and the model we can estimate the leakage flow as showed on the next tables.

time (h)	Salibauri outf .(l/s)	Salibauri outf. (m^3/h)	Injalo outf. (l/s)	Injalo outf. (m^3/h)	Injected Flow (m^3/h)
0:00	134,48	484,13	136,73	492,23	976,36
1:00	133,00	478,80	134,98	485,93	964,73
2:00	131,46	473,26	133,29	479,84	953,10
3:00	129,92	467,71	131,60	473,76	941,47
4:00	133,17	479,41	134,73	485,03	964,44
5:00	137,99	496,76	139,48	502,13	998,89

Table 28: Injected flow calculation during lower consumption time

time (h)	Basis demand nodes (l/s)	Basis demand nodes (m^3/h)	Consumption pattern coefficient	Demanded Flow (m^3/h)
0:00	320,45	1153,62	0,8	922,90
1:00	320,45	1153,62	0,8	922,90
2:00	320,45	1153,62	0,8	922,90
3:00	320,45	1153,62	0,7	807,53
4:00	320,45	1153,62	0,75	865,22
5:00	320,45	1153,62	0,8	922,90

Table 29: Demanded flow calculation during lower consumption time

time (h)	Injected Flow (m^3/h)	Demanded Flow (m^3/h)	Leakage Flow (m^3/h)
0:00	976,36	922,90	53,46
1:00	964,73	922,90	41,83
2:00	953,10	922,90	30,20
3:00	941,47	807,53	133,94
4:00	964,44	865,22	99,23
5:00	998,89	922,90	76,00

Table 30: Leakage flow calculation during lower consumption time

Once obtained the leakage flow during the minimum night time flow, it is possible to get the total leakage volume, as this will be the extrapolation of the leakage flow during the minimum night time flow, affected by a multiplier factor.

That flow multiplier called Hour to Day Factor (HDF) has a value between 18 and 22 in most hydraulic systems, according to the literature. In our case, we are going to use the average between these 2 coefficients to get our estimated leakage flow in the network.

time (h)	Leakage Flow (m^3/h)	Daily Leakage Flow (m^3)
3:00	133,94	2.678,76

Table 31: Daily leakage flow estimation

Finally, we are going to calculate the daily injected flow to compare it with the estimated daily leakage flow.

time (h)	Salibauri outflow (l/s)	Salibauri outflow (m^3/h)	Injalo outflow (l/s)	Injalo outflow (m^3/h)
0:00	134,48	484,13	136,73	492,23
1:00	133,00	478,80	134,98	485,93
2:00	131,46	473,26	133,29	479,84
3:00	129,92	467,71	131,60	473,76
4:00	133,17	479,41	134,73	485,03
5:00	137,99	496,76	139,48	502,13
6:00	160,21	576,76	162,05	583,38
7:00	188,76	679,54	191,08	687,89
8:00	203,06	731,02	205,54	739,94
9:00	212,60	765,36	215,16	774,58
10:00	211,06	759,82	213,45	768,42
11:00	206,36	742,90	208,51	750,64
12:00	200,07	720,25	201,95	727,02
13:00	190,62	686,23	192,16	691,78
14:00	184,32	663,55	185,62	668,23
15:00	184,36	663,70	185,54	667,94
16:00	182,76	657,94	190,33	685,19
17:00	177,50	639,00	189,26	681,34
18:00	172,34	620,42	188,09	677,12
19:00	168,85	607,86	188,44	678,38
20:00	167,15	601,74	190,20	684,72
21:00	157,07	565,45	184,34	663,62
22:00	139,98	503,93	172,69	621,68
23:00	124,32	447,55	162,80	586,08
Total/Reservoir		11.633,00		12.338,00
Total		23.971 m^3		

Table 32: Daily leakage flow estimation

As we can see, in these conditions, the leakage flow (NRW) is approximately 11%.

The NRW percentage estimated with the Night Flow Method will be useful to calibrate the model although we estimated the Hour to Day Factor.

As we said previously, we will repeat the NFM applied to DMA's where we will know exactly the inflow and also the billing data, to get more accurate values and achieve a better calibration of the model.

3.5 DMAs implementation

3.5.1 Introduction

The implementation of the district metering areas started some time ago with the civil and electrical works needed to build the metering chambers and to install the electrical boxes near it.

Between, it was designed a strategy to achieve the isolation of each area and have it documented.

Nowadays, most of the DMAs are isolated or it is possible to isolate them.

While the works were going on, there was the possibility to study 4 isolated areas at the end of the phase II.

On this chapter we are going to develop this bullets mentioned as an introduction.

3.5.2 Isolation strategy

It was designed using the information we had from maps and GIS system. Actually, there were so many errors on that info, so we made profit of the process to update it correctly.

Finally, we did a database linked to a GIS with this information:

- Valve designation and DMA
- DN pipe
- Correct status of the valve for isolation
- Observations
- Location
- Valve next to flow meter and transmitter or not

After the location and checking of the state of each valve, repairing and replacing some of them, we finalize the database and proceed to isolation following the strategy, which is presented on the next page.

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
17	V1	PE 225	Open	Connected to Chakvi line (1000)	Tbeti St.	FM12	YES
17	V2	ST 300	Closed	Supplying DMA 17 without MC nor FM. Connected to Chaisubani line (600)	Boundaries DMAs 17 and 12b		
12b	V3	ST 300	Closed	Supplying DMA 12a without MC nor FM Connected to Chaisubani line (600)	Boundaries DMAs 17 and 12b		
12a	V4	ST 500	Open	Inlet DMA 12a	Noneshvili St.	FM13	YES
12a	V5	PE 110	Closed	End pipe inside DMA 12a	Boundaries DMAs 12a and 12b		
11a	V6	ST 200	Open	Inlet DMA 11a (under Phase III) Connected to Chakvi line	Gogoli Noneshvili Sts.	FM15	YES
11a	V7	PE 225	Open	Inlet DMA 11a	Gogebashvili Makasaria junction Sts.	FM08	
11b	V8	ST 250	Open	Inlet DMA 11b (under Phase III) Connected to Chakvi line	Gogoli Mayakoski juction Sts.	FM16	
11b	V9	ST 500	Open	Inlet DMA 11b (under Phase III) Inlet DMA 6 Connected to Injalo Outlet	Mayakoski Dadiani juction Sts.	FM16A	
1-2-3	V10	PE 225	Open	Inlet DMA 1-2-3	Mayakoski Shavsheti junction Sts.	FM36	YES
1-2-3	V11	ST 600	Open	Inlet DMA 1-2-3	Tsereteli Imedashvili junction Sts.		
1-2-3	V12	PE 355	Closed	End pipe inside DMA 1-2-3	Tsereteli Imedashvili junction Sts.		
1-2-3	V13	ST 600	Open	Inlet DMA 1-2-3	Tsereteli Imedashvili junction Sts.	FM10	YES
1-2-3	V14	PE 110	Closed	Connected to DMA 4-5	Chavchavadze Asastiani junction Sts.		
1-2-3	V15	PE 110	Closed	Connected to DMA 4-5	Asiatini zubalashvili junction Sts.		

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
1-2-3	V16	PE 160	Closed	Connected to DMA 4-5	Asiatiani Gorgasali junction Sts.		
1-2-3	V17	PE 110	Closed	Connected to DMA 4-5	Asiatiani Farnavaz Meve junction Sts.		
1-2-3	V18	PE 110	Closed	Connected to DMA 4-5	Asiatiani Farnavaz Meve junction Sts.		
1-2-3	V19	PE 225	Closed	Connected to DMA 4-5	Asiatiani Era junction Sts.		
1-2-3	V20	PE 110	Closed	Connected to DMA 4-5	Asiatiani Memed Abashidze junction Sts.		
1-2-3	V21	PE 110	Closed	Connected to DMA 4-5	Asiatiani Kldiashvili junction Sts.		
1-2-3	V22	PE 110	Closed	Connected to DMA 4-5	Asiatiani Rustaveli junction Sts.		
1-2-3	V23	PE 110	Closed	Connected to DMA 4-5	Rustaveli Vaja Pshavela junction Sts.		
1-2-3	V24	PE 110	Closed	Connected to DMA 4-5	Rustaveli 26 Maisi junction Sts.		
1-2-3	V25	PE 160	Closed	Connected to DMA 4-5	Rustaveli 26 Maisi junction Sts.		
1-2-3	V26	PE 110	Closed	Connected to DMA 4-5	Rustaveli 26 Maisi junction Sts.		
1-2-3	V27	PE 110	Closed	Connected to DMA 4-5	Hihoshvili 26 Maisi junction Sts.		
1-2-3	V28	PE 110	Closed	Connected to DMA 4-5	Hihoshvili 26 Maisi junction Sts.		
1-2-3	V29	PE 160	Closed	Connected to DMA 4-5	Hihoshvili Melikishvili junction Sts.		
1-2-3	V30	PE 355	Closed	Connected to DMA 4-5	Hihoshvili Boundary DMAs 1-2-3 and 4-5		
4-5	V31	ST 600	Open	Inlet DMA 4-5	Chavchavadze Vaja Pshavela junction Sts.	FM11	
4-5	V32	PE 110	Closed	Connected to DMA 13	Near Griboedovi Era junction Sts.		
13	V33	ST 500	Open	Inlet DMAs 13 and 9	Abuseridze Griboedovi junction Sts.	FM30	YES
13	V34	ST 500	Open	Inlet DMA 13	Chavchavadze Griboedovi junction Sts.	FM30A	
13	V35	PE 110	Closed	Connected to DMA 9	Near Abuseridze Javahishvili junction Sts.		
13	V36	PE 160	Closed	Connected to DMA 9	Abuseridze Loria junction Sts.		

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
13	V37	PE 225	Closed	Connected to DMA 4-5	Abuseridze Gudiasvili junction Sts.		
13	V38	PE 225	Open	Inlet DMA 14	Abuseridze General Abashidze junc. Sts.	FM29	YES
13	V39	PE 225	Closed	Connected to DMA 14	General Abashidze Pirosmani junc. Sts.		
13	V40	PE 160	Closed	Connected to DMA 14	Inasaridze General Abashidze junc. Sts.		
13	V41	PE 110	Closed	End pipe inside DMA 13	Inasaridze General Abashidze junc. Sts.		
13	V42	PE 355	Closed	Connected to DMA 14	Boundary NW DMAs 13 and 14		
13	V43	PE 225	Closed	Connected to DMA 14	Boundary NW DMAs 13 and 14		
13	V44	PE 160	Closed	Connected to DMA 14	Boundary NW DMAs 13 and 14		
6	V45	ST 500	Open	Inlet DMA 6 (from DMA 11b)	Eristavi Bagriatoni junction Sts.		
6	V46	PE 355	Open	Inlet DMA 7-8	Eristavi Bagriatoni junction Sts.		
6	V47	ST 200	Open	Inlet DMA 6 (under Phase III) Connected to Chakvi line	Eristavi Shavsheti junction Sts.	FM17	
6	V48	PE 110	Closed	Connected to DMA 11b	Meshki Eristavi junction Sts.		
6	V49	PE 110	Closed	End pipe inside DMA 6	Mitisdziri Sulaberidze junction Sts.		
6	V50	PE 110	Closed	Connected to DMA 7-8	Mitisdziri Boundaries SW DMAs 6 and 7-8		
6	V51	PE 110	Closed	Connected to DMA 7-8	Mitisdziri Boundaries SW DMAs 6 and 7-8		
6	V52	ST 500	Open	Inlet DMA 7-8	Mitisdziri Asatiani junction Sts.	FM18	YES
6	V53	PE 355	Open	Inlet DMA 6	Tsereteli Maiakovski junction Sts.	FM09	YES

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
6	V54	PE 225	Closed	Connected to DMA 7-8	Chavchavadze Vaja Pshavela junction Sts.		
6	V55	PE 160	Closed	Connected to DMA 7-8	Pushkini Asatiani junction Sts.		
6	V56	PE 110	Closed	Connected to DMA 7-8	Giorgi Brtskinvale Asatiani junction Sts.		
6	V57	PE 225	Closed	Connected to DMA 7-8	Giorgi Brtskinvale Asatiani junction Sts.		
6	V58	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V59	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V60	PE 225	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V61	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V62	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V63	PE 225	Closed	Connected to DMA 7-8	Asatiani Bagrationi junction Sts.		
6	V64	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
6	V65	PE 110	Closed	Connected to DMA 7-8	Asatiani Boundery W DMAs 6 and 7-8		
7-8	V66	PE 355 EXT	Closed	Connected to DMA 9	Bagrationi Selim Khimshiashvili junct.		
7-8	V67	PE 355	Closed	Connected to DMA 9	Komakhide Selim Khimshiashvili junct.		
7-8	V68	PE 160	Closed	Connected to DMA 9	Komakhide Selim Khimshiashvili junct.		
7-8	V69	PE 355	Closed	Connected to DMA 9	Giorgi Brtskinvale Selim Khimshiashvili		

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
7-8	V70	PE 225	Closed	Connected to DMA 9	Chavchavadze Selim Khimshiashvili junct.		
10	V71	ST 500	Open	Outlet DMA 10	Mtisdziri Melikishvili junction Sts.	FM19	YES
10	V72	PE 110	Closed	Connected to DMA 7-8	Mtisdziri Melikishvili junction Sts.		
10	V73	PE 160	Open	Inlet DMA 10 (under Phase III) Connected to Chakvi line	Mtisdziri Melikishvili junction Sts.		
10	V74	PE 110	Open	Inlet DMA 10 (under Phase III) Connected to Chakvi line	Mtisdziri Melikishvili junction Sts.		
10	V75	PE 110	Closed	Connected to DMA 7-8	Boundary SE DMAs 10 and 7-8		
10	V76	ST 500 ST 600	Closed	Connected to DMA 7-8	Asatiani Asatiani I junction Sts.		
10	V77	PE 110	Closed	Connected to DMA 7-8	Asatiani Asatiani I junction Sts.		
10	V78	PE 110	Closed	Connected to DMA 7-8	Asatiani I St.		
10	V79	PE 110	Closed	Connected to DMA 7-8	Boundary NE DMAs 10 and 7-8		
10	V80	PE 110	Closed	Connected to DMA 9	Bagrationi Selim Khimshiashvili junct.		
10	V81	PE 125 EXT	Closed	Connected to DMA 9	Bagrationi Selim Khimshiashvili junct.		
10	V82	PE 110	Closed	Connected to DMA 9	Lermontovi Bagrationi junction Sts.		
10	V83	ST 400	Open	Inlet DMA 9	Lermontovi Bagrationi junction Sts.	FM26	
10	V84	PE 225	Closed	Connected to DMA 9	Bagrationi Javahishvili junction Sts.		
10	V85	PE 160	Closed	Connected to DMA 20	Sulxan-saba Orbeliani Javaxisvili Sts.		
10	V86	ST 400	Open	Inlet to DMA 10	Sulxan-saba Orbeliani Gen. Abashidze	FM25	YES
10	V87	PE 355	Closed	Connected to DMA 20	Sulxan-saba Orbeliani Gen. Abashidze		

DMA	VALVE DESIGNATION	PIPE DN	CORRECT STATUS	OBSERVATIONS	LOCATION	FM	TRANS
10	V88	PE 355	Open	Inlet to DMA 20	Sulxan-saba Orbeliani Gen. Abashidze	FM24	YES
10	V89	PE 160	Closed	Connected to DMA 16	Boundary W DMA 10		
10	V90	PE 160	Closed	Connected to DMA 15	Mtisdziri General Abashidze junction Sts.		
15	V91	ST 600	Open	Oulet DMA 15	Mtisdziri General Abashidze junction Sts.	FM20	
15	V92	ST 600	Open	Inlet DMA 15 and DMA 16	Khakhuli Gagarin junction Sts.	FM21 FM22	YES YES
15	V93	PE 110	Open	Khakhuli Gagarin junction Sts.	Khakhuli Gagarin junction Sts.		
16	V94	PE 160	Closed	Connected to DMA 10	Boundary NE DMA 16		
16	V95	ST 400	Open	Oulet DMA 16	Sulxan-saba Orbeliani Gen. Abashidze		
16	V96	PE 225	Closed	Connected to DMA 20	Sulxan-saba Orbeliani Gen. Abashidze		
16	V97	ST 500	Open	Inlet DMA 14	Agmashenebeli (Hopa Junction)	FM28	
16	V98	PE 110	Closed	Connected to DMA 18	Agmashenebeli Tabidze junction Sts.		
16	V99	PE 160	Closed	Connected to DMA 18	Agmashenebeli Khakhuli junction Sts.		
18	V100	PE 355	Open	Inlet to DMA 18	Khakhuli Leonidze junction Sts.	FM23	YES
18	V101	PE 110	Closed	Connected to DMA 16	Boundary SE DMA 18		
14	V102	PE 160	Closed	Connected to DMA 13	General Abashidze Inasaridze junc. Sts.		

Table 33: DMAs isolation strategy

3.5.3 Temporary DMAs study

On this sub-chapter our intention was to implement and to explain to the staff of the utility the procedure to isolate a metered area and how to calculate the water losses.

At that moment, as explained above, we had four isolated areas connected to the new network where pressure tests were being done. So, we benefit from the situation to do the study.

3.5.3.1.1 Introduction

The objective of this study is to present the results obtained after measuring water supply and consumption in four temporary DMAs while the on-going works rehabilitating the network and implementing the definitive DMAs.

3.5.3.1.2 Temporary DMAs

The isolation of these areas allowed the possibility to apply a water balance in each temporary DMA. The inflows were measured by installing flow meters in the metering chambers at the entrance of the DMAs (in three cases) or by data recorded in a flow meter installed in Injalo Reservoir (in one case). The outflows were obtained after receiving the billing data from the Marketing and Billing department of Batumi Tskali.

The situation of the DMAs is presented on the next drawings.

Figure 45: Temporary DMAs location

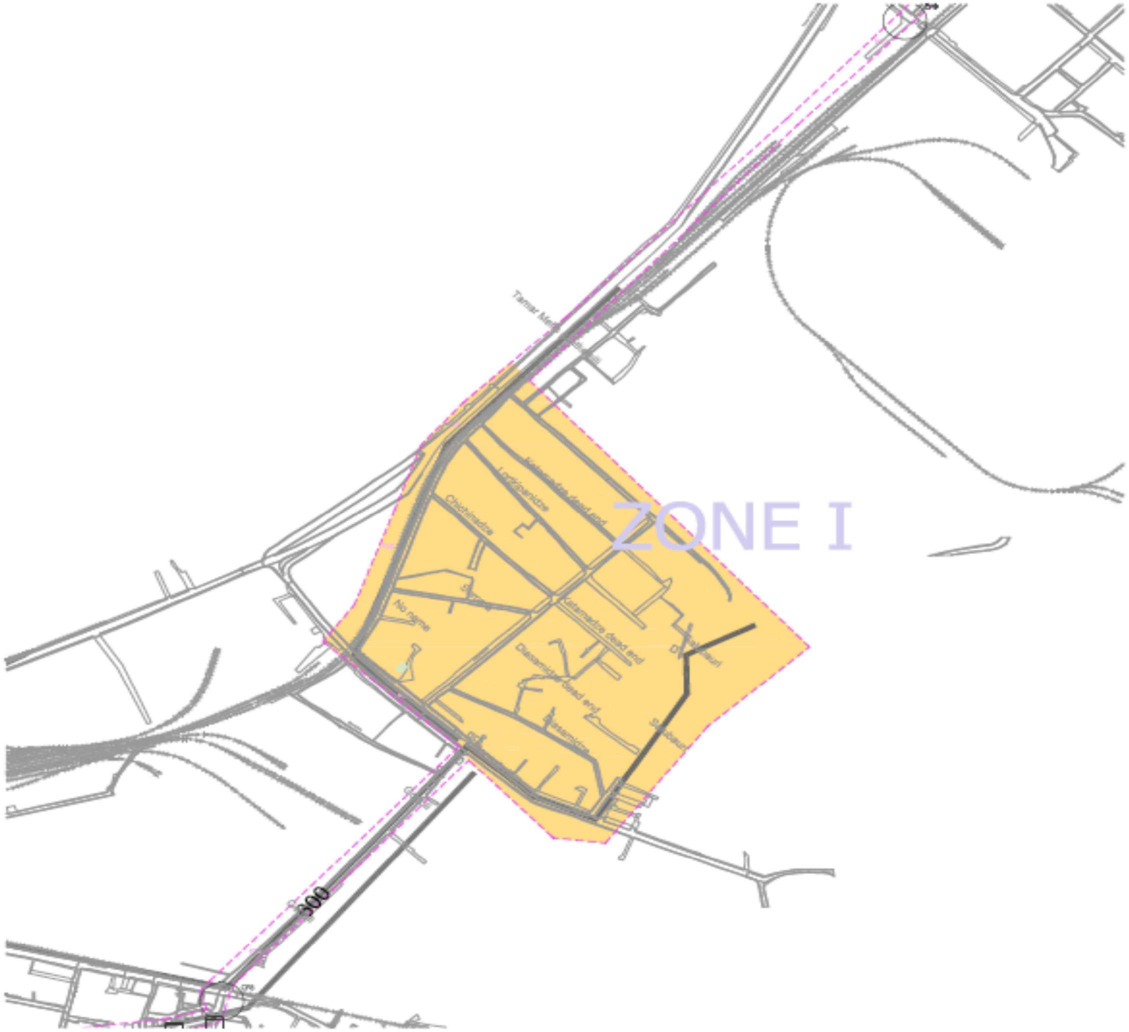


Figure 46: Temporary DMA “Barstkhana”

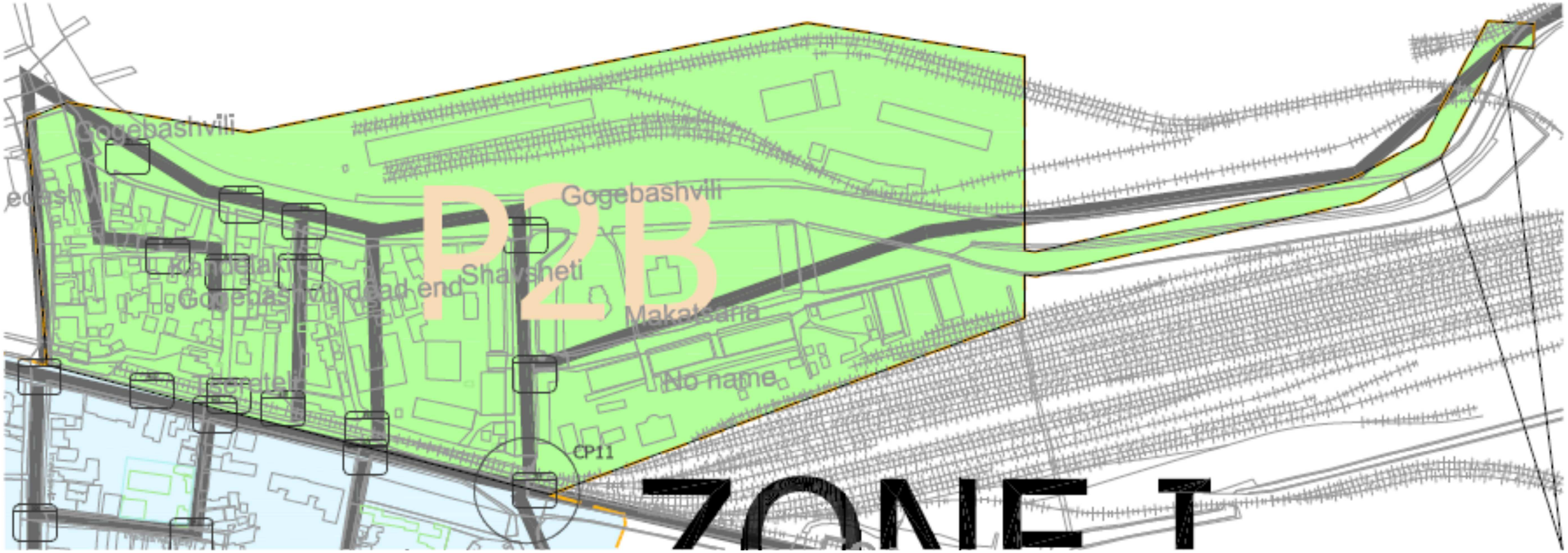


Figure 47: Temporary DMA "P2B area"

Figure 48: Temporary DMA “P2B-P2D1 area”

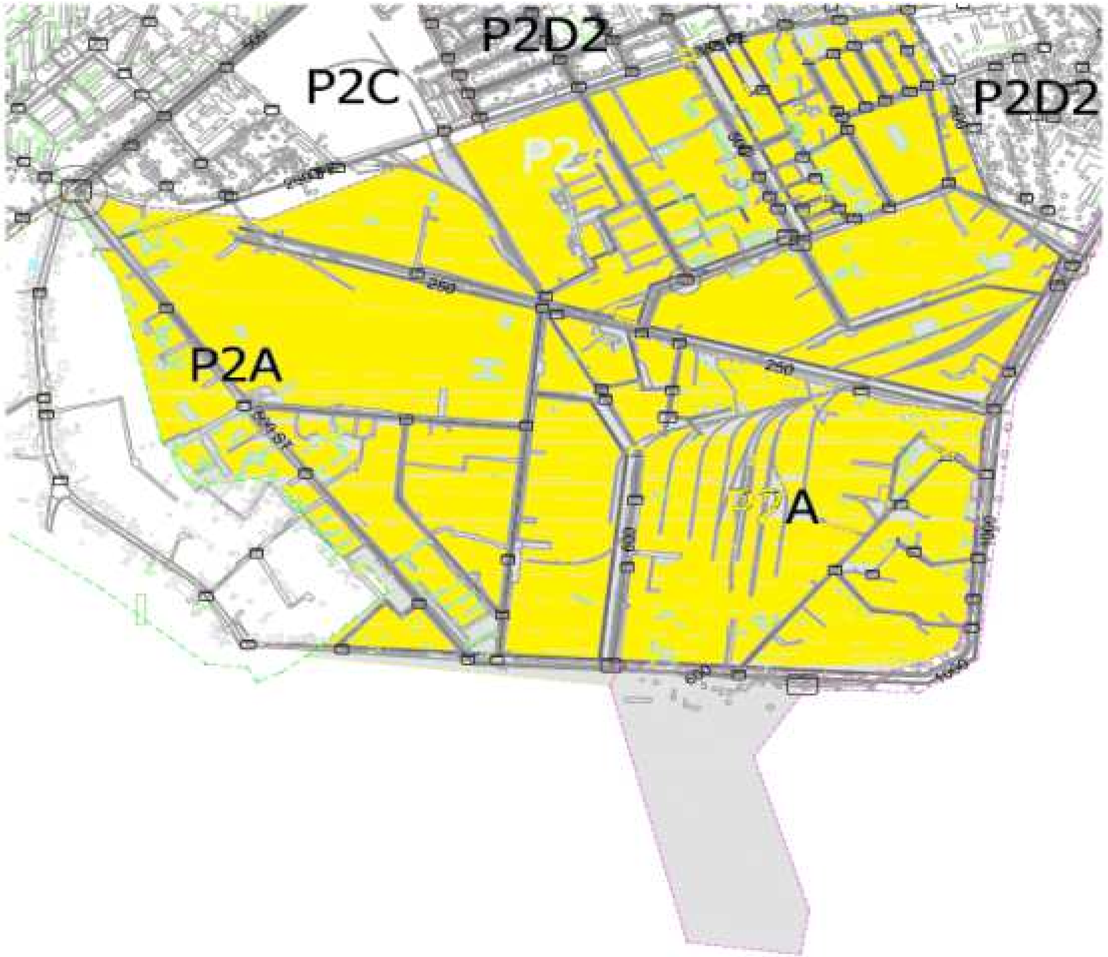


Figure 49: Temporary DMA "Injalo area"

On the next table we summarized the characteristics of the temporary DMA's.

DMA (drawing color)	AREA	ISOLATION
"Yellow"	Injalo	It's a closed area supplied by Injalo Reservoir (inflow measured with fix flow meter)
"Salmon"	Bartskhana	Measurements from chamber located at Noneshvili Street (Noneshvili Gogoli Junction).
		It's a closed area where the measurements were done installing a flow meter.
"Green"	P2B	Measurements from chamber located at CP11 (intersection Maiakovski-Shavsheti Streets).
		It's a closed area where the measurements were done installing a flow meter.
"Blue"	P2B-P2D1	Measurements from chamber located at CP11 (intersection Maiakovski-Shavsheti Streets).
		It's not a closed area. We needed to do the following operations to isolate it:
		1) Close valve at Pushkini Street (node 321 Pushkini Griboedovi junction)
		2) Close valve at Groboedovi street (on DN225 pipe at Griboedovi Chavchavadze junction)

Table 34: Temporary DMA's information

Before the explanation of each DMA, the next table shows a summary of the water balance done in those areas.

Water Balance (average period)		
Temporary DMA	Inflow (measurements) m^3	Outflow (billing) m^3
"Salmon" (Bartskhana)	235.260,61	27.678,58
"Green" (P2B)	13.860,01	13.743,50
"Blue" (P2B+P2D1)	192.055,43	172.314,83
"Yellow" (Injalo)	135.743,64	106.250

Table 35: Summary Water Balance DMA's

The structure of the following sub-points is the same for each of the four DMA. Our aim is to present tables and graphs with the results obtained from data processing and NRW calculation. In each one of them we can know the supplied water, the consumption and the amount of NRW during the studied period. NRW is presented divided into its different terms, as usual on the monthly Comprehensive Overviews.

- **Bartskhana area temporary DMA**

The inflow in this area during the measurement days oscillates around 400 m^3/h during day time and 250 m^3/h during night time as is showed on the next graph.

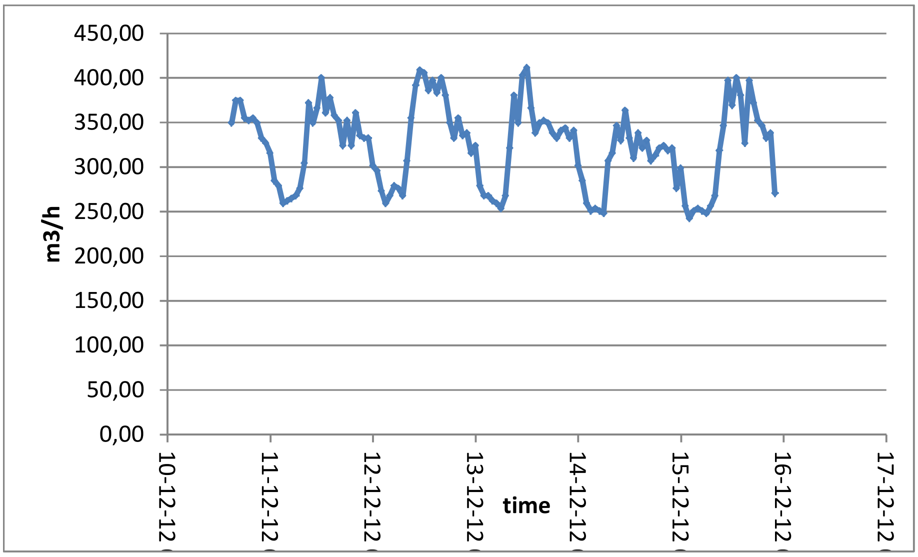


Figure 50: Supplied Water DMA Bartskhana

Although we noticed this diminution of supplied water during night hours, we still think that the amount of night flow is very high. The explanation to this fact could be the number of multi apartment buildings which are not metered with individual water meters yet. Due to past experiences Batumi Tskali had started installing individual water meters in a few buildings already. Those building have the characteristic of deteriorated internal piping and hence very high “consumption” due to a minimum maintenance of its water devices, presenting high intern leaks. The next figure shows the consumption pattern which follows a usual domestic consumption shape, with differences between day and night hours. The difference in consumption between working days and weekends that could be expected, in the case of Batumi is inexistent or not representative.

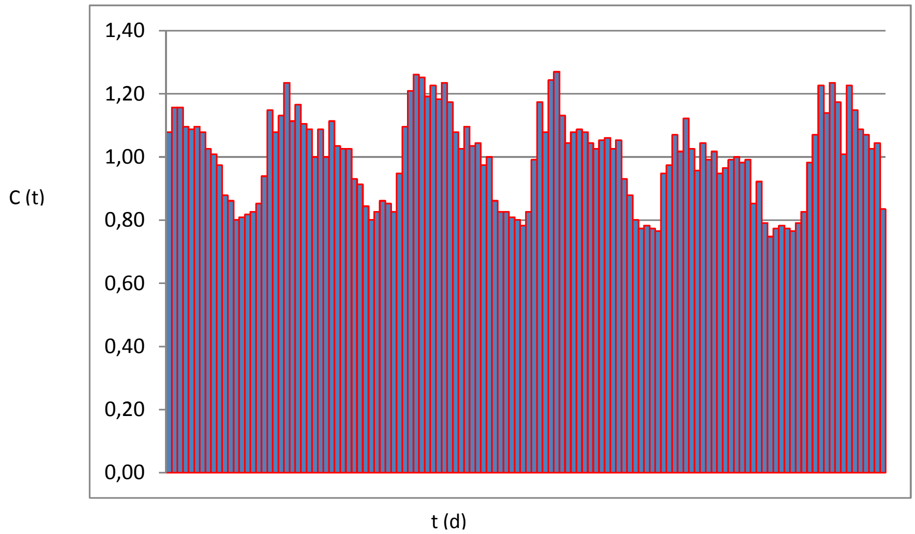


Figure 51: Consumption pattern DMA Bartskhana

Regarding NRW, we are going to present the obtained results as follows.

Sistem Input Volume	m^3	235.261
Billed Metered Consumption	m^3	6.774
Billed Unmetered Consumption	m^3	20.905
Revenue Water = Sum of Billed Metered Consumption + Sum of Billed Unmetered Consumption = Billed Authorized Consumption	m^3	27.679
Non-revenue Water = SIV - RW	m^3	207.582
unbilled Metered Consumption	m^3	10.379
unbilled Unmetered Consumption	m^3	24.910
unbilled Authorized Consumption = unbilled Met.Cons + unbilled Unmet.Cons.	m^3	35.289
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	62.968
Water Losses = Sistem Input Volume - Authorized Consumption	m^3	172.293
Unauthorized consumption	m^3	41.516
Metering Inaccuracies and Data Handling Errors	m^3	37.365
Leakage on Transmission and/or Distribution Mains	m^3	72.654
Leakage and Overflow s at Utility's Storage Tanks	m^3	
Leakage on Service Connections up to Point of Customer Metering	m^3	20.758
Real Loses=Leakage on Transmission+ Leakage and Overflow s at Tanks + Leakage on Service Connection	m^3	93.412
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	78.881

Table 36: Calculation NRW data DMA Bartskhana

System input volume 235.261 100%	Authorized Consumption 62.968 27%	Billed Authorized Consumption 27.679 12%	Billed Metered Consumption 6.774 3%	Revenue Water 27.679 12%
			Billed Unmetered Consumption 20.905 9%	
		Unbilled Authorized Consumption 35.289 15%	Unbilled Metered Consumption 10.379 4%	Non Revenue Water 207.582 88%
			Unbilled Unmetered Consumption 24.910 11%	
	Water Losses 172.293 73%	Apparent Losses 78.881 34%	Unauthorized Consumption 41.516 18%	
			Metering Inaccuracies and Data Handling Errors 37.365 16%	
		Real Losses 93.412 40%	Leakage on Transmission and/or Distribution Mains 72.654 31%	
			Leakage and Overflows at Utility's Storage Tanks 0 0%	
			Leakage on Service Connections up to Point of Customer Metering 20.758 9%	

Table 37: NRW IWA terms DMA Bartskhana

- **P2B area temporary DMA**

The inflow in this area during the measurement days oscillates between 30 m^3/h during day time and 10 m^3/h during night time, having a minimum of 5 m^3/h.

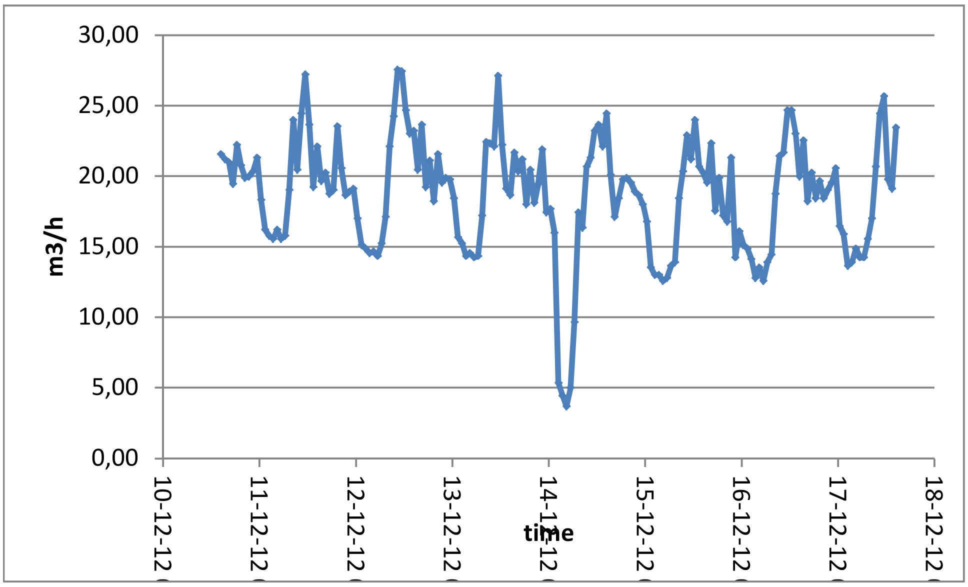


Figure 52: Supplied Water DMA P2B

The consumption pattern shows a domestic consumption shape, with peaks of consumption in the mornings, noon and evening, as usual.

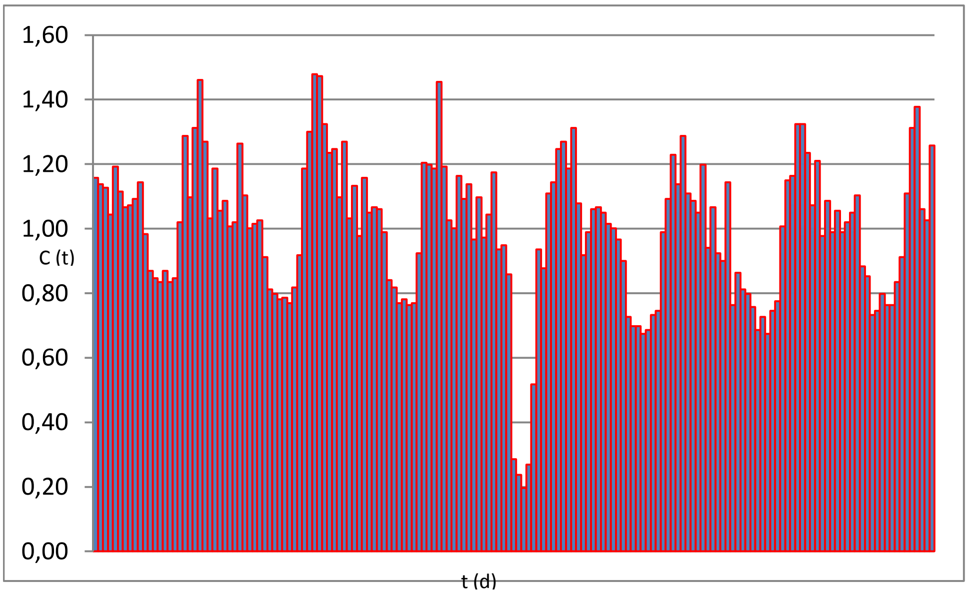


Figure 53: Consumption pattern DMA P2B

The observed minimum night flow in the night of Friday 14th of December can't be explained as something that happened due to human factors. It was explained as a supply problem in Salibauri reservoir. This fact was checked with the results of December Measurements Plan. Regarding NRW calculation we obtain the next results in this DMA.

Sistem Input Volume	m^3	13.860
Billed Metered Consumption	m^3	6.071
Billed Unmetered Consumption	m^3	7.673
Revenue Water = Sum of Billed Metered Consumption + Sum of Billed Unmetered Consumption = Billed Authorized Consumption	m^3	13.744
Non-revenue Water = SIV - RW	m^3	117
unbilled Metered Consumption	m^3	6
unbilled Unmetered Consumption	m^3	14
unbilled Authorized Consumption = unbilled Met.Cons + unbilled Unmet.Cons.	m^3	20
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	13.764
Water Losses = Sistem Input Volume - Authorized Consumption	m^3	97
Unauthorized consumption	m^3	23
Metering Inaccuracies and Data Handling Errors	m^3	21
Leakage on Transmission and/or Distribution Mains	m^3	41
Leakage and Overflow s at Utility's Storage Tanks	m^3	
Leakage on Service Connections up to Point of Customer Metering	m^3	12
Real Loses=Leakage on Transmission+ Leakage and Overflow s at Tanks + Leakage on Service Connection	m^3	53
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	44

Table 38: Calculation NRW data DMA P2B

<table>
<tr><td rowspan="9">System input volume
13.860
100%</td><td rowspan="4">Authorized Consumption
13.764
99%</td><td rowspan="2">Billed Authorized Consumption
13.744
99%</td><td>Billed Metered Consumption
6.071
44%</td><td rowspan="2">Revenue Water
13.744
99%</td></tr>
<tr><td>Billed Unmetered Consumption
7.673
55%</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
20
0%</td><td>Unbilled Metered Consumption
6
0%</td><td rowspan="7">Non Revenue Water
117
1%</td></tr>
<tr><td>Unbilled Unmetered Consumption
14
0%</td></tr>
<tr><td rowspan="5">Water Losses
97
1%</td><td rowspan="2">Apparent Losses
44
0%</td><td>Unauthorized Consumption
23
0%</td></tr>
<tr><td>Metering Inaccuracies and Data Handling Errors
21
0%</td></tr>
<tr><td rowspan="3">Real Losses
53
0%</td><td>Leakage on Transmission and/or Distribution Mains
41
0%</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks
0
0%</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering
12
0%</td></tr>
</table>

Table 39: NRW IWA terms DMA P2B

- **P2B-P2D1 area temporary DMA**

The inflow in this area during the measurement days oscillates between 350 m^3/h during day time and 200 m^3/h during night time, having a minimum of 50 m^3/h.

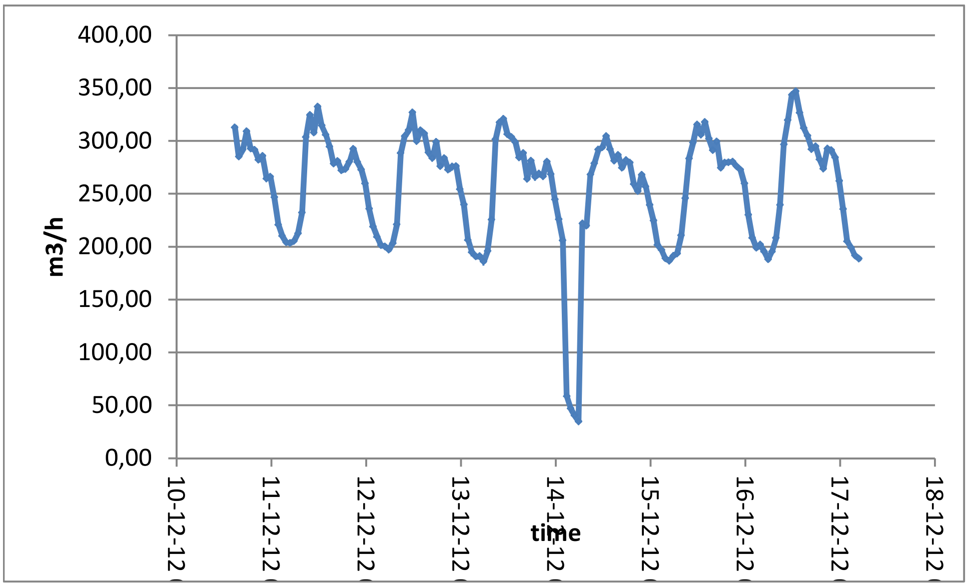


Figure 54: Supplied Water DMA P2B-P2D1

The consumption pattern is similar to the other ones that we are obtaining in Batumi.

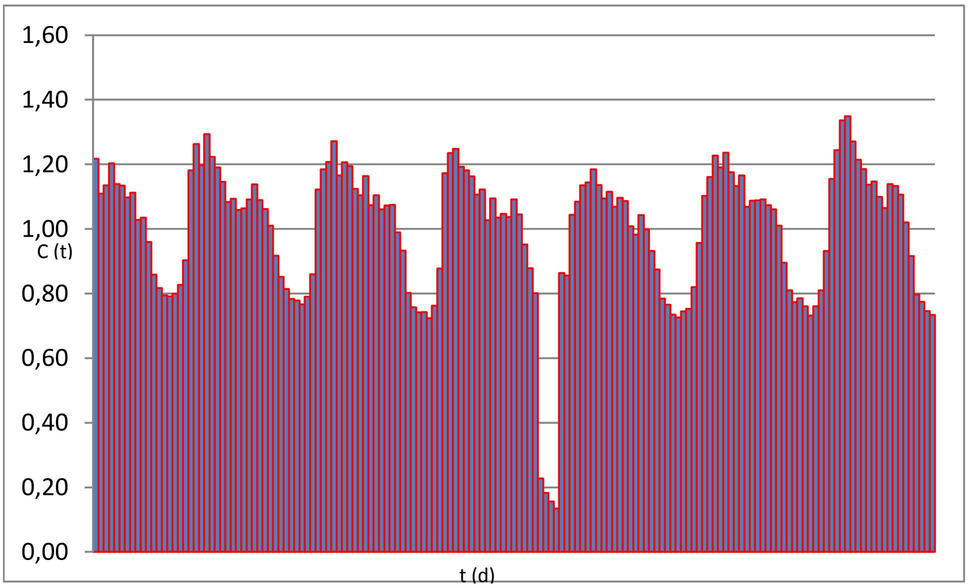


Figure 55: Consumption pattern DMA P2B-P2D1

In this case the minimum value during the night of Friday 14th of December also can be observed. It was expected because the measurements in both DMA were done from the same metering chamber, and both DMA's are supplied by Salibauri. Batumi Tskali water production department confirmed the problem on December 14th.

The NRW calculations are presented in the following tables.

Sistem Input Volume	m^3	191.151
Billed Metered Consumption	m^3	64.469
Billed Unmetered Consumption	m^3	107.846
Revenue Water = Sum of Billed Metered Consumption + Sum of Billed Unmetered Consumption = Billed Authorized Consumption	m^3	172.315
Non-revenue Water = SIV - RW	m^3	18.836
unbilled Metered Consumption	m^3	942
unbilled Unmetered Consumption	m^3	2.260
unbilled Authorized Consumption = unbilled Met.Cons + unbilled Unmet.Cons.	m^3	3.202
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	175.517
Water Losses = Sistem Input Volume - Authorized Consumption	m^3	15.634
Unauthorized consumption	m^3	3.767
Metering Inaccuracies and Data Handling Errors	m^3	3.390
Leakage on Transmission and/or Distribution Mains	m^3	6.593
Leakage and Overflow s at Utility's Storage Tanks	m^3	
Leakage on Service Connections up to Point of Customer Metering	m^3	1.884
Real Loses=Leakage on Transmission+ Leakage and Overflow s at Tanks + Leakage on Service Connection	m^3	8.477
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	7.157

Table 40: Calculation NRW data DMA P2B-P2D1

System input volume 191.151 100%	Authorized Consumption 175.517 92%	Billed Authorized Consumption 172.315 90%	Billed Metered Consumption 64.469 34%	Revenue Water 172.315 90%
			Billed Unmetered Consumption 107.846 56%	
		Unbilled Authorized Consumption 3.202 2%	Unbilled Metered Consumption 942 0%	Non Revenue Water 18.836 10%
			Unbilled Unmetered Consumption 2.260 1%	
	Water Losses 15.634 8%	Apparent Losses 7.157 4%	Unauthorized Consumption 3.767 2%	
			Metering Inaccuracies and Data Handling Errors 3.390 2%	
		Real Losses 8.477 4%	Leakage on Transmission and/or Distribution Mains 6.593 3%	
			Leakage and Overflows at Utility's Storage Tanks 0 0%	
			Leakage on Service Connections up to Point of Customer Metering 1.884 1%	

Table 41: NRW IWA terms DMA P2B-P2D

- **Injalo area temporary DMA**

Firstly, it is presented a graph regarding the measured inflow to this area.

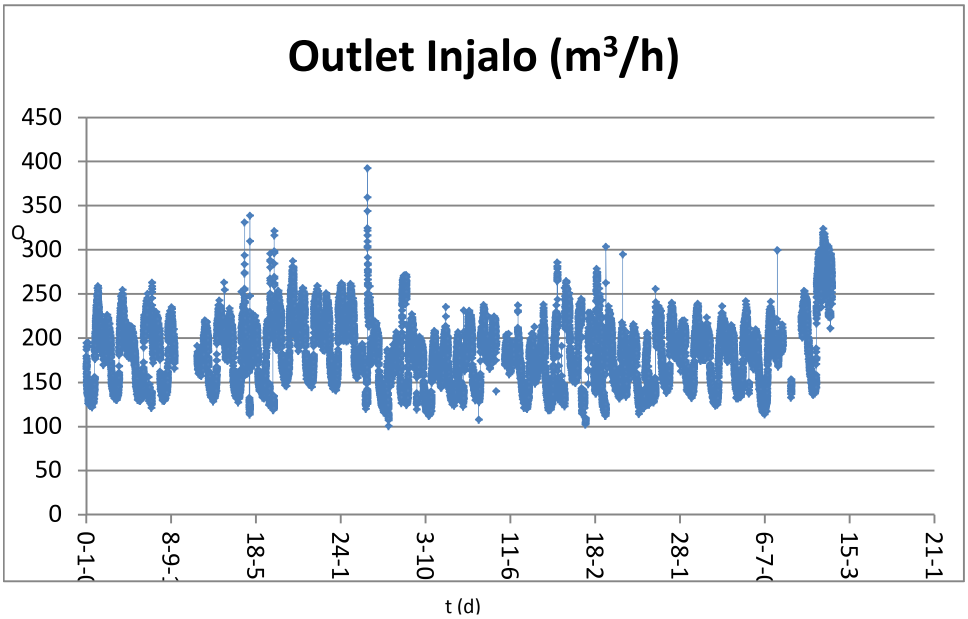


Figure 56: Supplied Water DMA Injalo

The order of magnitude of the inflows is close to 300 m^3/h as maximum and 100 m^3/h as minimum. The maximum corresponds to the consumption peaks during the day time, and the minimum is the consumption during night. Following we can see the consumption pattern during the calculating period.

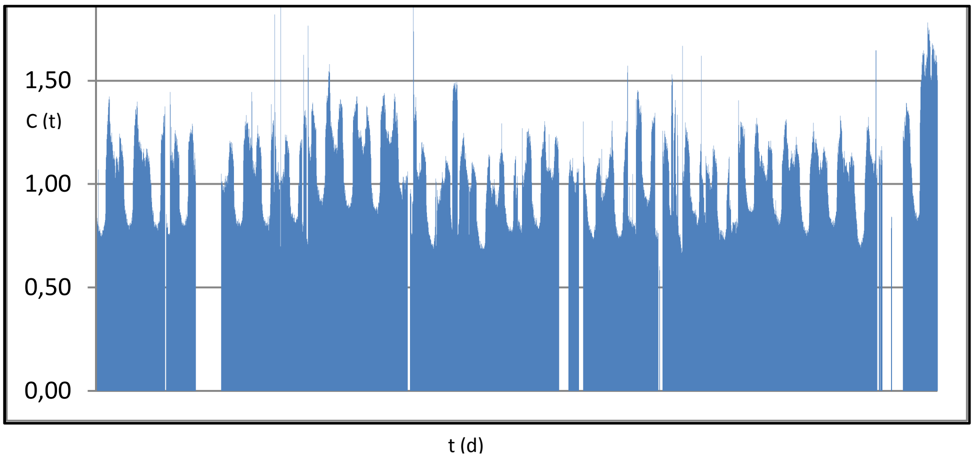


Figure 57: Consumption Pattern Injalo Reservoir

The NRW calculations are presented in the following tables.

Sistem Input Volume	m^3	135.744
Billed Metered Consumption	m^3	10.587
Billed Unmetered Consumption	m^3	95.663
Revenue Water = Sum of Billed Metered Consumption + Sum of Billed Unmetered Consumption = Billed Authorized Consumption	m^3	106.250
Non-revenue Water = SIV - RW	m^3	29.493
unbilled Metered Consumption	m^3	1.475
unbilled Unmetered Consumption	m^3	3.539
unbilled Authorized Consumption = unbilled Met.Cons + unbilled Unmet.Cons.	m^3	5.014
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	111.264
Water Losses = Sistem Input Volume - Authorized Consumption	m^3	24.479
Unauthorized consumption	m^3	5.899
Metering Inaccuracies and Data Handling Errors	m^3	5.309
Leakage on Transmission and/or Distribution Mains	m^3	10.323
Leakage and Overflows at Utility's Storage Tanks	m^3	
Leakage on Service Connections up to Point of Customer Metering	m^3	2.949
Real Loses=Leakage on Transmission+ Leakage and Overflows at Tanks + Leakage on Service Connection	m^3	13.272
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	11.208

Table 42: Calculation NRW data DMA Injalo

System input volume 135.744 100%	Authorized Consumption 111.264 82%	Billed Authorized Consumption 106.250 78%	Billed Metered Consumption 10.587 8%	Revenue Water 106.250 78%
			Billed Unmetered Consumption 95.663 70%	
		Unbilled Authorized Consumption 5.014 4%	Unbilled Metered Consumption 1.475 1%	Non Revenue Water 29.494 22%
			Unbilled Unmetered Consumption 3.539 3%	
	Water Losses 24.480 18%	Apparent Losses 11.208 8%	Unauthorized Consumption 5.899 4%	
			Metering Inaccuracies and Data Handling Errors 5.309 4%	
		Real Losses 13.272 10%	Leakage on Transmission and/or Distribution Mains 10.323 8%	
			Leakage and Overflows at Utility's Storage Tanks 0 0%	
			Leakage on Service Connections up to Point of Customer Metering 2.949 2%	

Table 43: NRW IWA terms DMA Injalo

3.5.3.1.3 Summary and conclusions

This table is included to allow a fast look on the presented balances along the temporary DMAs study.

TEMPORARY DMA	*REVENUE WATER (%)*	*NON-REVENUE WATER (%)*
"Salmon" (Bartskhana)	12	88
"Green" (P2B)	99	1
"Blue" (P2B+P2D1)	90	10
"Yellow" (Injalo)	78	22

Table 44: NRW balance on temporary DMAs

The conclusions highlighted on that moment are summarized below.

High NRW level observed in Bartskhana area is very likely due to high consumption not yet individually metered at the multi apartment buildings.

We used the assumption of 550 L/cap/d to calculate the revenue water as usual. Actually, we think that this consumption value has to be even higher in this kind of buildings and would allow achieving more % of Revenue Water.

It also indicates that individual metering needs to be promptly implemented in those areas were losses are the highest.

The difference of the percentage of NRW observed in the other three DMA should be more similar when all the customers will be billed by individual water meter readings.

The study was done using data of one month of measurement. In order to have more solid results a longer period of measurement and monitoring would be required. On the other hand, this study was only used to teach staff about isolation, to implement it properly on the definite DMAs.

3.5.4 Definitive DMAs

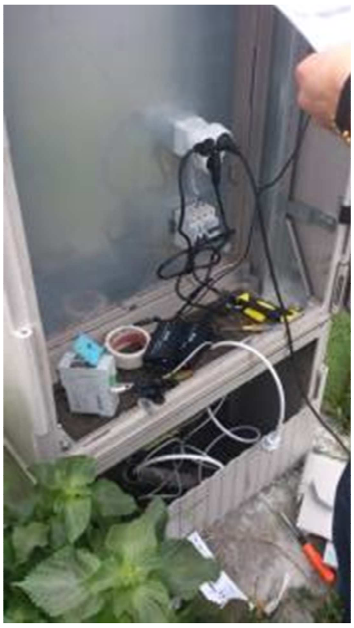
The implementation of the district metered areas in the new network was based in two mains actions: isolation and water metering in each area.

The isolation strategy has been explained above.

On the other hand, as commented previously, flow meters and transmitters were installed in order to fulfil the other main action: metering.

The electrodes of the ultrasonic flow meters were installed on the pipes using the underground metering chambers built for that. Near the metering chambers, the flow meters were installed inside the electrical boxes together with the transmitters and antennas. The electrodes were connected to the flow meters using underground protective tubes between the metering chamber and the electrical box.

The NRW team was trained to install, configure and use the devices. The next photos show the process.



3.5.5 Zero pressure tests

After a reasonable time when finishing the installation of the devices and isolation strategy in order to see the network performance on these new conditions, we checked the isolation by zero pressure tests.

In order to check the correct isolation of DMAs, it was decided to do “zero pressure tests” in each isolated area under Phase II. The procedure to realize these tests is explained following: during night time NRW team closed each inlet/outlet present on the DMA we were working on that moment. Before the closing maneuver we installed pressure loggers inside the DMA. Once valves were closed, we waited some time to see the pressure going down until values around 0 bar, the signal that those areas were totally isolated and not connected to any water source.

The results of the tests were satisfactory. Main DMAs under Phase II are isolated and ready for operation. Some small issues occurred as problems with the mechanism of some valves which impeded the maneuvering but it was solved rapidly.

Rest of DMAs under Phase III or the ones partly connected to DMAs under Phase III will be better tested during next months. Anyway, a detailed study of the state of valves and connections was already done.

The followed strategy and results of the tests are presented on the next table.

1-2-3						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
1-2-3	V10	PE 225	Open	Inlet DMA 1-2-3	Mayakoski Shavsheti junction Sts.	Closed
1-2-3	V13	ST 600	Open	Inlet DMA 1-2-3	Tsereteli Imedashvili junction Sts.	Closed
4-5	V33	ST 600	Open	Outlet DMA 1-2-3	Tsereteli Imedashvili junction Sts.	Closed
Isolated						
4-5						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
4-5	V33	ST 600	Open	Inlet DMA 4-5	Chavchavadze Vaja Pshavela junction Sts.	Closed
13	V37	ST 500	Open	Outlet DMA 4-5	Chavchavadze Griboedovi junction Sts.	Closed
Isolated						
6						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
6	V47	ST 500	Open	Inlet DMA 6 (from DMA 11b)	Eristavi Bagriatoni junction Sts.	Closed
6	V49	ST 200	Open	Inlet DMA 6	Eristavi Shavsheti junction Sts.	Closed
6	V54	PE 355	Open	Inlet DMA 6	Tsereteli Maiakovski junction Sts.	Closed
11b	V9	ST 500	Open	Inlet DMA 6 (via DMA 11b) Connected to Salibauri	Mayakoski Dadiani juction Sts.	Closed
Isolation Phase III (Connected to Chakvi line)						
7-8						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
6	V48	PE 355	Open	Inlet DMA 7-8	Eristavi Bagriatoni junction Sts.	Closed
6	V51	ST 500	Open	Inlet DMA 7-8	Mitisdziri Asatiani junction Sts.	Closed
Isolation Phase III						
9						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
10	V89	ST 400	Open	Inlet DMA 9	Lermontovi Bagrationi junction Sts.	Closed
13	V37	ST 500	Open	Inlet DMA 9	Chavchavadze Griboedovi junction Sts.	Closed
Isolation Phase III						
10						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
10	V79	PE 160	Open	Inlet DMA 10	Mtisdziri Melikishvili junction Sts.	Closed
10	V80	PE 110	Open	Inlet DMA 10	Mtisdziri Melikishvili junction Sts.	Closed

10	V92	ST 400	Open	Inlet to DMA 10	Sulxan-saba Orbeliani Gen. Abashidze	Closed
Isolation Phase III (Connected to Chakvi line)						
11a						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
11a	V6	ST 200	Open	Inlet DMA 11a	Gogoli Noneshvili Sts.	Closed
11a	V7	PE 225	Open	Inlet DMA 11a	Gogebashvili Makasaria junction Sts.	Closed
Isolated Phase III (Connected to Chakvi line)						
11b						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
11b	V8	ST 250	Open	Inlet DMA 11b	Gogoli Mayakoski juction Sts.	Closed
Isolation Phase III (Connected to Chakvi line)						
12a						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
12a	V4	ST 500	Open	Inlet DMA 12a	Noneshvili St.	Closed
12a	V5	PE 110	Closed	Valve is open suppling DMA12a (Phagava Street) and part of DMA12b Connected by BTS	Boundaries DMAs 12a and 12b	Closed
Isolated						
12b						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
Isolation Phase III						
13						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
13	V36	ST 500	Open	Inlet DMA 13	Chavchavadze Griboedovi junction Sts.	Closed
Isolated						
14						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
13	V40	PE 225	Open	Inlet DMA 14	Abuseridze General Abashidze junc. Sts.	Closed
16	V104	ST 500	Open	Inlet DMA 14	Agmashenebeli (Hopa Junction)	Closed
Isolated						
15 & 16						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
15	V98	ST 600	Open	Inlet DMA 15&16	Khakhuli Gagarin junction Sts.	Closed

Isolation Phase III						
17						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
17	V1	PE 225	Open	Inlet DMA17	Tbeti St.	Closed
Isolated (Connected to Chakvi line)						
18						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
18	V107	PE 225	Open	Inlet to DMA 18	Khakhuli Leonidze junction Sts.	Closed
Isolation Phase III						
19						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
Isolation Phase III						
20						
DMA	VALVE DESIGNATION	DN PIPE	VALVE CORRECT STATUS	FUNCTION / ISOLATION	LOCATION	***0 P test***
10	V94	PE 355	Open	Inlet to DMA 20	Sulxan-saba Orbeliani Gen. Abashidze	Closed
Isolation Phase III						

Table 45: DMAs isolation status, zero pressure tests

As we can see on the table, most of the DMAs under Phase II are totally isolated. Rest of DMAs under Phase II connected to DMAs under Phase III is mostly isolated and will be tested during next months (as some of its borders are connected to DMAs under Phase III and on isolation process).

The next image shows DMAs totally isolated and yet tested.

Figure 58: Isolated tested DMAs

Following, some pictures showing the process of "zero pressure tests".

During the “zero pressure tests” time, NRW team was trained using new leakage detection equipment which they will continue using during the valve identification.

3.6 Managing information system

3.6.1 Introduction

In order to fulfill the targets set in the business plan, while optimizing the performance of Batumi Tskali and sustaining the service quality provided to the population of Batumi, it was required an adequate management Information System (MIS). The MIS should combine the storage and computing of generated customer, financial and technical information while allowing the management proper decision making and business control. It furthermore has to enable the utility management and board to carry out proper monitoring and guidance of the business development. Such an MIS for a water utility has to consider the planning and documentation of works as well as reporting and monitoring of the performance. The creation of reliable information and communication routines for the different departments of the utility as well as the involved stakeholders is one of the key requirements for of the whole project.

⇒ **Sub-Tasks to be carried out:**

It is our goal to assist the utility in a radical turnaround by following a change management approach. For this purpose, we started by supporting the management to base their decision making on a holistic assessment of the problem and on reliable, adequate MIS information. For instance, with the help of real time payment information by customers, targeted activities of customer communication or payment enforcement to boost revenue generation and improvement of collection efficiency are possible. Furthermore without reliable and timely information about the water production and consumption patterns, proper assurance of supply quality and planning for peak demand will be impossible.

As a result Batumi Tskali management will be able to regain the initiative for the development of the utility as well as the ownership of actions and responsibilities essential for the operation of a water supply system and adequate service provision.

⇒ **Assessment of MIS features**

At the beginning of the process we will carry out an assessment of the MIS features currently used. The main focus hereby should be on the customer database, the billing system, the accounting system and other MIS modules in use. Consequently, their functionality will be contrasted vis-à-vis the requirements of the current system as well as the potential for optimization. According to our understanding the following figure 10 depicts the MIS modules which might be desirable.

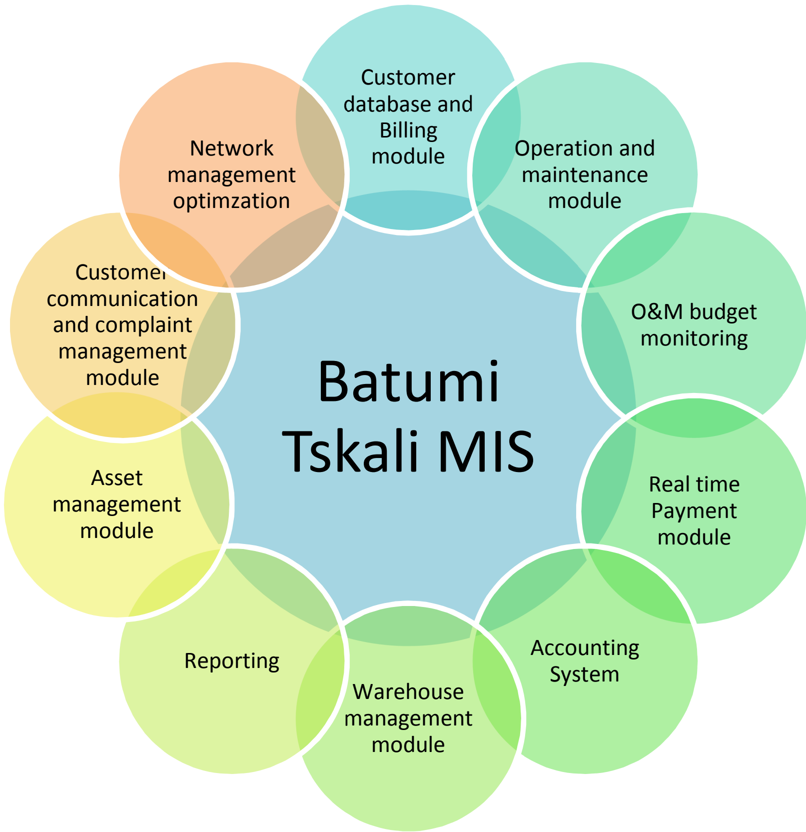


Figure 59: MIS modules

After the assessment, we proposed a course of action in close coordination with the management, and support the realization of the utility MIS to achieve the envisioned objectives. With unpredictable developments in mind, the MIS should be organized in a modular structure as this allows incremental development while updating and exchanging modules if the need arises. The main modules are as follows:

⇒ **The customer database and billing module**

In a first step, the module for billing and the customer database of the utility should be verified in an active process of the billing department. Together with the billing utility staff, we developed and implemented a procedure for database verification as an important step to eradicate illegal connections and legalize all customers. Moreover, a thorough verification will clean the database from obsolete information such as faulty and non-updated names and addresses as well as new or changed connections, new inhabitants, etc.

⇒ **The asset management (network and facilities)**

Asset management should be depicted in a MIS module which runs with the help of GIS. The utility GIS data should be as broad as possible and updated as frequently as possible. Hence, all new features, facilities and equipment will be reflected in terms of material, year of construction, performance, energy consumption (if any) and geographical location. Based on the data of this module, adequate asset management, repair, maintenance and replacement will be organized. The utility SCADA will be linked to the asset management module as respective information can be properly used by the relevant departments in the most appropriate and non-redundant manner.

⇒ **Warehouse management**

Warehouse management is of critical importance for network utilities, as spare parts and O&M material are necessary for daily O&M. Moreover, it signifies an important cost aspect of the utility and is also critical to avoid loss of material and spare parts due to inaccurate inventory. In order to optimize warehouse management and monitor the usage of materials and spare parts, a proper warehouse module linked to the accounting software is necessary.

⇒ **O&M budget monitoring system**

Budget monitoring for O&M is fundamental for the utility regarding the planning and implementation of O&M work. Instead of drafting daily, weekly or monthly hard copy reports, the data should be collected in real time in the O&M module, allowing using the most actual data for decision-making of relevant actions for the O&M teams. Moreover, any O&M cost can be attributed to the O&M of facilities (cost places) by line items, thus allowing proper documentation and reporting. Analytic reports about the dynamic of O&M costs/supply areas can be instrumental in the process of decision-making.

⇒ **The network management optimization module**

The network management optimization module is an important tool to manage the District Metered Areas and Non-Revenue Water reduction works. This module will synthesize the utility's network and water facility SCADA, DMA maps and flow and consumption monitoring making a real time monitoring of the utility network performance possible. The overall MIS structure and specific functionalities of the MIS module features will be discussed in the framework of MIS assessment with key stakeholders. In this context, we will link the technical and institutional capacities of the utility by applying the change management index. This will assure that in parallel, the identified training needs will be focused on staff capacity and institutional development.

⇒ **GIS system assessment**

A coherent, reliable and factually correct GIS database is vitally important for the successful implementation of the project. The transition from legacy systems to a modern GIS solution will create the necessary preconditions for ensuring that the asset data of the utility are geographically, descriptively and temporarily accurate. In order to achieve this, the existing GIS database shall be put through the following processes:

- Identification and evaluation of existing data model, design of a new data model if necessary.
- Identification of temporal granularity level of existing data.
- Checks on data consistency, geographical and topological correctness, data projection, existence and completeness of attributes.
- Analysis of address data, identification of gaps and duplicates and establishment of non-amlargeuous relationships between user accounts, addresses and spatial parcels.

- Rectification of data irregularities and inconsistencies, filling the gaps and generation of a neat and coherent network topology.
- Analysis and optimization of GIS database performance (software and hardware).

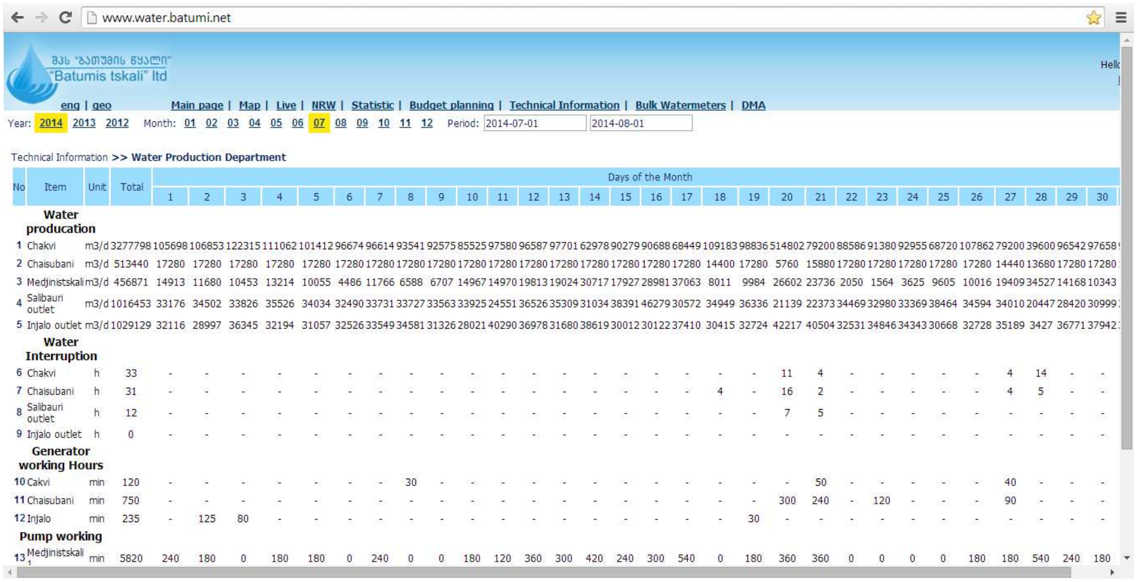
The final GIS database will be implemented as a modern, spatially enabled database-driven and standard-compliant solution that is accessible through a variety of interfaces and can be directly used as input for billing systems and hydrological models. The optimal GIS solution will be based on the OGC standard compliant software stack, such as PostgreSQL/PostGIS database, which can be accessed through both proprietary (i.e. ArcGIS) and open-source (QGIS) clients.

3.6.1 Batumi Tskali MIS

As explained above, in order to have a monitoring system where allocate the information it was developed the MIS for Batumi Tskali, online, at www.water.batumi.net

Focusing on NRW issue, we have implemented on the MIS the next information:

⇒ Technical information: on this lab for authorized users it is possible to consult the water production of each month, besides other information like water quality analysis, reparations, waste water…



No	Item	Unit	Total	Days of the Month																													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Water producation																																
1	Chakvi	m3/d	3277798	105698	106853	122315	111062	101412	96674	96614	93541	92575	85525	97580	96587	97701	62978	90279	90688	68449	109183	98836	514802	79200	88586	91380	92955	68720	107862	79200	39600	96542	97658
2	Chaisubani	m3/d	513440	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	17280	14400	17280	5760	15880	17280	17280	17280	17280	17280	14440	13680	17280	17280
3	Medjinistskali	m3/d	456871	14913	11680	10453	13214	10055	4486	11766	6588	6707	14967	14970	19813	19024	30717	17927	28981	37063	8011	9984	26602	23736	2050	1564	3625	9605	10016	19409	34527	14168	10343
4	Salibauri outlet	m3/d	1016453	33176	34502	33826	35526	34034	32490	33731	33727	33563	33925	24551	36526	35309	31034	38391	46279	30572	34949	36336	21139	22373	34469	32980	33369	38464	34594	34010	20447	28420	30999
5	Injalo outlet	m3/d	1029129	32116	28997	36345	32194	31057	32526	33549	34581	31326	28021	40290	36978	31680	38619	30012	30122	37410	30415	32724	42217	40504	32531	34846	34343	30668	32728	35189	3427	36771	37942
	Water Interruption																																
6	Chakvi	h	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	4	-	-	-	-	-	4	14	-	-
7	Chaisubani	h	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	16	2	-	-	-	-	-	4	5	-	-
8	Salibauri outlet	h	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	5	-	-	-	-	-	-	-	-	-
9	Injalo outlet	h	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Generator working Hours																																
10	Cakvi	min	120	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	50	-	-	-	-	-	40	-	-	-
11	Chaisubani	min	750	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	300	240	-	120	-	-	-	90	-	-	-
12	Injalo	min	235	-	125	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-
	Pump working																																
13	Medjinistskali 1	min	5820	240	180	0	180	180	0	240	0	0	180	120	360	300	420	240	300	540	0	180	360	360	0	0	0	0	180	180	540	240	180

Figure 60: MIS water production

⇒ DMA: here is where the flow meters data sent by the transmitters is shown. Clicking on the flow meter we are interested on, the chart below will show the evolution of the flow from the last 24 hours.

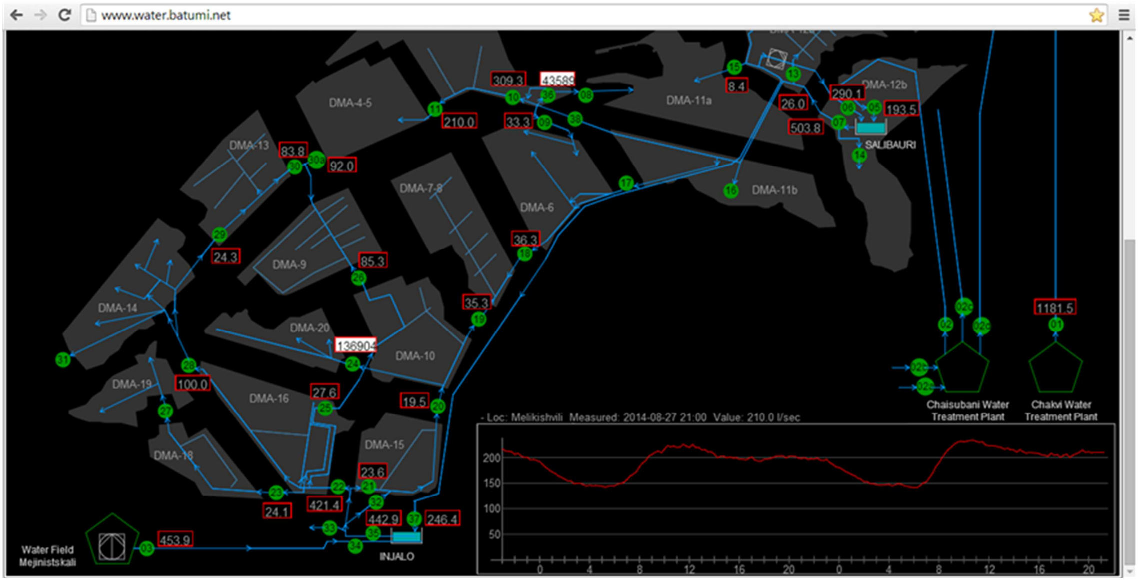
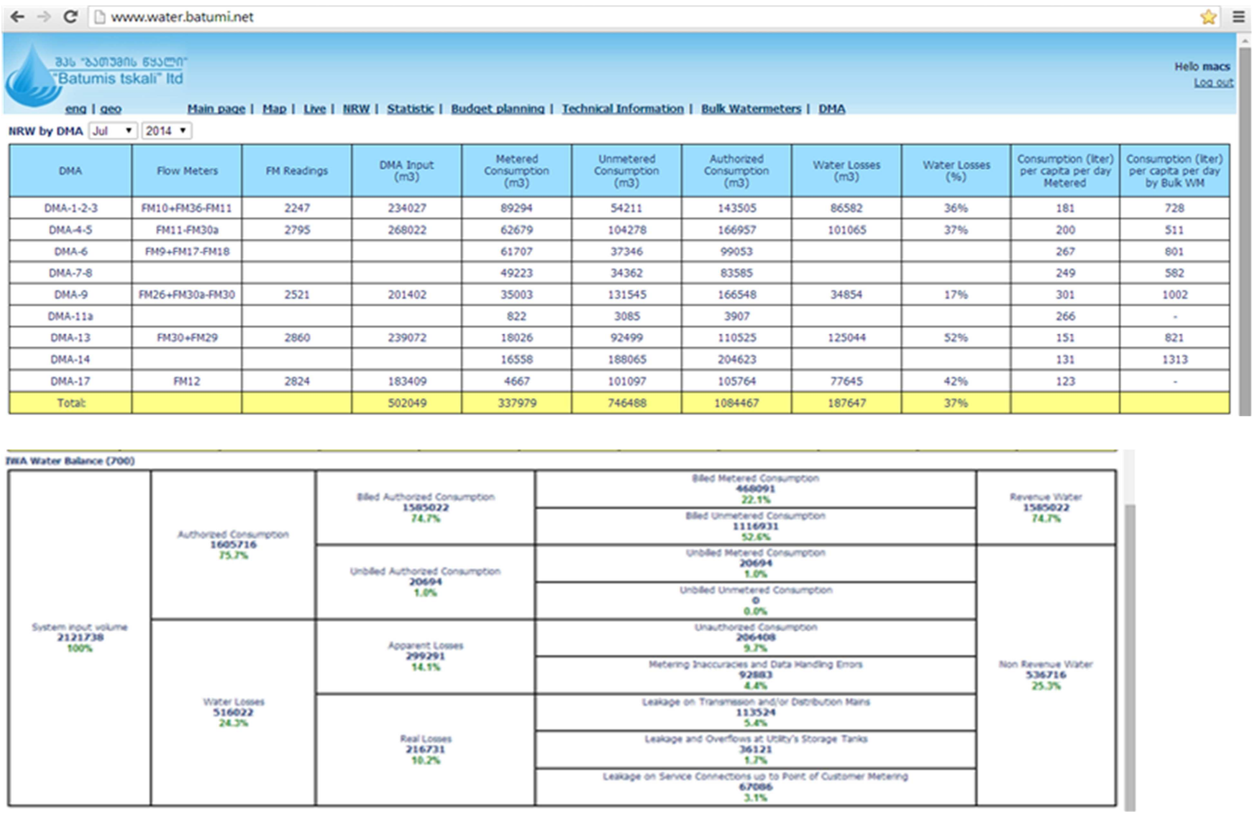


Figure 61: MIS DMA flow metering

⇒ NRW: on this page the IWA is calculated per DMA with the specification of each term. This is the version online of part of our comprehensive overview.



DMA	Flow Meters	FM Readings	DMA Input (m3)	Metered Consumption (m3)	Unmetered Consumption (m3)	Authorized Consumption (m3)	Water Losses (m3)	Water Losses (%)	Consumption (liter) per capita per day Metered	Consumption (liter) per capita per day by Bulk WM
DMA-1-2-3	FM10+FM36-FM11	2247	234027	89294	54211	143505	86582	36%	181	728
DMA-4-5	FM11-FM30a	2795	268022	62679	104278	166957	101065	37%	200	511
DMA-6	FM9+FM17-FM18			61707	37346	99053			267	801
DMA-7-8				49223	34362	83585			249	582
DMA-9	FM26+FM30a-FM30	2521	201402	35003	131545	166548	34854	17%	301	1002
DMA-11a				822	3085	3907			266	-
DMA-13	FM30+FM29	2860	239072	18026	92499	110525	125044	52%	151	821
DMA-14				16558	188065	204623			131	1313
DMA-17	FM12	2824	183409	4667	101097	105764	77645	42%	123	-
Total:			502049	337979	746488	1084467	187647	37%		

IWA Water Balance (700)

System input volume 2121738 100%	Authorized Consumption 1605716 75.7%	Billed Authorized Consumption 1585022 74.7%	Billed Metered Consumption 468091 22.1%	Revenue Water 1585022 74.7%
			Billed Unmetered Consumption 1116931 52.6%	
		Unbilled Authorized Consumption 20694 1.0%	Unbilled Metered Consumption 20694 1.0%	Non Revenue Water 536716 25.3%
			Unbilled Unmetered Consumption 0 0.0%	
	Water Losses 516022 24.3%	Apparent Losses 299291 14.1%	Unauthorized Consumption 206408 9.7%	
			Metering Inaccuracies and Data Handling Errors 92883 4.4%	
		Real Losses 216731 10.2%	Leakage on Transmission and/or Distribution Mains 113524 5.4%	
			Leakage and Overflows at Utility's Storage Tanks 36121 1.7%	
			Leakage on Service Connections up to Point of Customer Metering 67086 3.1%	

Figure 62: MIS NRW calculation

4 APPLICATION TO DMA 1-2-3: MODELING AND SIMULATION

4.1 Introduction

On this chapter we will repeat the process to include NRW in the mathematical model focusing only on DMA 1-2-3.

The aim is to present what the next steps we are going to implement are, once the ongoing works of micro-metering installation, DMAs isolation and network rehabilitation phase III finish.

The reasons to choose this DMA are as follows:

- ⇒ Situated on the touristic area of Batumi, close to the beach, where most of the large hotels are, so it was rehabilitated firstly.
- ⇒ The micro-metering is widely implemented yet, with near 70% of the customers being billed with water meter.
- ⇒ Nowadays the DMA is completely isolated and tested positively.
- ⇒ Installation of bulk meters to estimate the unbilled unmetered consumption.

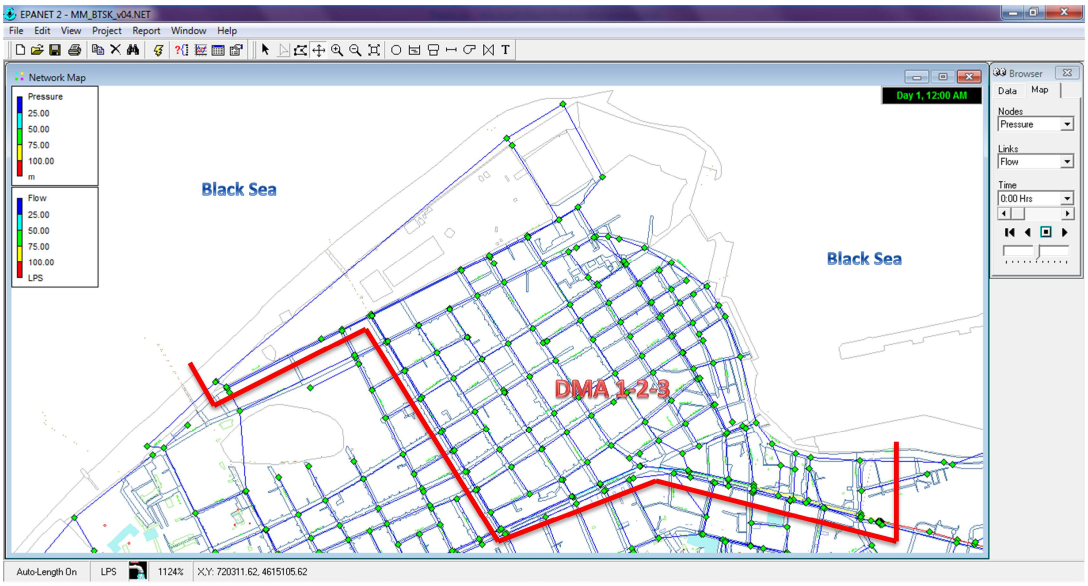


Figure 63: DMA 1-2-3 model

4.2 DMA isolation modeling

Isolation of the DMAs on the mathematical model was done basically adding one fictitious junction close to the DMA boundaries junctions, then the pipes ending on those DMA boundaries junctions were obliged to finish on the added fictitious junctions. Finally, one pipe acting as an isolating valve (closed status) was added joining the fictitious junction with the DMA boundary one.

Each one of this fictitious junctions and isolating valve pipes was tagged with the number of the DMA which is isolating and called with the same ID of the existing valve (same ID as on the GIS, CAD and isolation strategy data).

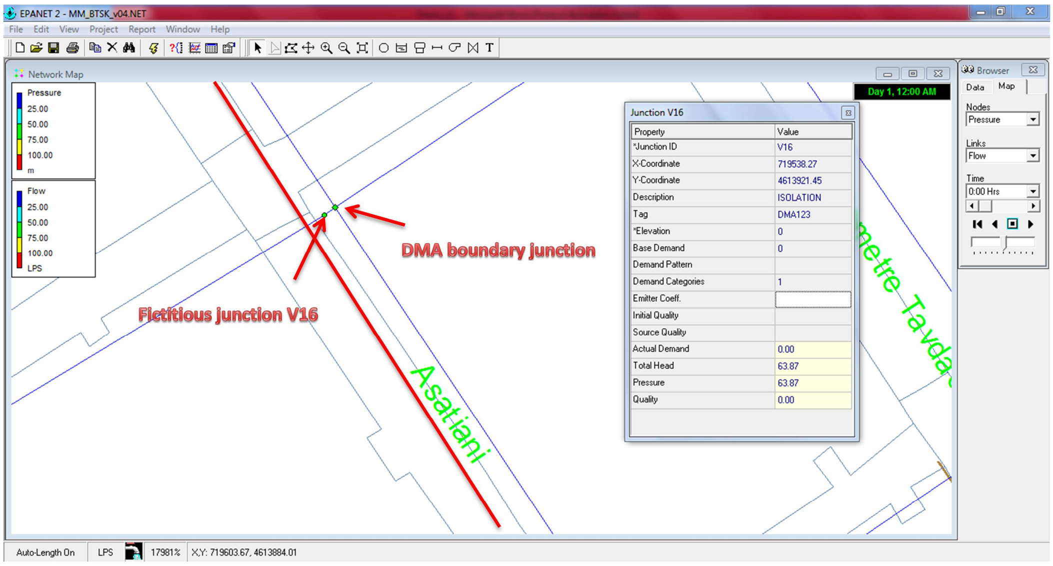


Figure 64: DMA boundary junction modeling

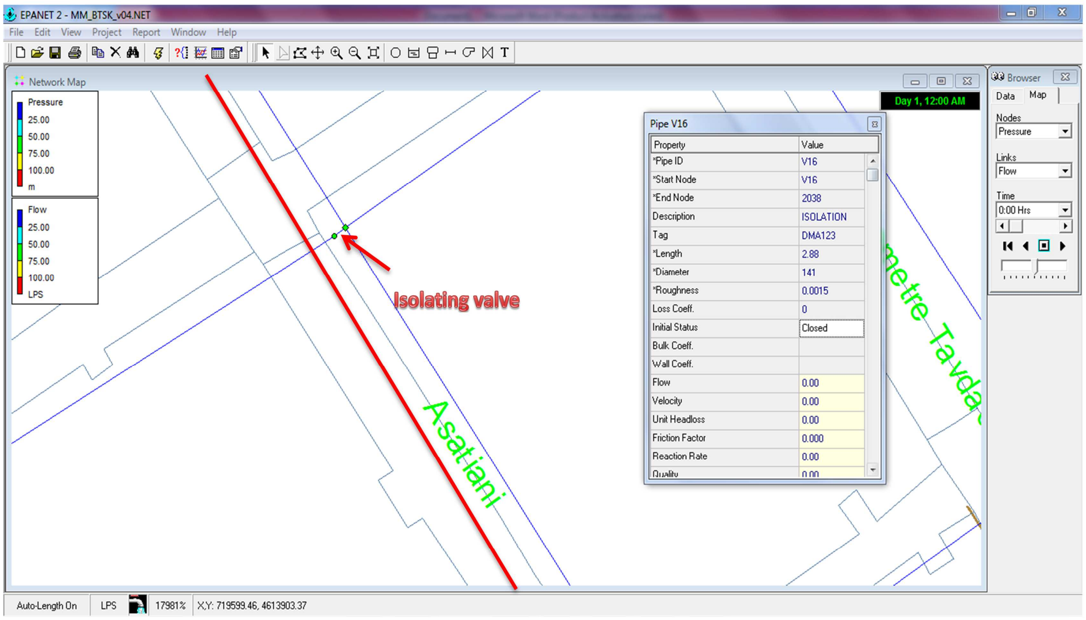


Figure 65: DMA isolating valve modeling

4.3 Unbilled unmetered consumption investigation

DMA 1-2-3 has been settled fully operational during last month. Its calculations could be already considered as reliable to calibrate the hydraulic model for the system. However, it was noticed that the volume of water loss calculated for this DMA was surprisingly high. Therefore, an investigation methodology was initiated at the middle of May.

The billing department from Batumi Tskali was involved in the examination since the very beginning in order to agree and understand better where might be the source of losses. After some meetings it was observed that the volume of Authorized Not Billed Consumption for the beach promenade was coming from an estimated value rather than metered water. This estimation could or could not be correct. Therefore, a three days measurement campaign was initiated installing six new bulk water meters. Those new bulk water meters measured volumes are included from now on in the calculation of the water balance. Also, calculations will include the Unmetered Unbilled Authorized Consumption from flashing the pipes during night time in a most precise way, trying to avoid inaccuracies. The table below shows the ID of those bulk water meters as well as the concrete address where they are installed and the volume registered during the investigation campaign. The map that is accompanying the table shows part of DMA 1-2-3 and the position of the bulk water meter involucrate in the investigation which are giving the entrance of water to the promenade area.

ID	DMA	Building	Address	Volume (m^3)
800/801	1-2-3	Boulevard centre		2.927
800/802	1-2-3	Neighbouring area of the summer theatre		205
800/803	1-2-3	Yacht Club	Gviniashvili #11	166
101/11	1-2-3	wedding house	gogebashvili	79
150/1	1-2-3	Circus parking	Baratashvili #23	5
139/23	1-2-3			2
				3.384

Table 46: DMA 1-2-3 Bulk meters metering

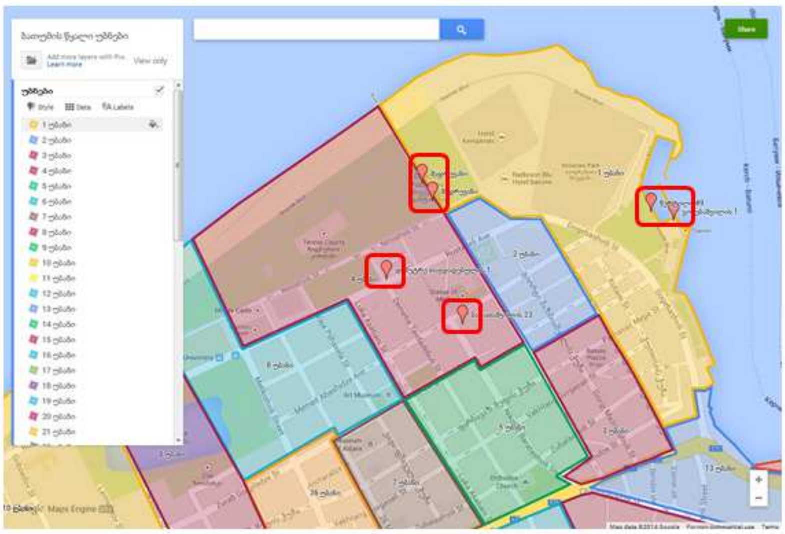


Figure 66: Bulk meters location at DMA 1-2-3

For three days (16th-17th-18th of May) the total measured volume was 3.384 m^3. Now, supposing this consumption (or similar) was taken place in June and extrapolating to the whole month it would result to a volume of around 34.968 m^3 Metered Unbilled Authorized Consumption.

Once presented these results to Batumi Tskali technical management it was agreed to start a leakage detection campaign on this area of the sea boulevard, where most of the fountains are leaking. With the increment of the pressure value during the night time, that leaking reaches the maximum.

4.4 Leakage and Overflows at Utility's Storage Tanks

From the beginning of the current year we have calculated the difference between the reservoirs inflows and outflows, in order to have one term of the real water losses calculated and not estimated by technical literature.

Regarding the other 2 terms of the real water losses, leakage on transmission and/or distribution mains and leakage on service connections up to point of customer metering, random measurement campaigns per DMA are being designed at this moment of the program.

The table with the results as follows.

					2014			
		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	AVERAGE
Salibauri	**Inflow (m^3):**	**774.006,00**	**631.986,00**	**679.944,00**	**747.970,00**	**954.087,00**	**1.225.810,00**	**835.633,83**
	Chakvi TP	6.942,00	12.753,00	58.592,00	148.297,00	419.365,00	812.434,00	243.063,83
	Chaisubani TP	767.064,00	619.233,00	621.352,00	599.673,00	534.722,00	413.376,00	592.570,00
	Outflow (m^3)	**742.849,00**	**608.317,00**	**618.056,00**	**700.089,00**	**920.664,00**	**1.174.545,00**	**794.086,67**
	Losses (m^3)	**31.157,00**	**23.669,00**	**61.888,00**	**47.881,00**	**33.423,00**	**51.265,00**	**41.547,17**
	Losses (%)	**4,03%**	**3,75%**	**9,10%**	**6,40%**	**3,50%**	**4,18%**	**4,97%**
Injalo	**Inflow (m^3):**	**455.014,29**	**279.308,00**	**409.924,00**	**557.732,00**	**961.388,00**	**881.011,00**	**590.729,55**
	Chakvi TP	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	MejinisTkali	455.014,29	279.308,00	409.924,00	557.732,00	961.388,00	881.011,00	590.729,55
	Outflow (m^3)	**452.864,29**	**248.545,00**	**371.454,00**	**517.931,00**	**883.869,00**	**794.766,00**	**544.904,88**
	Losses (m^3)	**2.150,00**	**30.763,00**	**38.470,00**	**39.801,00**	**77.519,00**	**86.245,00**	**45.824,67**
	Losses (%)	**0,47%**	**11,01%**	**9,38%**	**7,14%**	**8,06%**	**9,79%**	**7,76%**
							Total average	**6,36%**

Table 47: Leakage reservoirs

That was the total percentage of losses at the reservoirs calculated with the inflow to the entire network, so we should estimate the part for DMA 1-2-3.

		Losses reservoirs (m^3)
Network inflow (m^3)	1.229.020,29	87.371,83
DMA inflow (m^3)	220.918,00	**15.705,20**

Table 48: Leakage reservoirs DMA 1-2-3 part

4.5 Large consumption identification and allocation at the model

As presented above when describing the NRW modeling, the emitter coefficients were calculated the same for every consumption node on the model. When achieving the isolation of DMAs and the implementation of the micro-metering by individual water meters we should identify the "large customers" on each DMA. Once identified the large consumption should be allocated on the nearest consumption node in the model charging the consumption, and calculate the specific emitter coefficient for that node.

Using the stored information in the MIS we can identify the large customers on the DMA, as show the next image.

150-20b	Sps "baTumis sazRvao navsadguri"	q. baTumi gogebaSvilis q #3	6108.0000
166-1a	ss "nurol inSaaT ve TijareTi"-s warmomadgenloba saqarTveloSi	q. baTumi/vaJa-fSavela ninoSvilis q #2/21	5801.0000
101-1	Sps argo menejmenti	q. baTumi ninoSvilis q #1	3350.0000
126-5	Sps plaza fitnesi	q. baTumi, WavWavaZis #5	3247.0000
103-18	Sps sastumro "inturist palas"	q. baTumi,ninoSvilis q.11	2702.0000
114-25	Sps ""	farnavaz mefis 25	1237.0000
101-7e	Sps	q. baTumi, meliqiSvilis #151	1059.0000
155-8b	Sps	k.gamsaxurdias 8	1054.0000
150-9	Sps arkadia menejmenti	q. baTumi gogebaSvilis q #9	986.0000
150-1g1	Sps jift of aWara	bulvaris mimdebare teritoria	916.0000

Figure 67: DMA 1-2-3 large customer identification on the MIS

The first three columns show the location and the identification of the consumption, and the last one is the consumption measured in m^3. In this case we considered as a large customer the consumption over 500 m^3/month.

With this information the next step was the location of the customers and their allocation on the nearest consumption node at the model, as presented on the next image.

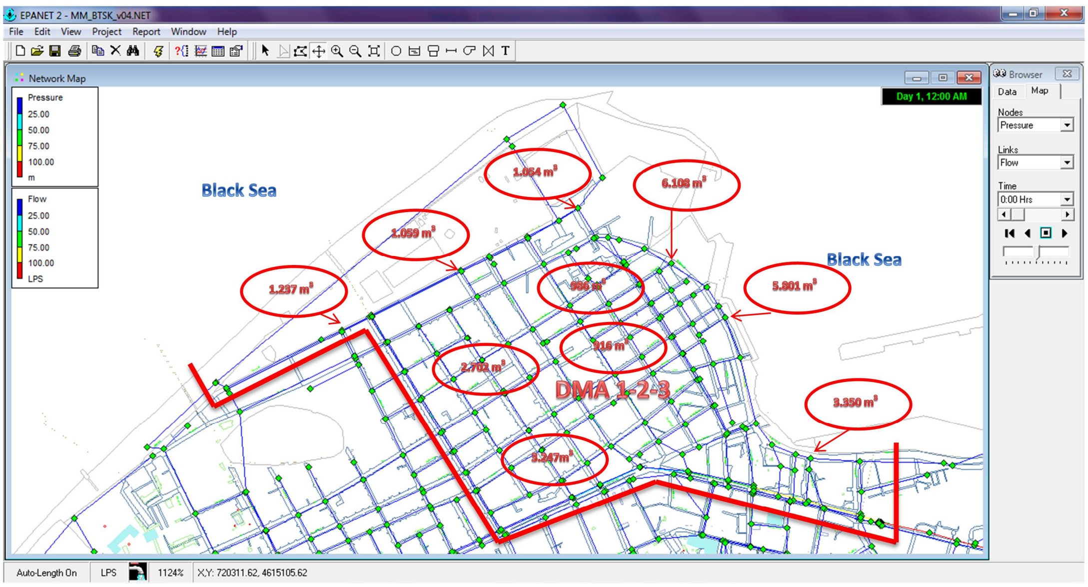


Figure 68: DMA 1-2-3 large customer allocation at the model

The next table show the base demand at the nodes of DMA 1-2-3, where we separated the nodes with the large customers specific demand and the rest of the nodes with equal base demand which represents the total inflow at the DMA less the consumption of the large customers.

	Inflow (m^3/mes)	Consumption (m^3/mes)	Inflow (l/s)	Consumption (l/s)
DMA 1-2-3	194.458,00		72,60	
Large Customers:				
1		6.108,00		2,28
2		5.801,00		2,16
3		3.350,00		1,25
4		3.247,00		1,21
5		2.702,00		1,01
6		1.237,00		0,46
7		1.059,00		0,39
8		1.054,00		0,39
9		986,00		0,37
10		916,00		0,34
	220.918,00		0,42	
	m3 total		l/s node	
			172 nodes	

Table 49: Base demand nodes DMA 1-2-3

4.6 Water balance

On this paragraph the water balance of DMA 1-2-3 during the calculation month, June, will be defined.

As explained when presenting NRW modeling, we need to know the distribution of the consumption in order to identify what part of the water losses are real losses, which are pressure dependant.

The table on the next page show the water balance applied to DMA 1-2-3 during the month of June. The NRW terms distribution was done as follows:

⇒ Unbilled Metered Consumption: as explained above, a measurement campaign with bulk meters was performed to quantify this amount of water. It resulted to be the 56% of the total monthly NRW.

⇒ The leakage and overflows at the reservoirs was calculated as presented above. This quantity supposed the 25% of the total monthly NRW, but it was deleted of the DMA balance as the DMA has not any reservoir. We only took into account this percentage to quantify the percentages of the other two terms of real losses.

⇒ Leakages on transmission mains and connections were estimated as 20% of NRW (10% one term and 10% the other one). The reason is because following AEAS orientations (figure 24), the real losses are around 45% of the total NRW. So, in this case we supposed 25% of leakages on the reservoirs (part applied to DMA 1-2-3), and the other 20% on the pipes.

- ⇒ Metering Inaccuracies and Data Handling Errors are estimated as 18% of the total of NRW, as indicated by AEAS (figure 24).
- ⇒ Unauthorized consumption was estimated with 5% of the NRW because the DMA is situated at the touristic part of Batumi, the richest and more maintained one. When simulating the entire network we are using a percentage of 40% of the total NRW.
- ⇒ Unbilled Unmetered Consumption are estimated as a 1% of NRW by subtracting from the total the other terms.

Sistem Input Volume (inflow DMA 1-2-3)	m^3	220.918
Billed Metered Consumption = Sum of Billed Metered Consumption DMA 1-2-3	m^3	83.834
Billed Unmetered Consumption = Sum of Billed Unmetered Consumption DMA 1-2-3	m^3	74.463
Revenue Water = Sum of Billed Metered Consumption DMA 1-2-3 + Sum of Billed Unmetered Consumption DMA 1-2-3 = Billed Authorized Consumption	m^3	158.297
Non-revenue Water = Inflow - Revenue Water	m^3	62.621
Unbilled Metered Consumption	m^3	34.968
Unbilled Unmetered Consumption	m^3	626
Unbilled Authorized Consumption = Unbilled Met.Cons + Unbilled Unmet.Cons.	m^3	35.594
Authorized Consumption = Billed Auth. Cons. + unbilled Auth. Cons.	m^3	193.891
Water Losses = Inflow - Authorized Consumption	m^3	27.027
Unauthorized consumption	m^3	3.131
Metering Inaccuracies and Data Handling Errors	m^3	11.272
Leakage on Transmission and/or Distribution Mains	m^3	6.262
Leakage and Overflows at Utility's Storage Tanks	m^3	-
Leakage on Service Connections up to Point of Customer Metering	m^3	6.262
Real Loses=Leakage on Transmission+ Leakage and Overflows at Tanks + Leakage on Service Connection	m^3	12.524
Apparent Losses = Unaothorized Consumption + Metering Inaccuracies and Data Handling Errors	m^3	14.403

Table 50: DMA 1-2-3 water balance

Once realized the NRW distribution we proceed to calculate it with the IWA water balance, resulting to be 28% as show the next table.

System input volume 220.918 100%	Authorized Consumption 193.891 88%	Billed Authorized Consumption 158.297 72%	Billed Metered Consumption 83.834 38%	Revenue Water 158.297 72%
			Billed Unmetered Consumption 74.463 34%	
		Unbilled Authorized Consumption 35.594 16%	Unbilled Metered Consumption 34.968 16%	Non Revenue Water 62.521 28%
			Unbilled Unmetered Consumption 626 0%	
	Water Losses 26.927 12%	Apparent Losses 14.403 7%	Unauthorized Consumption 3.131 1%	
			Metering Inaccuracies and Data Handling Errors 11.272 5%	
		Real Losses 12.524 6%	Leakage on Transmission and/or Distribution Mains 6.262 2,8%	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to Point of Customer Metering 6.262 3%	

Table 51: DMA 1-2-3 IWA balance, NRW

4.7 NRW modeling

As explained on point 2.4.6 we will proceed modeling the NRW considering part of it as pressure dependent.

The other part non-pressure dependent will be included as consumed water, following the consumption pattern.

The leakage flow is divided using emitters at the nodes and simulated, having maximum at night time with lower consumption and higher pressure. The other part of the flow is assigned constant or proportional to the base demand.

The next table presents the partition on pressure dependant and non-dependant, as explained on the water balance for DMA 1-2-3.

	m^3/d	L/s
NRW	2.020	23,40
Pressure dependent Flow	404	4,67
Non Pressure dependent Flow	1.616	18,7

Table 52: DMA 1-2-3 P dependant and non-dependant flows

Following the methodology explained on point 2.4.6 the next step is to divide the non-P dependant flow between the consumption nodes of DMA 1-2-3, taking into account that we have identified large customers and calculated its particular base demand. For the other consumption nodes the base demand is the same as calculated above. The next table shows the sum of this non-P dependant flow to the demand basis of the nodes.

Node	$Q_{BaseDemand}$ (L/s)	$Q_{Non\text{-}P\ dependent}$ (L/s)	Q_{total} (L/s)
172 “Normal customers” nodes	0,42	0,10	0,52
10 “Large customers” nodes			
1	2,28	0,10	2,38
2	2,16	0,10	2,26
3	1,25	0,10	1,35
4	1,21	0,10	1,31
5	1,01	0,10	1,11
6	0,46	0,10	0,56
7	0,39	0,10	0,49
8	0,39	0,10	0,49
9	0,37	0,10	0,47
10	0,34	0,10	0,44

Table 53: DMA 1-2-3 P dependant and non-dependant flows

On the other hand, the pressure dependent flow will be used to calculate the emitter's coefficients, as presented on the methodology, using the next equation.

$$Q = Ec \cdot \sqrt{P}$$

The pressure term is calculated in each node at the instant of lower flow (night time) which presents the higher pressure value. Results presented on the next table.

Node	$Q_{P\text{-dependent}}$ (L/s)	P (mca)	$\sqrt{P}$	Ec
172 "Normal customers" nodes	0,03	50	7,07	0,0042
10 "Large customers" nodes	0,03	50	7,07	0,0042

Table 54: DMA 1-2-3 emitter coefficients calculation

The pressure value used applied to the "normal customers" was an average extracted from the next pressure contour plot, consulted for the night time with higher pressure.

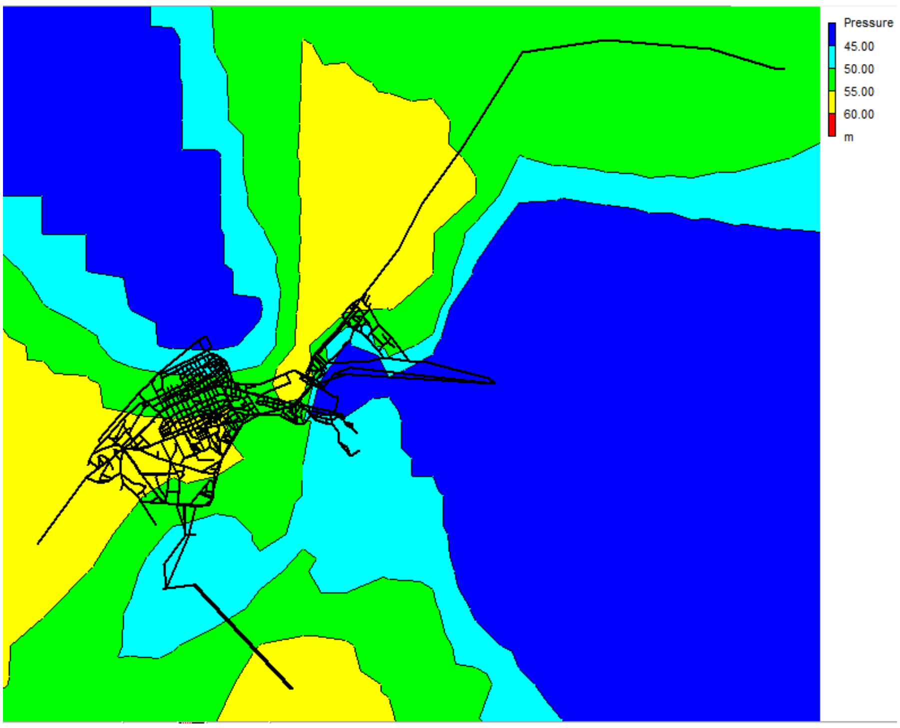


Figure 69: P contour plot from the model

For the "large customers" the pressure value was consulted at each node.

4.8 Consumption pattern

The consumption pattern used to this last update of the model and simulation was the correspondent to the last quarter. Previously we have presented the consumption patterns for Salibauri and Injalo separately.

As the network normally is being supplied half and half by each reservoir, the consumption pattern presented as follows is the average between them.

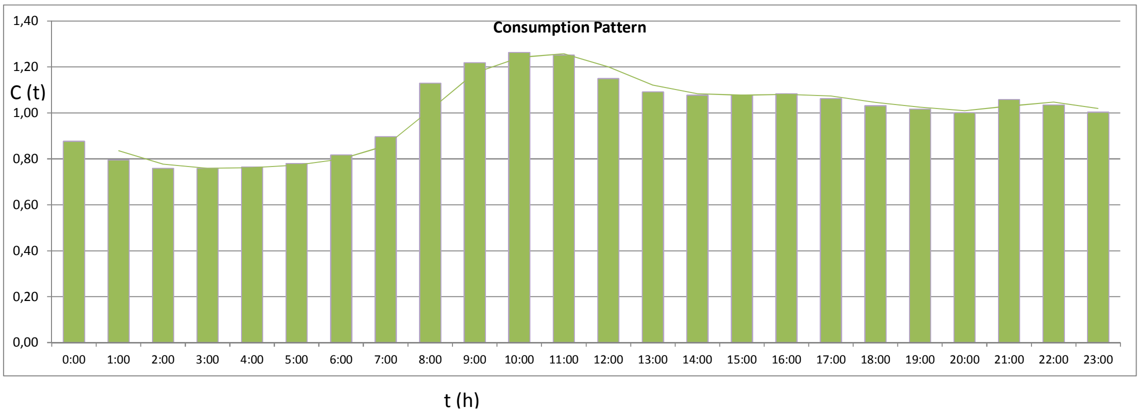


Figure 70: Consumption pattern, simulation DMA 1-2-3

4.9 Pressure management

One of the next most important steps to fight against leakages is to agree with the water utility management the installation of pressure reduction valves (PRV) working during night time.

As observed on the consumption pattern the night consumption on the network is still high.

On this chapter we are presenting how to model the installation of PRV applied to the DMA 1-2-3, in order to check the results which can be extrapolated to the rest of the network.

Pressure reduction valves are automatic control valves which function is to keep constant the value of the pressure downstream of its installation point.

Likewise, limiting the pressure, the valve can limit the instantaneous flow supplying the area downstream and also limit the leakages.

The PRVs operating conditions are the following:

- ⇒ Totally open: when the pressure value exiting the valve is lower than the set pressure value.
- ⇒ Partially open: if the pressure value exiting the valve rises the set pressure value, the valve closes partially introducing higher head losses to get the set value.
- ⇒ Closed: if for any reason the pressure value exiting the valve is higher than the entering one, then the valve closes avoiding the flow circulation.

In our case we have introduced two PRV on the mathematical model, one acting in each reservoir.

The installation points are situated on the outflow mains of the reservoirs when entering the city, in order to be at similar height at the consumption nodes.

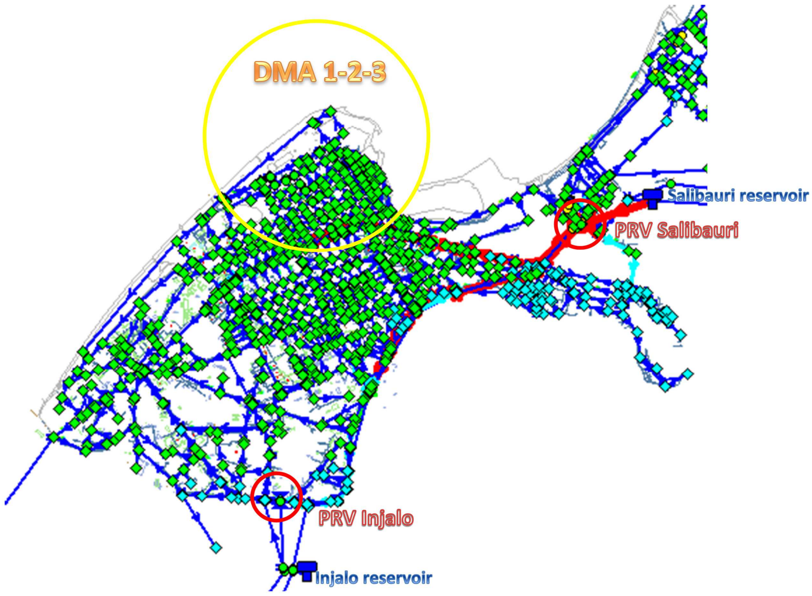
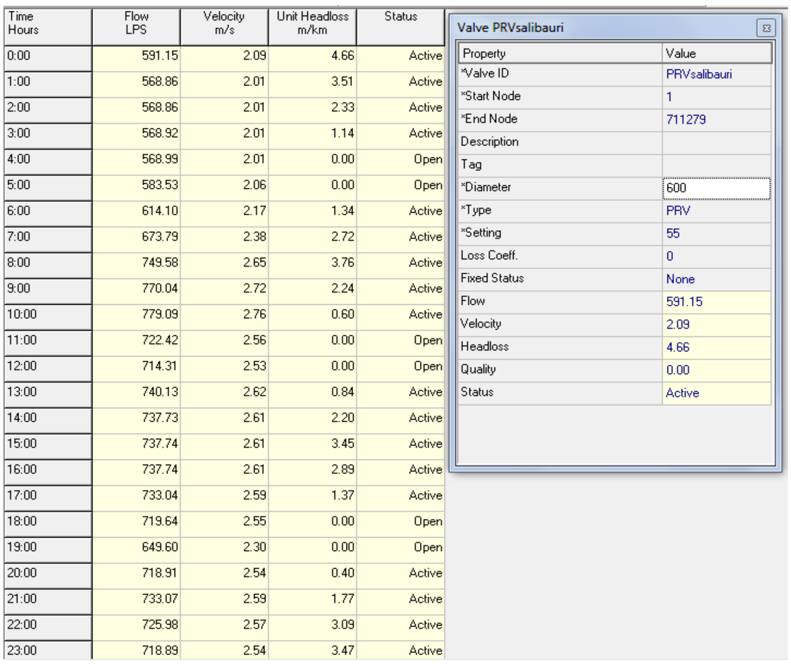


Figure 71: PRV location

Once the valves were modelled we proceeded to simulate the network with the new elements to check the conditions. The first setting value for the PRVs was 5 mwc lower than the node downstream. The results will be presented on the next point.



Time Hours	Flow LPS	Velocity m/s	Unit Headloss m/km	Status
0:00	591.15	2.09	4.66	Active
1:00	568.86	2.01	3.51	Active
2:00	568.86	2.01	2.33	Active
3:00	568.92	2.01	1.14	Active
4:00	568.99	2.01	0.00	Open
5:00	583.53	2.06	0.00	Open
6:00	614.10	2.17	1.34	Active
7:00	673.79	2.38	2.72	Active
8:00	749.58	2.65	3.76	Active
9:00	770.04	2.72	2.24	Active
10:00	779.09	2.76	0.60	Active
11:00	722.42	2.56	0.00	Open
12:00	714.31	2.53	0.00	Open
13:00	740.13	2.62	0.84	Active
14:00	737.73	2.61	2.20	Active
15:00	737.74	2.61	3.45	Active
16:00	737.74	2.61	2.89	Active
17:00	733.04	2.59	1.37	Active
18:00	719.64	2.55	0.00	Open
19:00	649.60	2.30	0.00	Open
20:00	718.91	2.54	0.40	Active
21:00	733.07	2.59	1.77	Active
22:00	725.98	2.57	3.09	Active
23:00	718.89	2.54	3.47	Active

Valve PRVsalibauri

Property	Value
*Valve ID	PRVsalibauri
*Start Node	1
*End Node	711279
Description	
Tag	
*Diameter	600
*Type	PRV
*Setting	55
Loss Coeff.	0
Fixed Status	None
Flow	591.15
Velocity	2.09
Headloss	4.66
Quality	0.00
Status	Active

Figure 72: PRV setting and simulation

4.10 Simulation and results

First, we are going to analyse the inflows and outflows of DMA 1-2-3 in order to know the consumption and present results.

After that, we will compare the obtained results when modeling and simulating the pressure reducing valves.

DMA 1-2-3 has two inflows and two outflows as we can see on the network schema. Each one is metered by one flow meter sending the readings each 15 minutes via transmitters to the MIS, as explained above.

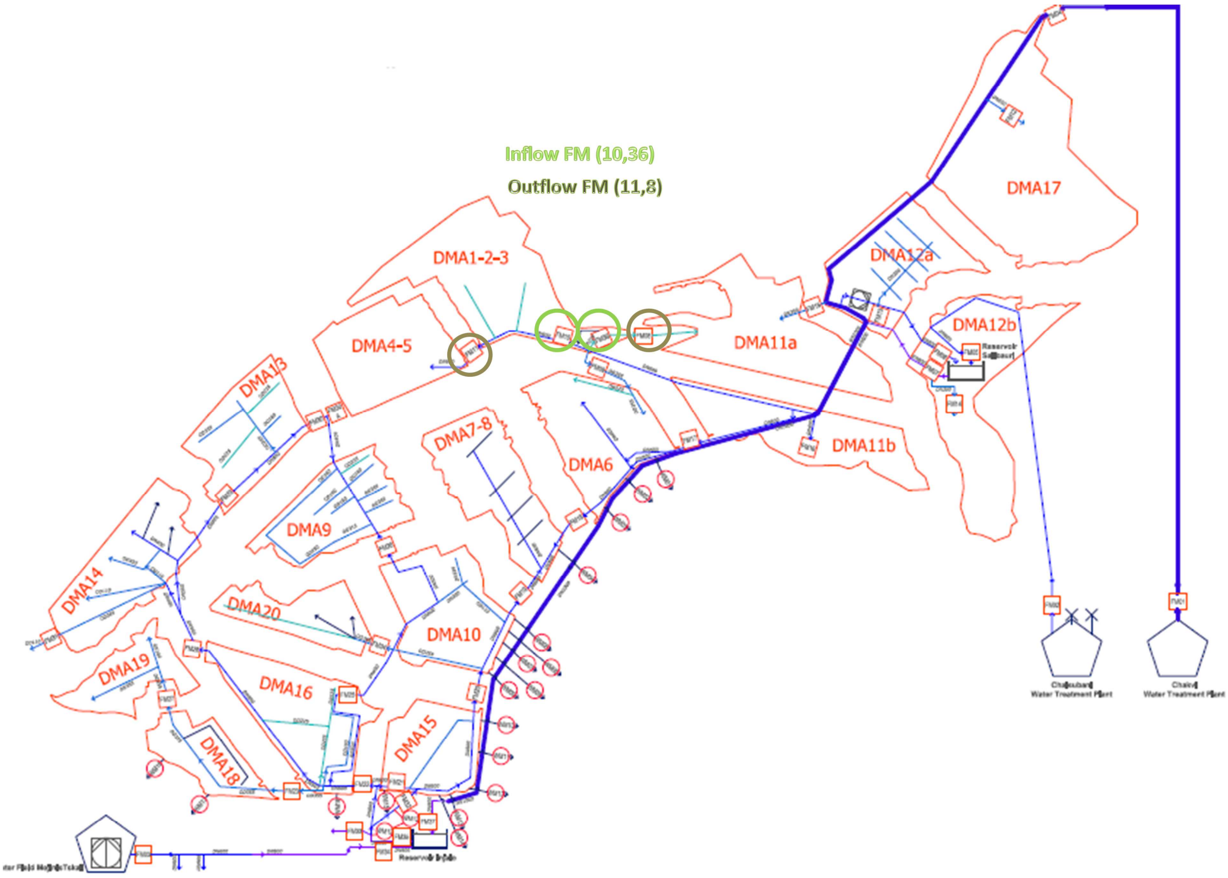


Figure 73: DMA 1-2-3 flow meters, schema network

The inflows to the DMA during a 24 h simulation are presented on the next images.

The green line corresponds to FM 10 and the red one to FM 36. As we can notice most of the inflow is entering at this moment through one of the system main distribution pipes, where FM 10 is installed.

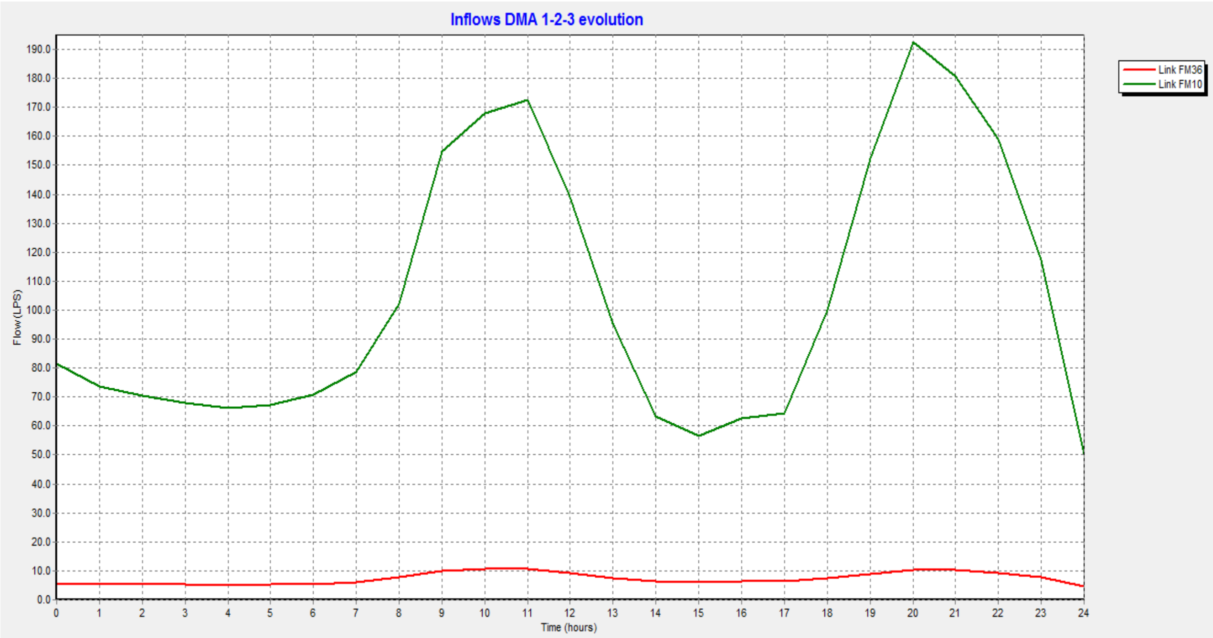


Figure 74: DMA 1-2-3 inflows evolution

Time Hours	Flow LPS
0:00	81.44
1:00	73.60
2:00	70.33
3:00	68.02
4:00	66.34
5:00	67.31
6:00	70.71
7:00	78.49
8:00	102.18
9:00	154.63
10:00	168.08
11:00	172.63
12:00	139.27
13:00	95.32
14:00	63.45
15:00	56.68
16:00	62.45
17:00	64.29
18:00	99.84
19:00	152.18
20:00	192.54
21:00	180.61
22:00	159.22
23:00	117.46

Time Hours	Flow LPS
0:00	5.82
1:00	5.44
2:00	5.32
3:00	5.22
4:00	5.15
5:00	5.25
6:00	5.51
7:00	6.07
8:00	7.75
9:00	9.90
10:00	10.50
11:00	10.62
12:00	9.12
13:00	7.35
14:00	6.35
15:00	6.20
16:00	6.33
17:00	6.29
18:00	7.32
19:00	9.07
20:00	10.38
21:00	10.19
22:00	9.34
23:00	7.82

Figure 75: FM10 and FM36 24 h measurement

Following, the results of the simulation of the outflows are presented.

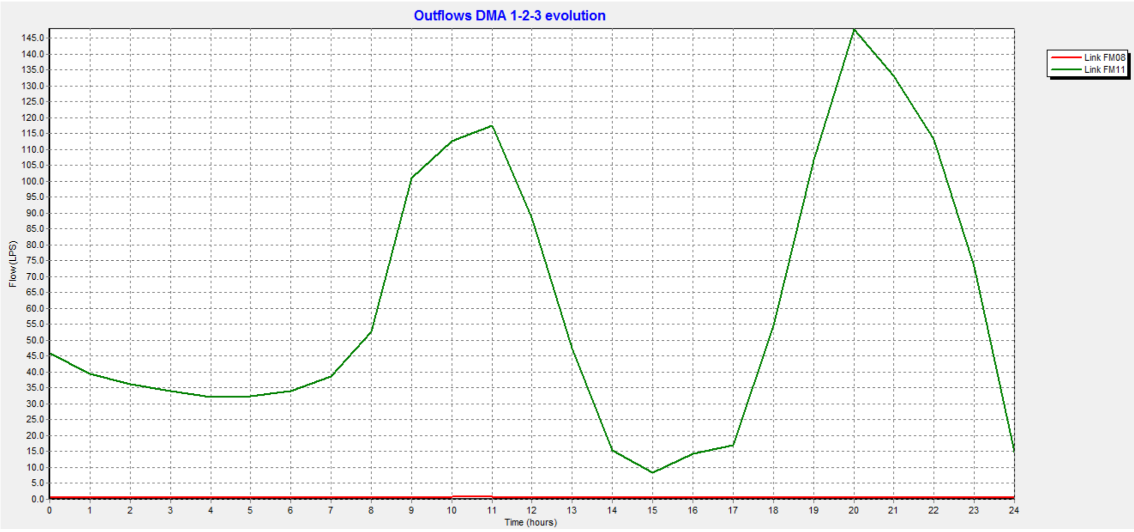


Figure 76: DMA 1-2-3 outflows evolution

Time Hours	Flow LPS
0:00	46.01
1:00	39.46
2:00	36.20
3:00	33.90
4:00	32.22
5:00	32.37
6:00	34.11
7:00	38.59
8:00	52.73
9:00	101.05
10:00	112.66
11:00	117.52
12:00	88.65
13:00	47.46
14:00	15.31
15:00	8.32
16:00	14.30
17:00	17.10
18:00	54.52
19:00	106.63
20:00	147.60
21:00	133.20
22:00	113.21
23:00	73.22

Time Hours	Flow LPS
0:00	0.44
1:00	0.43
2:00	0.43
3:00	0.43
4:00	0.43
5:00	0.44
6:00	0.46
7:00	0.50
8:00	0.62
9:00	0.67
10:00	0.69
11:00	0.68
12:00	0.63
13:00	0.60
14:00	0.59
15:00	0.59
16:00	0.59
17:00	0.58
18:00	0.57
19:00	0.56
20:00	0.55
21:00	0.58
22:00	0.57
23:00	0.55

Figure 77: FM11 and FM08 24 h measurement

As expected, the most of the outflow from DMA 1-2-3 is though FM11 which also is an inflow to DMA 4-5.

The next chart shows the evolution of the consumption in DMA 1-2-3 using the previous data of inflows and outflows.

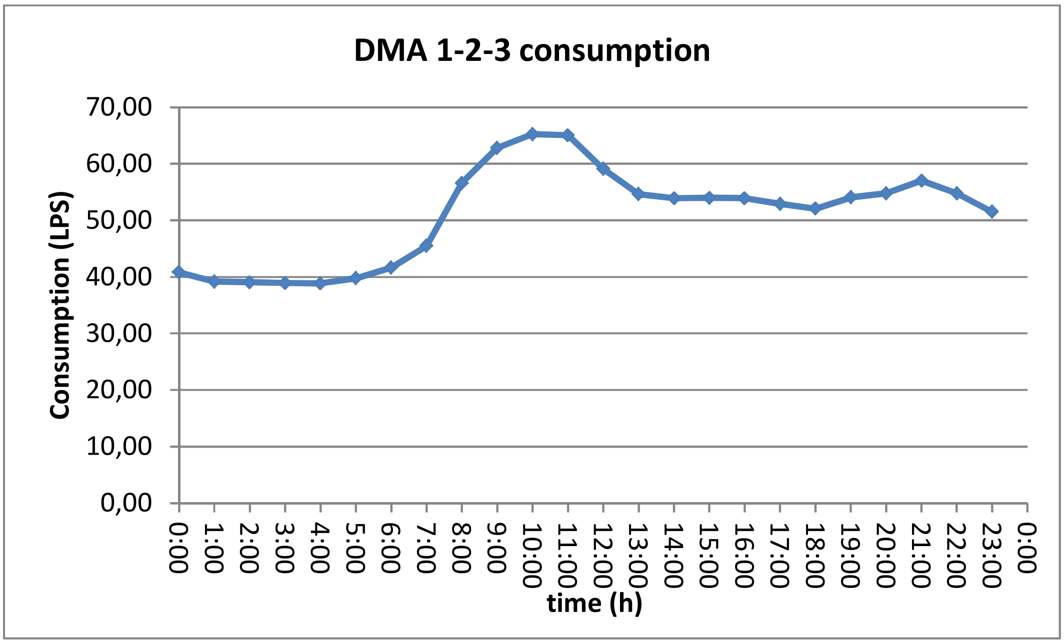


Figure 78: 24 h DMA 1-2-3 consumption

As we can see on the chart and despite it has improved significantly when comparing with the beginning, night consumption is still a bit high being more than the half of the maximum consumption.

On the next tables we have calculated the total consumption per day in order to compare it with the billing data to test the DMA 1-2-3 modeling explained along this chapter.

Time	Inflow FM36	Volume	Inflow FM10	Volume	Total inflow	Total volume	Time	Outflow FM11	Volume	Outflow FM08	Volume	Total outflow	Total volume	Time	Consumption	Volume
(h)	LPS	m^3	LPS	m^3	LPS	m^3	(h)	LPS	m^3	LPS	m^3	LPS	m^3	(h)	LPS	m^3
0:00	5,82	20,95	81,44	293,18	87,26	314,14	0:00	46,01	165,64	0,44	1,58	46,45	167,22	0:00	40,81	146,92
1:00	5,44	19,58	73,60	264,96	79,04	284,54	1:00	39,46	142,06	0,43	1,55	39,89	143,60	1:00	39,15	140,94
2:00	5,32	19,15	70,33	253,19	75,65	272,34	2:00	36,20	130,32	0,43	1,55	36,63	131,87	2:00	39,02	140,47
3:00	5,22	18,79	68,02	244,87	73,24	263,66	3:00	33,90	122,04	0,43	1,55	34,33	123,59	3:00	38,91	140,08
4:00	5,15	18,54	66,34	238,82	71,49	257,36	4:00	32,22	115,99	0,43	1,55	32,65	117,54	4:00	38,84	139,82
5:00	5,25	18,90	67,31	242,32	72,56	261,22	5:00	32,37	116,53	0,44	1,58	32,81	118,12	5:00	39,75	143,10
6:00	5,51	19,84	70,71	254,56	76,22	274,39	6:00	34,11	122,80	0,46	1,66	34,57	124,45	6:00	41,65	149,94
7:00	6,07	21,85	78,49	282,56	84,56	304,42	7:00	38,59	138,92	0,50	1,80	39,09	140,72	7:00	45,47	163,69
8:00	7,75	27,90	102,18	367,85	109,93	395,75	8:00	52,73	189,83	0,62	2,23	53,35	192,06	8:00	56,58	203,69
9:00	9,90	35,64	154,63	556,67	164,53	592,31	9:00	101,05	363,78	0,67	2,41	101,72	366,19	9:00	62,81	226,12
10:00	10,50	37,80	168,08	605,09	178,58	642,89	10:00	112,66	405,58	0,69	2,48	113,35	408,06	10:00	65,23	234,83
11:00	10,62	38,23	172,63	621,47	183,25	659,70	11:00	117,52	423,07	0,68	2,45	118,20	425,52	11:00	65,05	234,18
12:00	9,12	32,83	139,27	501,37	148,39	534,20	12:00	88,65	319,14	0,63	2,27	89,28	321,41	12:00	59,11	212,80
13:00	7,35	26,46	95,32	343,15	102,67	369,61	13:00	47,46	170,86	0,60	2,16	48,06	173,02	13:00	54,61	196,60
14:00	6,35	22,86	63,45	228,42	69,80	251,28	14:00	15,31	55,12	0,59	2,12	15,90	57,24	14:00	53,90	194,04
15:00	6,20	22,32	56,68	204,05	62,88	226,37	15:00	8,32	29,95	0,59	2,12	8,91	32,08	15:00	53,97	194,29
16:00	6,33	22,79	62,45	224,82	68,78	247,61	16:00	14,30	51,48	0,59	2,12	14,89	53,60	16:00	53,89	194,00
17:00	6,29	22,64	64,29	231,44	70,58	254,09	17:00	17,10	61,56	0,58	2,09	17,68	63,65	17:00	52,90	190,44
18:00	7,32	26,35	99,84	359,42	107,16	385,78	18:00	54,52	196,27	0,57	2,05	55,09	198,32	18:00	52,07	187,45
19:00	9,07	32,65	152,18	547,85	161,25	580,50	19:00	106,63	383,87	0,56	2,02	107,19	385,88	19:00	54,06	194,62
20:00	10,38	37,37	192,54	693,14	202,92	730,51	20:00	147,60	531,36	0,55	1,98	148,15	533,34	20:00	54,77	197,17
21:00	10,19	36,68	180,61	650,20	190,80	686,88	21:00	133,20	479,52	0,58	2,09	133,78	481,61	21:00	57,02	205,27
22:00	9,34	33,62	159,22	573,19	168,56	606,82	22:00	113,21	407,56	0,57	2,05	113,78	409,61	22:00	54,78	197,21
23:00	7,82	28,15	117,46	422,86	125,28	451,01	23:00	73,22	263,59	0,55	1,98	73,77	265,57	23:00	51,51	185,44
					TOTAL INFLOW	**9.847,37**						**TOTAL OUTFLOW**	**5.434,27**		**TOTAL CONSUMPTION**	**4.413,10**
					m3/d							**m3/d**			**m3/d**	

Table 55: DMA 1-2-3 total inflow, outflow and consumption

TOTAL CONSUMPTION	TOTAL BILLING	NRW	
m^3/d	m^3/d	m^3/d	l/s
4.413,10	4.385,74	27,36	0,32

Table 56: DMA 1-2-3 consumption vs billing

As can been consulted on the last table, this last updating of the model applied to DMA 1-2-3 had good results when comparing with the billing information, for Scenario 2.

This study will be repeated when finishing the installation of individual water meters and all customers will be billed by their real consumption.

In the second place, the next images show the evolution of the inflows, outflows and consumption when simulating with the pressure reducing valves, with pressure setting 5 mca lower than the downstream consumption nodes.

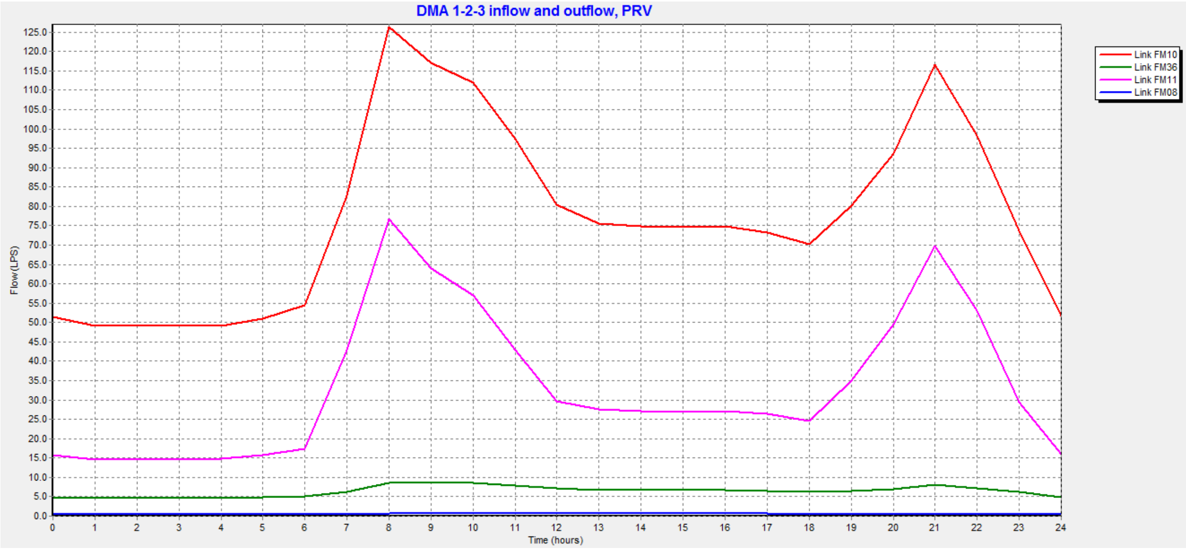


Figure 79: DMA 1-2-3 inflow and outflow evolution with PRV

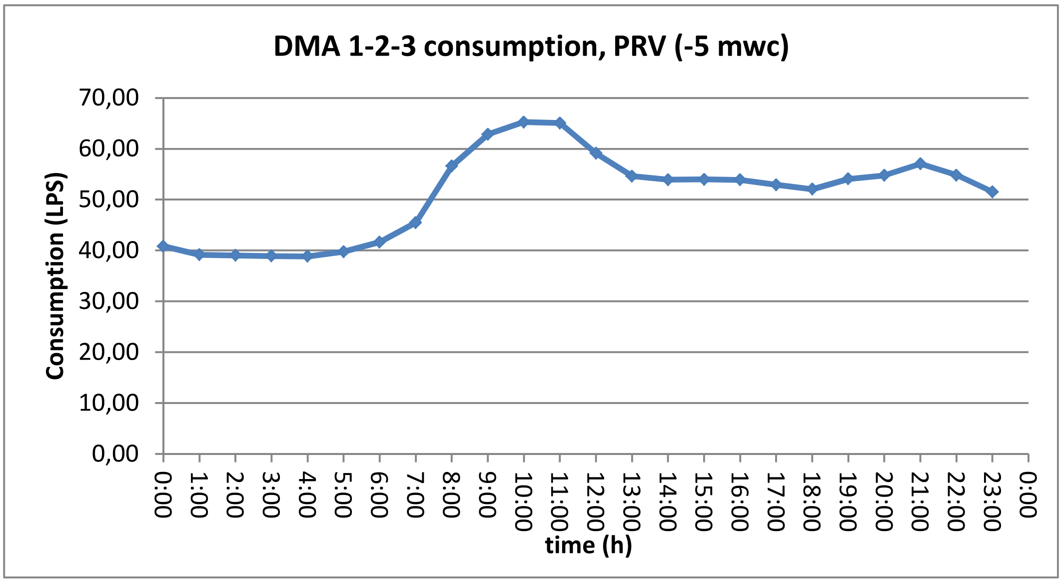


Figure 80: 24 h DMA 1-2-3 consumption, PRV (-5 mwc)

As we can notice on the chart, the consumption did not change at all with this pressure setting value. We will try another time with lower pressure settings for the PRVs.

It were done two more simulations reducing the pressure setting of the PRV 5 and 10 mwc and we notice that this strategy does not reduce the night consumption significantly, as we can see on the next chart.

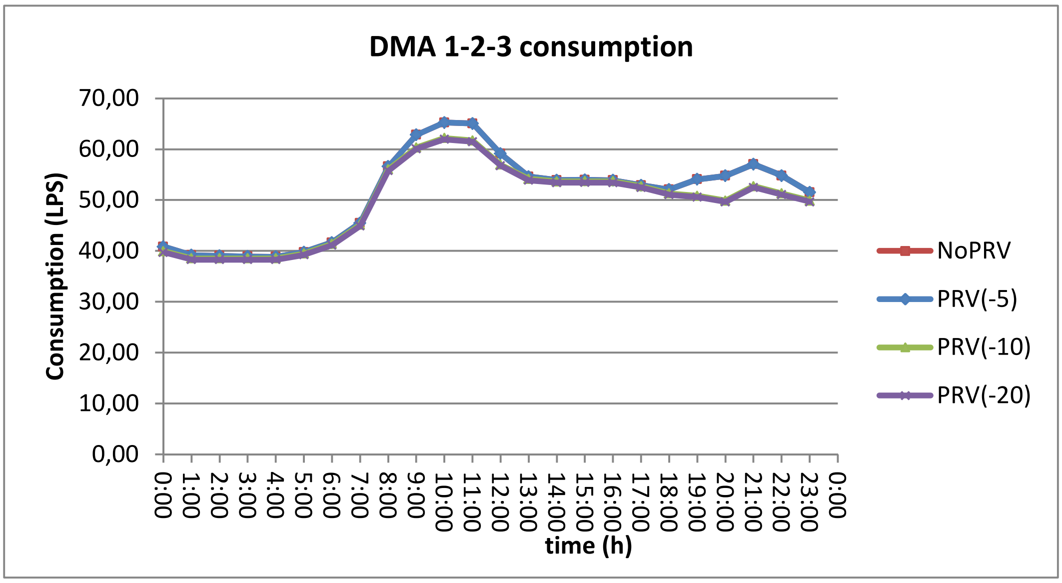


Figure 81: 24 h DMA 1-2-3 PRV consumption effect

The total daily decrease on the consumption if installing PRV is around 150 m^3, as calculated on the next table.

	No PRV		PRV (-20 mwc)		
Time	Consumption	Volume	Consumption	Volume	Difference
(h)	LPS	m3	LPS	m3	m3
0:00	40,81	146,92	39,7	142,92	107,22
1:00	39,15	140,94	38,27	137,772	102,67
2:00	39,02	140,47	38,28	137,808	102,19
3:00	38,91	140,08	38,28	137,808	101,80
4:00	38,84	139,82	38,27	137,772	101,55
5:00	39,75	143,10	39,22	141,192	103,88
6:00	41,65	149,94	41,12	148,032	108,82
7:00	45,47	163,69	44,89	161,604	118,80
8:00	56,58	203,69	55,78	200,808	147,91
9:00	62,81	226,12	60,05	216,18	166,07
10:00	65,23	234,83	61,93	222,948	172,90
11:00	65,05	234,18	61,47	221,292	172,71
12:00	59,11	212,80	56,73	204,228	156,07
13:00	54,61	196,60	53,89	194,004	142,71
14:00	53,90	194,04	53,42	192,312	140,62
15:00	53,97	194,29	53,43	192,348	140,86
16:00	53,89	194,00	53,42	192,312	140,58
17:00	52,90	190,44	52,47	188,892	137,97
18:00	52,07	187,45	51,05	183,78	136,40
19:00	54,06	194,62	50,58	182,088	144,04
20:00	54,77	197,17	49,64	178,704	147,53
21:00	57,02	205,27	52,48	188,928	152,79
22:00	54,78	197,21	51,05	183,78	146,16
23:00	51,51	185,44	49,64	178,704	135,80
	TOTAL CONSUMPTION m3/d	4.413,10	TOTAL CONSUMPTION m3/d	4.266,22	146,88

Table 57: DMA 1-2-3 PRV consumption reduction estimation

5 CONCLUSIONS

When a consultant arrives to a developing or in transition country, where the political system was changed not so long ago and the infrastructures are being updated and reconstructed, he/she has to do a big effort thinking not in the “what the work process implementation can be” but in “how the work process will be implemented”.

In my case, when were asked to stablish a water losses control program in a country without any water saving culture or knowledge about what non-revenue water is, the first question was that one, how could we implement it satisfactorily.

The idea to use the process of building a NRW Mathematical Model as a methodology to implement the water losses control program at the Utility was born reviewing the info we would need to model the new system and leakages.

On the other hand, the staff and the management of the water utility are who physically have to do the works needed to get each stage of the methodology, so they are trained on it at the same time the water losses are being reduced.

Despite of being an ongoing process, and the problems derived of tendering time like paralysations and design changes, it is possible to model and simulate the system and update it each time we achieve a more accurate data or we get the next stage of the program.

The next graph shows the NRW evolution since the first beginning of the methodology implementation.

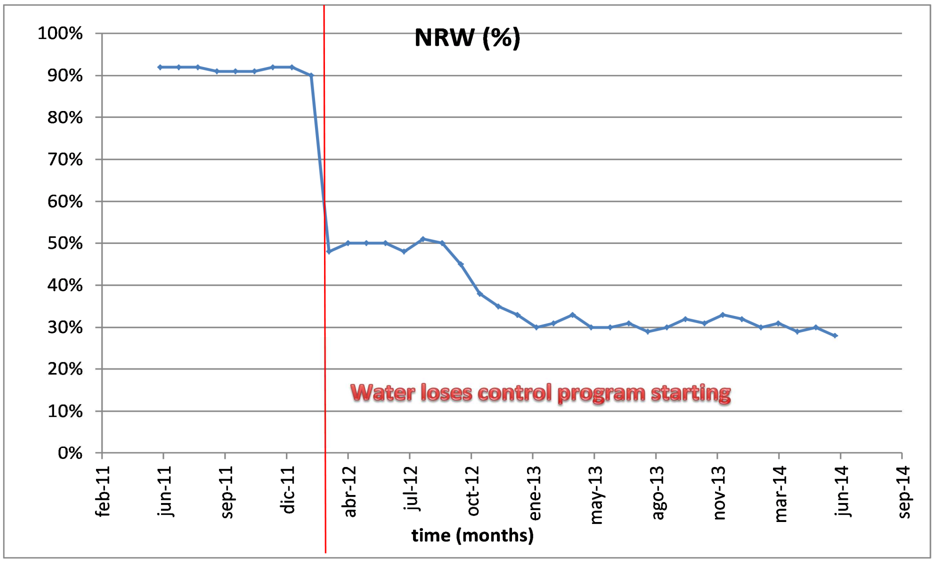


Figure 82: NRW evolution along water losses control implementation time

As we have seen in the above graph, we would like to finish saying at a main conclusion that it is worth to use the methodology to get a mathematical model of a new system, where to include the modeling of non-revenue water, to improve the management of a water utility in developing or in transition countries.

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