Water Supply Challenge

Submitted By:

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Executive Summary

Increased population and economic development have a direct impact on the water demand. This situation puts pressure on diminishing water resources, and to compensate for this situation rivers and aquifers are being over-exploited. Managing water loses effectively not only can help mitigate this situation but is also a tool for the sustainable use of water resources within the framework of a better management of the Water - Energy - Carbon nexus.

Water Losses are classified in two classes: Real Losses, which refers to the physical loss of water due leaking pipes, overflow of tanks, malfunctioning valves, etc. Apparent Losses on the other hand, do not refer to physical losses but instead is the amount of produced and provided to the user that does not generate any income. These losses can be caused by user fraud, errors in metering, malfunctioning meters, etc. In this study, we will only focus on the identification and solution of real losses within a metered area.

The objective of the calibration procedure is to produce a match between the model results and the measured data. For this objective, data sets of measured field data such as water pressure in the nodes and measurement of flow in the main pipe were used. The accuracy of the existing model was improved by performing several calibration simulations of parameters such as the demand and the pipe roughness.

A total of 4 calibration/optimization runs where performed using the available data sets, and with every run, the model performance kept increasing and producing reliable results. With the calibrated model, the team was able to pinpoint the location of the nodes with leakage within the water network. These leaks had different degrees of magnitude, therefore highlighting the importance of the use of mathematical modelling for its detection.

Within the solutions proposed for this case study we find suggestions aimed at controlling the pressure within the water network, such as creating District Measured Areas (DMA). Another solution considered is the installation of Pressure Control Valves (PRV) to regulate the pressure and avoid pipe bursts. To increase the system reliability, it is also suggested an optimization of the current water network based on the pipe age and leakage recurrence within the system by means of replacing pipes of the network.

Introduction

Water is a limited resource and in a time where the threat of climate change and other pressure agents such as demographic and urbanization increase, economic development and industrialization, the risk of drought and water scarcity becomes more real especially in areas already under hydric stress; therefore water preservation and the reduction of water losses has become a top priority for governments and water service providers, in aims to achieve target #6 of the Sustainable Goals: “Ensure availability and sustainable management of water and sanitation for all”.

Water Losses are classified in two: Real Losses and Apparent losses.

Real Losses refers to the physical loss of water due leaking pipes, overflow of tanks, malfunctioning valves, etc. These can be caused by several external agents such as: pressure fluctuations, traffic loads, low quality materials, errors during the installation, corrosion, defective pumping equipment, lack of maintenance and pressure transients.

Apparent Losses on the other hand, do not refer to a tangible loss of water itself but instead to the water that is distributed but does not translate into economic revenue. These can be caused by defect water meters, fraudulent connections, lack of proper water accounting and metering practices and uncalibrated or faulty equipment.

Amongst the negative impacts of water losses, we can find:

- Economic Impacts.
- Low Pressure, Service Disruptions, Health Risks.
- Intermittent Water Supply.
- Increased Production Costs.
- Overexploitation of Water Sources to compensate for the water losses.

Geographical Information Systems (GIS) coupled with mathematical models of water distribution networks can be used to simulate the response under a diverse number of changing scenarios. It also has the advantage that implementing a model is usually cheaper than making the interventions in the water network. These tools can help support decision making and are a quintessential part of a successful water loss reduction program. Hence, this exercise uses a similar model, namely WaterGEMs.

The strategies to combat water loss reduction are usually englobed into a Water Loss Reduction program. They combine frameworks, guidelines, actions and strategies to produce solutions to manage the leaks into economically manageable levels.

Literature Review

In this project, some relevant concepts are used as the foundations for the understanding of the scope of work we are working on. These concepts are connected to the topics of water distribution network, water network modeling, and water losses.

Water Distribution Network

A network for water distribution functions in grids, junctions, and pipelines. Within the past decades, the problem of finding leaks in Water Distribution Networks (WDN) has been challenging (Fereidooni, et al., 2021). The WDN varies according to the topographical conditions, and this is where the modeling perception plays a big role. When these leaks are detected faster, it will be able to avoid economic and environmental consequences. However, when done too fast, sometimes the detection is not accurate, and may also lead to false detection, which also leads to high cost. Within this case study, the network is represented in a model.

Ewa Ociepa, et al, (2019), defined that the problem of water losses during the distribution process is one of the major issues concerning water governance and water management. The loss of water occurs mainly because of leakages in water supply pipes and due to outdated water infrastructure. This International Water Association (IWA) suggested four methods to reduce leakages: active leakage control; speed and quality of repairs; pressure management; and pipeline and asset management. In the water distribution process, water losses are an integral part as it integrates infrastructural decisions concerning modernizing a water distribution system. When an accurate hydraulic network model is available, direct modeling techniques are very straightforward and reliable for on-line leakage detection and localization applied to large classes of water distribution networks. Nonetheless, the assumption of single-leak scenarios is usually considered and may not hold in real applications. To avoid these inconveniences, leakage detection and localization based on mathematical models may be used which can “compare” the data gathered by installed sensors in the network with the data obtained by a model of this network (Meseguer, et al., 2014).

The International Water Association has devised many models to do a comparative analysis of water losses. It is true for many past years water losses due to leakages in pipes of the water distribution network have become a challenging issue. It is focusing on the problem that despite being very important for water network leakage detection, still, the literature did not encapsulate it fully on the account of its every aspect (Fereidooni, et al,.2020; Ali and Choi, 2019).

Water Network Modeling and Calibration

A water distribution model is a mathematical description of a real-world system. Before building a model, it is necessary to gather information describing the network. It uses sources of data for constructing the models, by means of skeletonization or the process of simplifying the real system for model representation, and it involves making decisions about the level of detail to be included (Walski, et al., 2003).

By this skeletonization, the main infrastructures for water distribution networks are simplified into nodes or points representing different functions, such as reservoirs, water treatment plants, joints, also taps, while lines are representing the pipelines. It is similar to making a system map, with additional information such as pipe alignment (connectivity, material, diameter), the locations of other system components, such as tanks and valves, pressure zone boundaries, elevations, miscellaneous notes or references for tank characteristics, background information, such as the locations of roadways, streams, planning zones, and other utilities (Walski, et al., 2003).

This map is where the GIS takes a role in providing representation of the water network and relates it to the positioning on earth. Its technology integrates common database operations with the unique visualization and geographic analysis benefits offered by maps. It stores data on thematic layers linked geographically, which can be used to determine relationships between data and to synthesize new information (Walski, et al., 2003).

In this exercise, we are using Bentley’s WaterGems. It is a widely applied tool for modeling water distribution systems with an advanced interoperability. It also supports the design process of new distribution systems, develops network flushing plans, identifies water losses, assess fire flow capacity, manages, and minimizes energy use and also prioritizes pipe renewal (Świtnicka, et al., 2017).

It functioned as a numerical model where the water supply networks were composed only of main distribution pipes, without households’ connections. Within the model, it also features the Darwin Scheduler or the Darwin Calibrator module, a genetic algorithm (Świtnicka, et al., 2017), hence the AI, which allows automatic optimization of pump operation using variable pump speed modifications, to fulfill hydraulic parameters. It resulted with the lowering of the energy consumption and decreasing of pumping costs. However, it should be noted that the Darwin Calibrator module does not include the automatized possibility of new fitting installations or new pipe connections, but rather performs optimization actions. This exercise will make use of this software and the Darwin Calibrator module to recommend which course of actions are needed to manage the leaks.

Water Losses and Leak Detection

As already mentioned above, water losses which are related to leaks in pipes, may occur due to variations of causes from improper pipe material, weak joints, earth movement, internal corrosion, corrosive soils, construction or utility digging, seasonal changes in temperature, heavy traffic load, tidal influence, water hammer, air entrapment, or other cause (Fereidooni, et al., 2021). Continuous improvements on water loss management are being applied based on the use of new available technologies. Nonetheless, the whole leakage localization process may still require long periods of time (i.e. weeks, months) with an important volume of water wasted before the leak is found (Meseguer, et al., 2014). Real losses are mainly the result of water network breakages and failures (Musz-Pomorska, et al., 2017).

Many scientists nowadays use the most recent technological and scientific developments, such as modeling and artificial intelligence (AI) to additionally add efficient methods to limit failures (Musz-Pomorska, et al., 2017). Nevertheless, real losses of water cannot entirely be eliminated. Since the population pressure is mounting, consequently demand for drinking water is increasing more than ever. The use of flow and pressure sensors together with hydraulic models of the water network for leak detection and localization is a suitable approach for the on-line monitoring of water balance presents a straightforward direct modelling methodology for leakage detection and localization in district metered areas (DMAs) of water distribution networks which is inspired by the binary model-based fault diagnosis theory and takes benefit from those available DMA hydraulic models used by water operators (Meseguer, et al., 2014). The water demand can be met by designing a technically efficient water distribution network. Mohini, et al, (2018) proposed that by using a WaterGems software, which is a systematic tool that provides a comprehensive design for water supply and distribution the water supply network can be improved.

The leak detection used in this report used a similar approach, by producing a model and running them in an application, which has an AI where analysis can be performed and report back to the users and present the results of the calculations as useful information for decision making in the real world.

Water Losses Quantification

According to a study by the World Bank around 40 - 50% of the water produced in the developing world is lost (Kingdom B. et al, 2008). This number represents a very significant volume of water that is not being supplied to the population, therefore it is important to know how much water is being produced and how much water is being lost. For this objective, the IWA developed a Water Balance tool that allows to identify the amount of Non-Revenue Water (NRW).

Table 1: Water Balance Table

System Input Volume	Autorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unauthorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Metering Innacuracies	
			Unautorized Consumption	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows on Storage Tanks	
			Leakage on Service Connections	

Naturally for this water balance to work, it needs to be supported by macro and micro-metering practices. To further aid the NRW calculation, there are several indicators that allow to further quantify the amount of NRW lost, the infrastructural state of the water network and monitor the effectiveness and progress of the water control reduction program. There are several of these indicators, we will list some of the most used.

The percentage of water lost is the most widely used indicator as it gives a current and quick overview of the situation. It is obtained by dividing the volume of water lost by the volume of total water produced.

The IWA suggested the use of the Infrastructure Leakage Index (ILI). It is an adimensional performance indicator that takes into consideration the length of the network and its operational pressure. It is obtained by dividing the Current Annual Real Losses (CARL); which can be obtained by using a Water Balance methodology, by the Unavoidable Annual Real Losses or UARL (this refers to the lowest technically achievable reduction of the real losses). The lower the value of the ILI, the better is performing the system.

$$ILI = \frac{\mathrm{CARL}}{\mathrm{UARL}} \tag{1}$$

The amount of water lost is also determined not only by the pressure in the system, but also by the type of leakage, the response time that it takes to detect the leak and fix the issue. Unlike a pipe burst on a water main (that is detected and solved in a short amount of time) an undetected background leakage can be a source of a significant water loss due to the long time it takes to be detected.

Economic Impact of Water Losses

Water losses management is also an economical issue for governments and water utilities. Therefore, it is important to determine the economical level of water losses. Washali et al, (2020), indicates that water loss reduction at zero levels is not possible neither technically nor economically. However, if the causal factor of water leakages is accurately assessed then consequently the losses can be minimized.

A very important metric to take in consideration when creating a water loss control plan and strategic measures is the Economic Level of Water Losses; it helps to establish what should be the target to achieve in the reduction of water losses, this means that it represents the optimal point to reduce the water losses. The ELL is defined by the leakage point on which further investments in water loss reduction are no longer cost effective, further reducing the amount of water lost would be more expensive. It is worth noting that the ELL is a susceptible indicator that can evolve with time, because it depends on many variables such as the network size, age, seasonal changes of water demand, and any other parameter that can change the network, but also the cost of producing water can change due to increased demand, global economy, etc.

The following table and graph values depict how much water is being supplied without getting any revenue. Only New Zealand and Australia are the countries where water proliferation and siphoning is less compared to the world, due to the efficient and vigilant revenue generation pricing framework. Further, these countries developed the most effective water supply and distribution network which works aptly (Limburger, R., & Wyatt, A. (2019). Tariff rate on water consumption plays a significant role to achieve multiple objectives which are major reasons behind the water conflict among the sectors. Basically, local people's behaviors and government policy framework concerning water pricing shape the framework which is called best practices. Economic regulations and improvement in institutional arrangements pave the way for efficient water pricing policy, although countries topography and demography also matter most (Crase, et al, 2020).

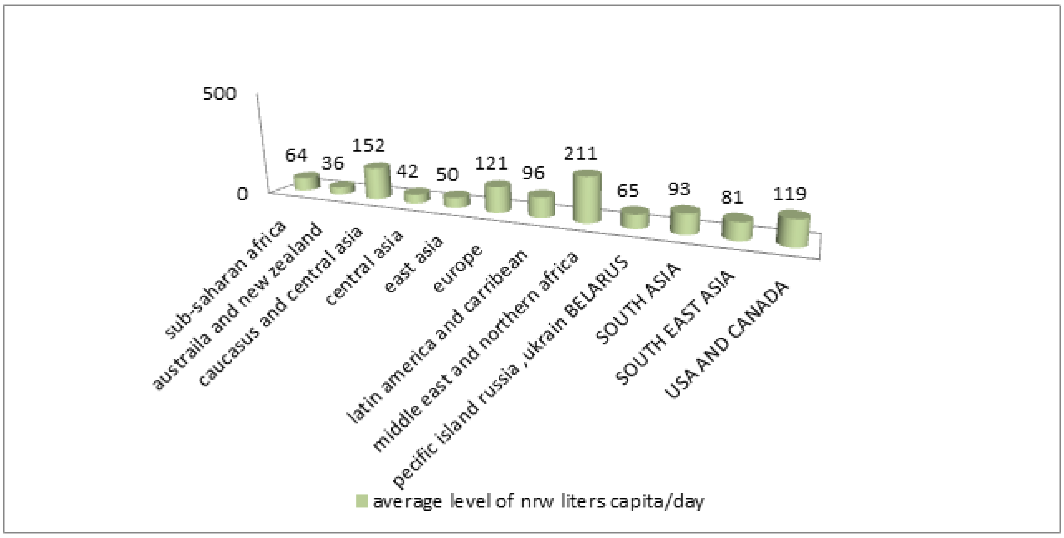


Figure 1: Amount of Non-Revenue Water per Capita/day

SOURCES: IBNET, IWA, AWWA, European Union, and the study of Limburger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. Water Supply, 19(3), 831-837. Data is collected on the basis of the parameters of: 1) connections which depend upon; household connections, main pipelines length, median household income, water demand/stress in a particular region. 2) operational: billing on the basis of volume, continuity of water supply, water pressure in pipes, micro metering, staff complaints and rates of burst. 3)

Financial: revenue collection of water, operating cost, taxes (tariff rate), and money collection efficiency. 4) Water balance: non-revenue water components split component.

Table 2: Global Non-Revenue Water Generation Statistics

Regions	Million M^3/Day	Billion M^3/Year	Average Level Of NRW Liters Capita/Day	Cost Value Of NRW Billion US$/Year
Sub-Saharan Africa	114.1	5.2	64	1.4
Australia and New Zealand	1	0.3	36	0.1
Caucasus and Central Asia	8	2.9	152	0.8
Central Asia	53	19.3	42	6.2
East Asia	26.8	9.8	50	3.4
Europe	69.6	25.4	121	8
Latin America and Caribbean	41.2	15	96	4.8
Middle East and Northern Africa	0.5	0.2	211	0.1
Pacific Island Russia, Ukraine Belarus	9.5	3.5	65	1.1
South Asia	63.4	23.2	93	6
South East Asia	18.4	6.7	81	2
USA and Canada	40.7	14.8	119	5.7

SOURCES: IBNET, IWA, AWWA, European Union, and the study of Limburger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. Water Supply, 19(3), 831-837.

The Role of Water Pressure

Water pressure management is vital for a reduction of the real water losses, as transients and excessive pressures in the system creates leaks in the pipes, joints, and valves of the water system. The volume of water lost in a pipe leak is proportional to the pressure as shown in the following equation:

$$\frac{L1}{LO} = \left[\frac{P1}{P0}\right]^N \qquad (2)$$

Where L1/L0 is the ratio of leakage flow, P1/P0 is the pressure ratio and N is a leakage exponent that can range from 0,5 to 2,5; however, in practice the typical ranges go from 0,5 (rigid pipes) to 1,5 (plastic pipes). Using equation (2), we can observe the effect of the pipe material (α Value) and pressure on the leak volume can be summarized in the following graph:

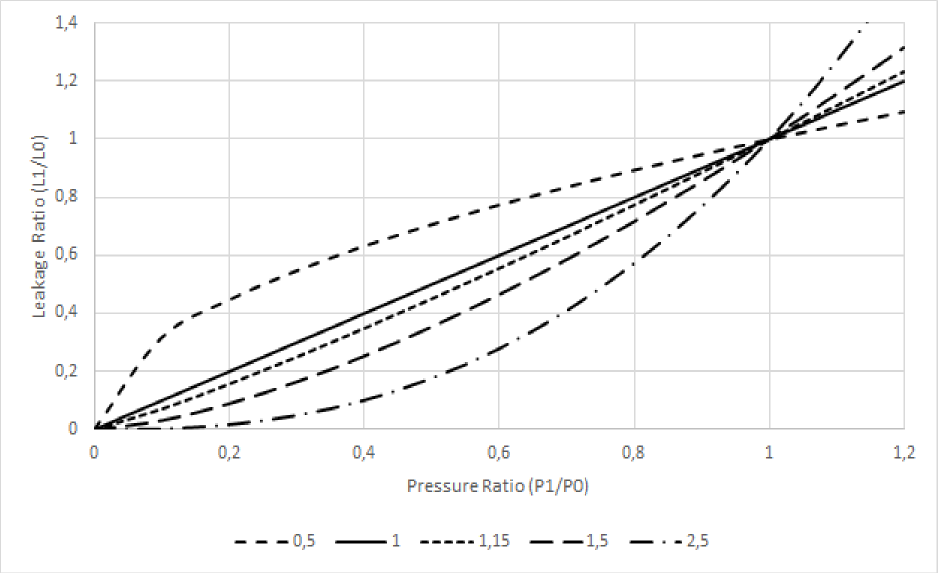


Figure 2: Relation of Pressure and Leakage Ratio

This shows that regardless of the pipe material, an increase water pressure translates into an increase of the leakage discharge.

The equation used by the software to find leakages in a node is a simplification of the orifice equation, but it also shows a direct correlation between the pressure and the leak discharge. This equation is defined by:

$$Q = kP^n \tag{3}$$

Where, Q represents the flow, k the emitter coefficient, P is the pressure in the node and n is an exponent with the typical value of 0.5.

Case Study Description

The main task of this challenge consists in the use of a mathematical model with subsequent calibration process and sensitivity analysis to figure out where, within the DMA significant losses of water volume (due to water leaks) occur and with this information propose suitable solutions to mitigate this effect.

Strategies and programs need to be implemented to successfully reduce apparent and real water losses, however in this case study will only focus on the identification of leaks, and propose solutions related to water pressure management to control real water losses.

Materials and Methods

Data

The flow data used in this case study consists of 2 datasets, one represents the simulated flow at the outlet pipe of the reservoir (P-872), which oscillates between 1.03 and 12.43 LPS, and a second dataset of real measurements at the same pipe with values of discharge ranging between 8.76 and 17.72 LPS. It is this discrepancy between both data sets that leads to the hypothesis of water leaks within the network and shows that the model needs to be calibrated.

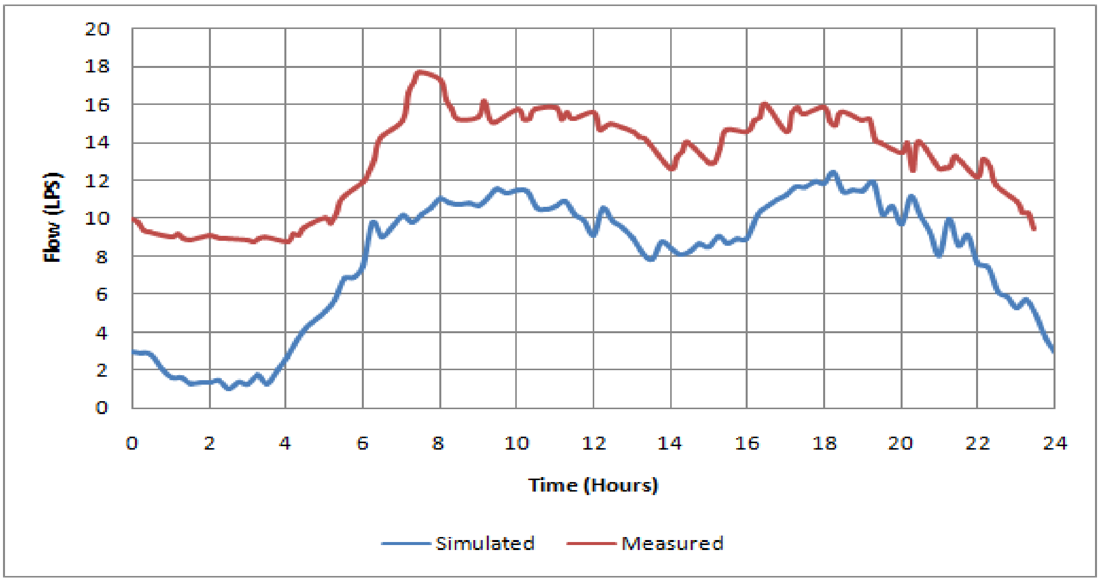
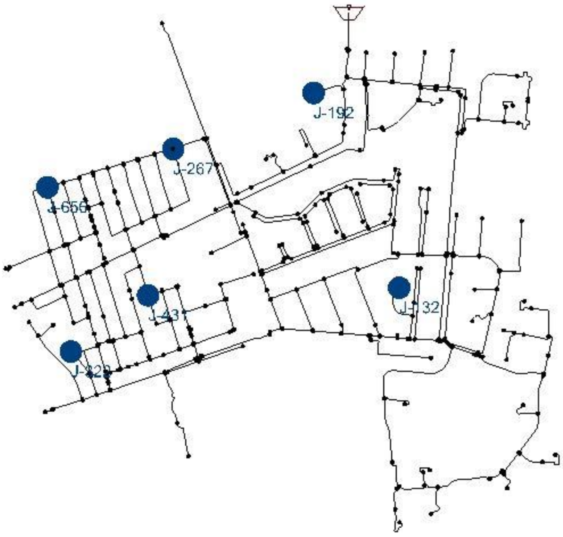


Figure 3: Comparison of Available Flow Data



Field measurements of pressure during a 24-hour period in 6 locations in the network are also supplied. This data will be used for alongside the flow data for the calibration and validation purposes to check the robustness and precision of the model.

Figure 4: Location of Pressure Data Loggers

A quick analysis of the data shows a pressure drop at around 8:00 A.M. This drop could be caused by the water demand, as there is a correlation between this drop and the water demand at this time step.

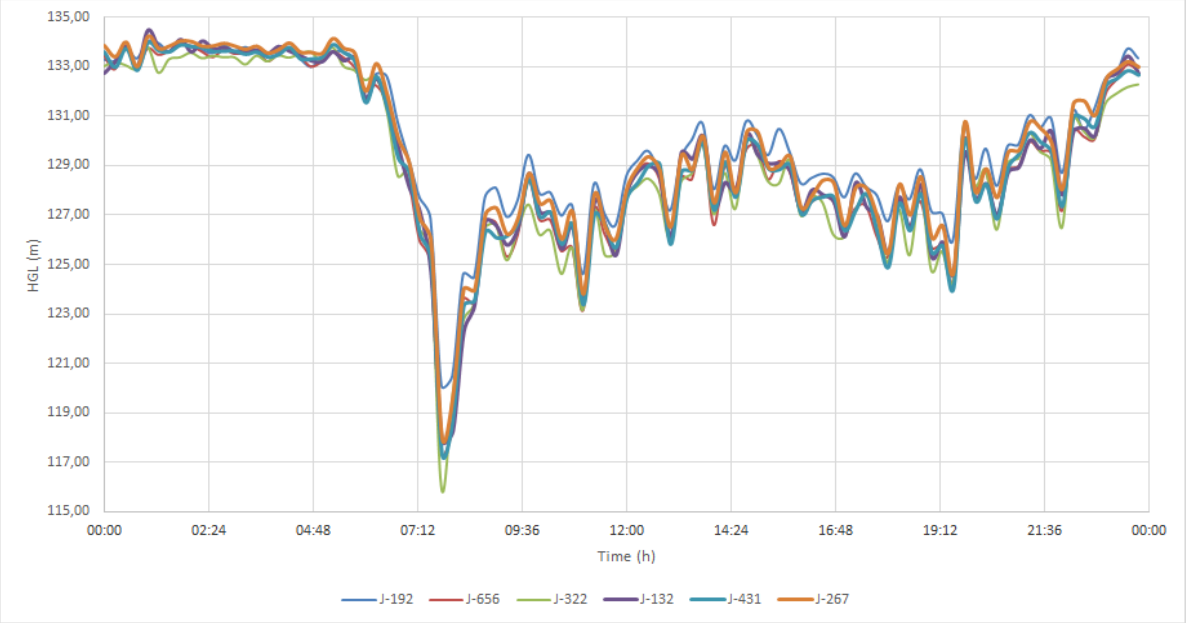


Figure 5: Measured Pressure Data

A water Demand pattern is also provided that represents the water consumption in the nodes throughout the network for a period of 24 hours.

Figure 6: Domestic Water Demand Pattern

Software

The software to be used for this challenge is WaterGems by Bentley. It is a powerful and robust simulation tool for water distribution networks that can aid in the tasks of design, optimization, operation of networks, as well the pipe renewal and energy consumption reduction of the pumping equipment.

Within this software, we find the Darwin Calibrator module. As it names states, it helps with the calibration of the different parameters that comprise a water distribution network model. It allows the user to do either manual calibration or an automatic calibration using genetic algorithms by aiming to minimize the difference between the observed values and the simulated values by means of doing different trial runs with changing the set parameter values (roughness, demand, etc.) until an optimal set is found that achieves this constraint. It is also used to run optimization analysis to find the solution for this exercise.

Hydraulic Model

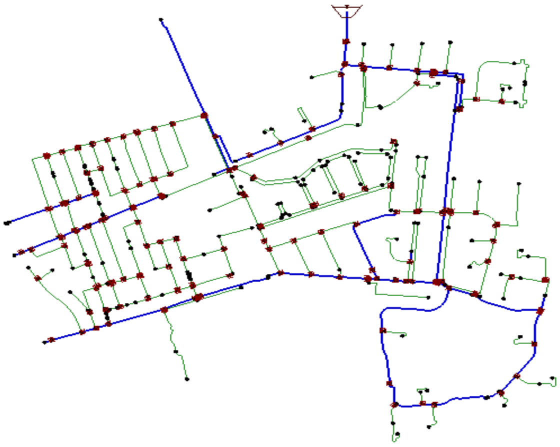


Figure 7: Hydraulic Model in WaterGems

An existing model of the DMA is used to identify the leaks. The model contains 701 nodes, a reservoir and 924 pipes of Ductile Iron, with a total length of 17,228m and diameters ranging from 50mm (representing household connections) to 2,514mm (water mains). The simulation performed for this task is a Dynamic State, taking place during a 24-hour period.

The diameter distribution is shown in the following image:

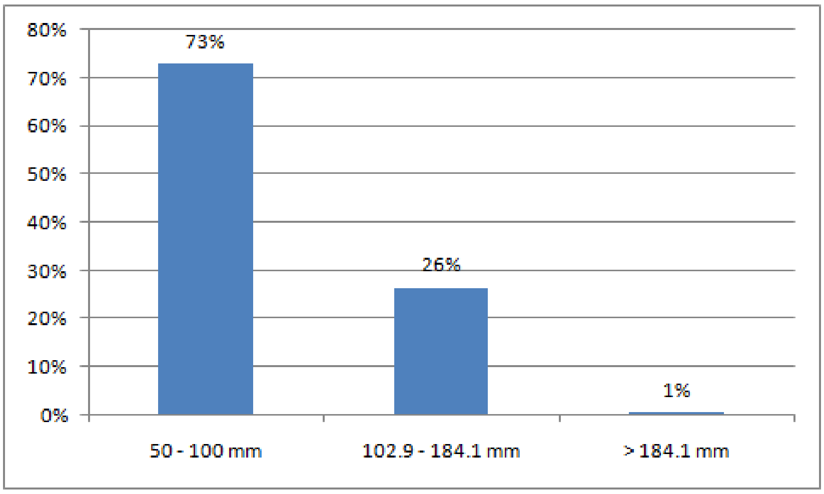


Figure 8: Pipe Diameter Distribution in the Model

As observed by the terrain elevation curves, there is a descending gradient from the zone of the reservoir into the low zones in the south of the model; this was expected because the lack of pumping equipment found in the network was an indicator that this is a gravity system. Around the middle of the map, there are nodes located at a higher altitude, indicating a high elevation zone in the system.

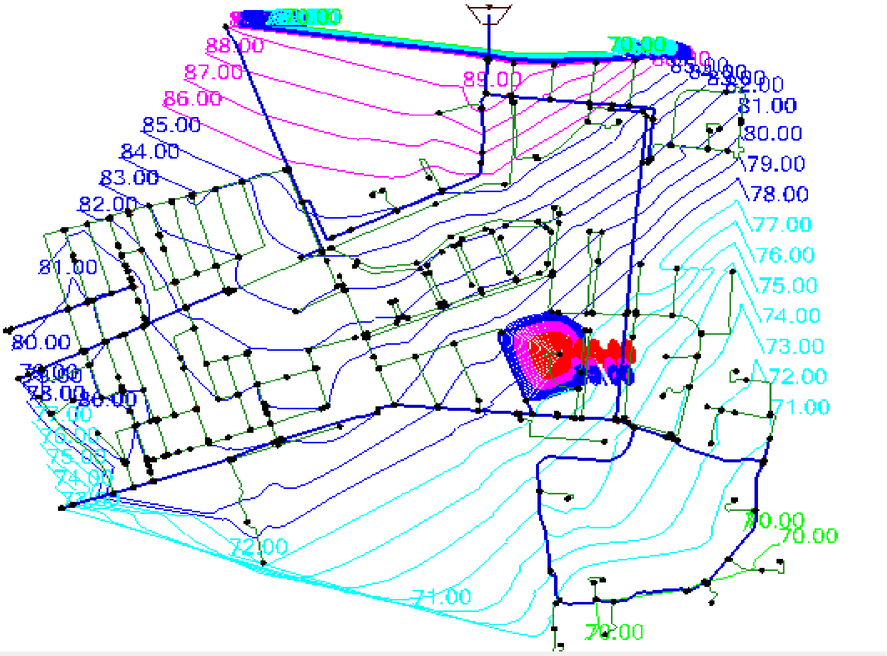


Figure 9: Elevation Contour Lines

Methodology

The supplied observed data is imported into the model and a Leakage Detection Run is performed with the help of the Darwin Calibrator tool to pinpoint possible nodes where water leaks can be expected.

The “Goodness of Fit” criteria used to assess the accuracy and model performance for this study is the Minimize Difference Squares. It aims to reduce the squared sum of the difference between the field data and the model results. The lower this number is, the better and reliable are the model results.

The first step was to import the measured field data for flow and pressure data into the model. Once this step was completed, the first optimization run for leak detection within the water network was initiated. For this study, all the nodes in the system were included due to the present uncertainty as to which nodes of the whole network present leakage. This first run was conducted during the period of low flow in the network (03:15), it is a time where the pressures in the network tend to be high and leaks in the network can be easily detected. The minimum, maximum and increment of the emitter coefficient were added as a criterion for the calibration run.

Once the completion of the initial run, a new leak detection run was performed combining two different datasets to get a more representative results, during periods of high and low water demand and pressure. At the end of this run, a correction to the demand pattern values was done, allowing the model to better represent the measured flow.

To further refine the model results, a new calibration study was performed, this time using pipe roughness as the parameter. It is known that as pipe age increases, the roughness increases as well and generates waterhead losses due to the increased friction and this can be represented by the Darcy-Weisbach roughness coefficient; this helped calibrate the model during the high demand period of the simulation.

Results

Demand Pattern and Pipe Roughness Calibration

Thanks to the calibration run, new values for the demand pattern coefficient during low hour periods are found and then used to correct and substitute the existing values.

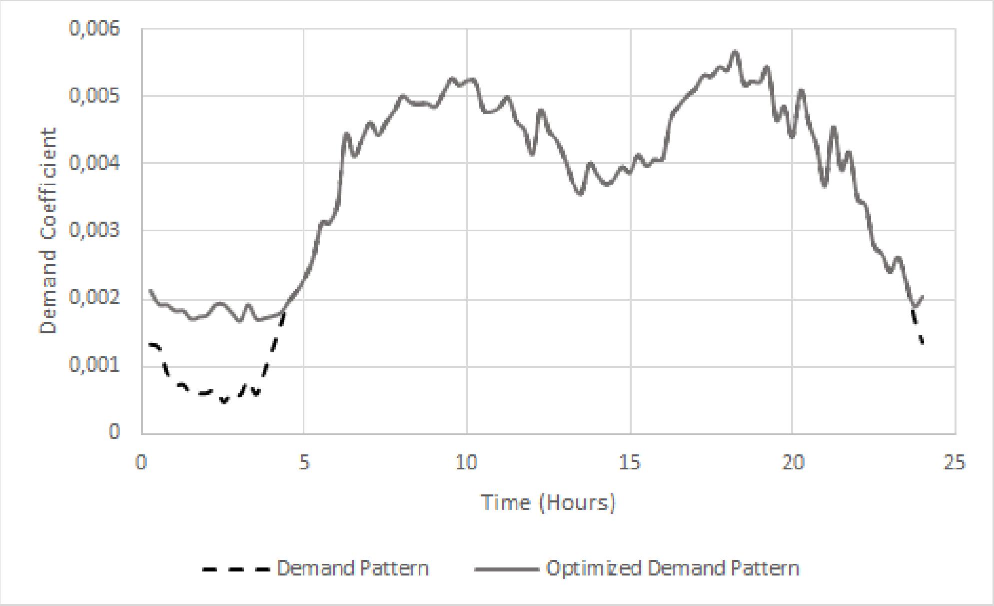
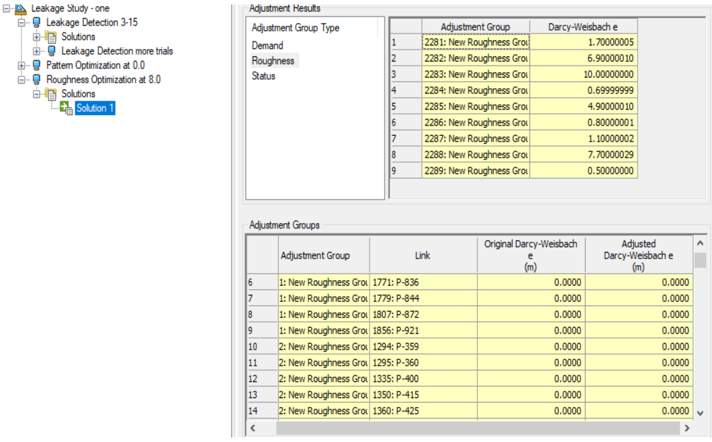


Figure 10: Demand Pattern Comparison

After performing the calibration for the demand pattern for low hours, it was important to adjust it as well for periods of high demand. For this purpose, another calibration run using the data for 10:00 was implemented and using this time pipe roughness as a parameter. After an initial roughness calibration run, the model showed no improvement of the Roughness coefficient as shown in the next image.

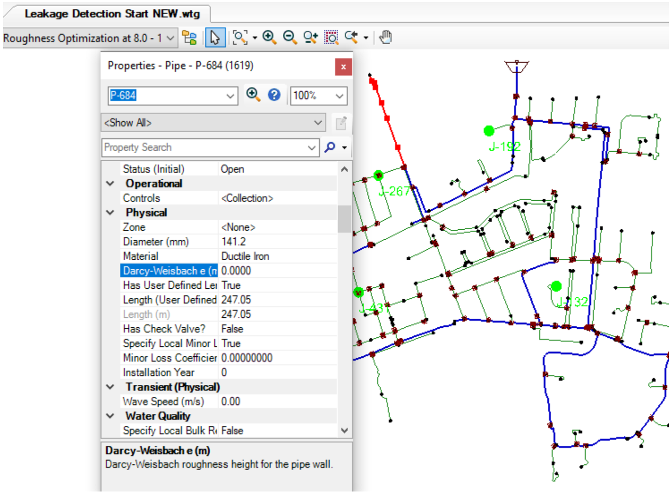


	Adjustment Group	Darcy-Weisbach e
1	2281: New Roughness Grou	1.70000005
2	2282: New Roughness Grou	6.90000010
3	2283: New Roughness Grou	10.00000000
4	2284: New Roughness Grou	0.69999999
5	2285: New Roughness Grou	4.90000010
6	2286: New Roughness Grou	0.80000001
7	2287: New Roughness Grou	1.10000002
8	2288: New Roughness Grou	7.70000029
9	2289: New Roughness Grou	0.50000000

	Adjustment Group	Link	Original Darcy-Weisbach e (m)	Adjusted Darcy-Weisbach e (m)
6	1: New Roughness Grou	1771: P-836	0.0000	0.0000
7	1: New Roughness Grou	1779: P-844	0.0000	0.0000
8	1: New Roughness Grou	1807: P-872	0.0000	0.0000
9	1: New Roughness Grou	1856: P-921	0.0000	0.0000
10	2: New Roughness Grou	1294: P-359	0.0000	0.0000
11	2: New Roughness Grou	1295: P-360	0.0000	0.0000
12	2: New Roughness Grou	1335: P-400	0.0000	0.0000
13	2: New Roughness Grou	1350: P-415	0.0000	0.0000
14	2: New Roughness Grou	1360: P-425	0.0000	0.0000

Figure 11: Roughness Optimization Results (No Improvement)

After a further analysis showed that in the original model, the pipes in the model did not have a roughness coefficient assigned.



Status (Initial)	Open
Operational	
Controls	<Collection>
Physical	
Zone	<None>
Diameter (mm)	141.2
Material	Ductile Iron
Darcy-Weisbach e (m	0.0000
Has User Defined Le	True
Length (User Defined	247.05
Length (m)	247.05
Has Check Valve?	False
Specify Local Minor L	True
Minor Loss Coefficier	0.00000000
Installation Year	0
Transient (Physical)	
Wave Speed (m/s)	0.00
Water Quality	
Specify Local Bulk R	False

Darcy-Weisbach e (m)
Darcy-Weisbach roughness height for the pipe wall.

Figure 12: Pipe Properties before Editing

Using the engineering library located in the WaterGEMs software, it was found that the roughness coefficient for a ductile iron pipe is equal to 0,0003. This value was included in all the pipes and the roughness optimization run was implemented again.

This time, the software was able to run the calibration algorithms and provided a much better fit, as well as a new set of demand pattern coefficients as can be seen in the following graph:

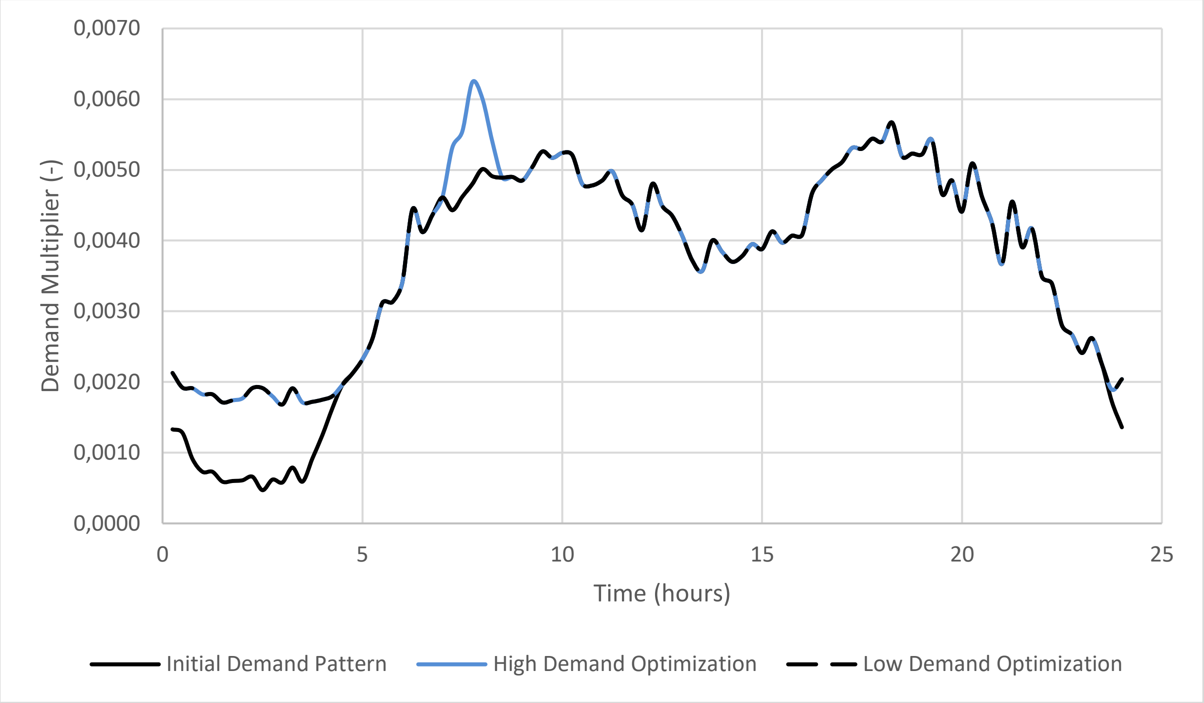


Figure 13: Demand Pattern Optimization

Flow and Pressure

The goal of the various calibration runs in this case study was to improve the model results in comparison with the observed flow. Each calibration run further improves the model results, reducing the Sum of Squared Errors, and making them match the measured flow on the main pipe.

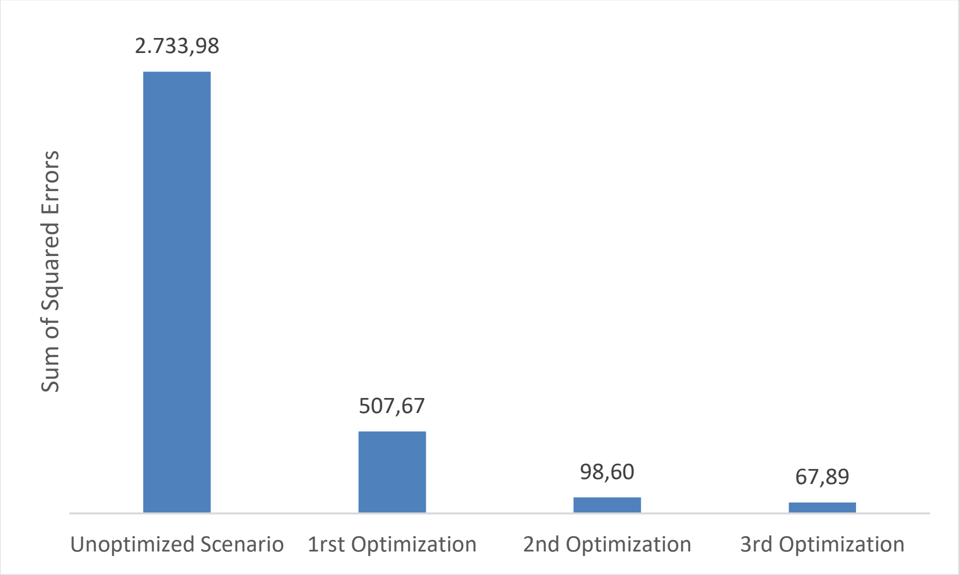


Figure 14: Effects of the Calibration on Model Performance

This reduction of the SSE translates into a better fit between the observed flow and the model results as shown in the following chart:

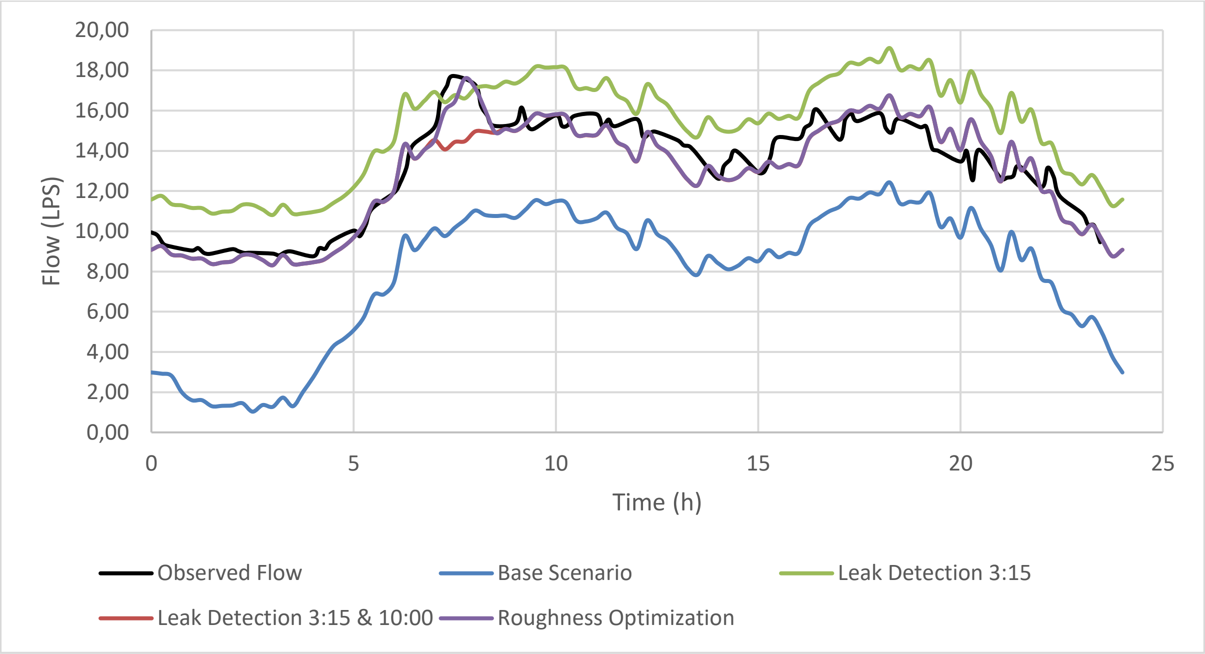


Figure 15: Flow Comparison of Different Scenarios

The same argument can be used for the pressure measurements within the study area. The roughness optimized scenario provides a very close fit.

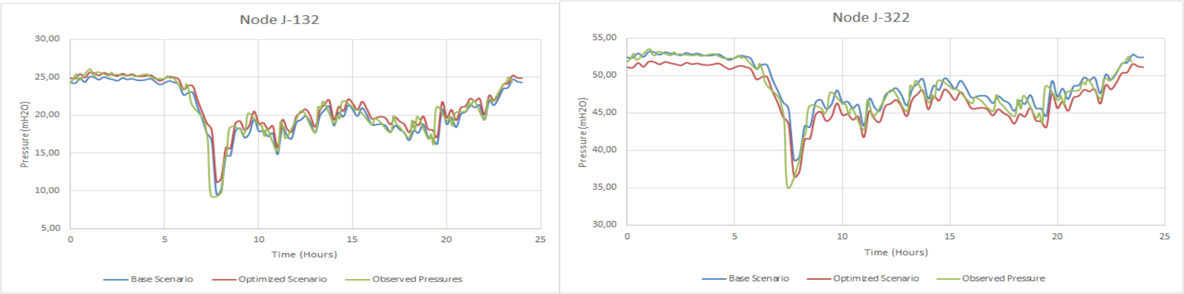


Figure 16: Pressure Comparison

Location of the Leaks

Once the model was properly calibrated, a leak detection run was performed during the low hours of the model using data from 12:00 AM to 4:00AM. After running a total of 12 Simulations, the solutions started to converge to the nodes indicated on the map.

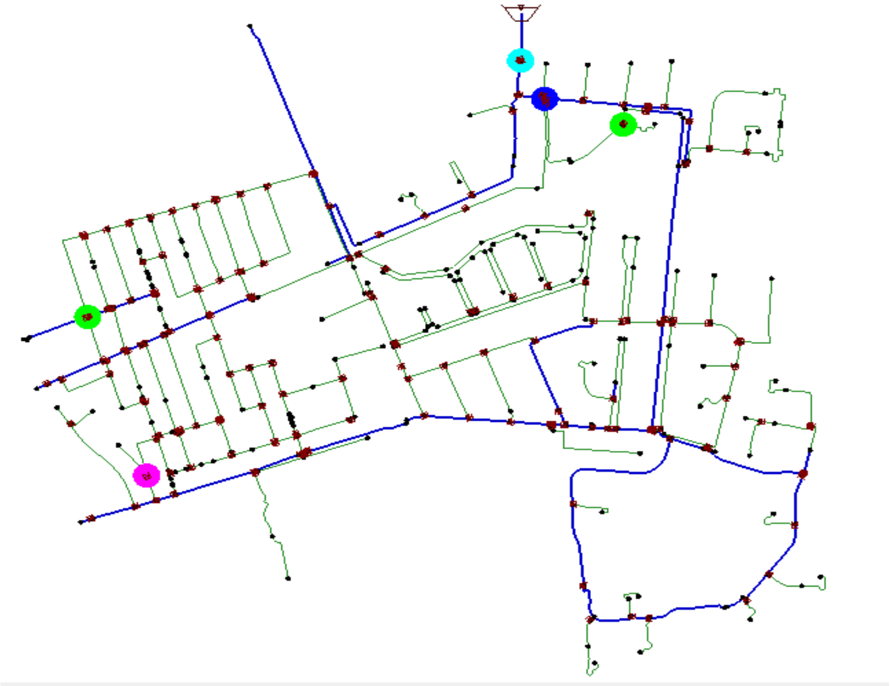


Figure 17: Location of the Nodes with Leakage

The degree of magnitude of the Emitter Coefficient values, indicate that there are leaks with a very low discharge, that could have been difficult to identify without the help of the model, however the model detected also leaks with a significant discharge.

Table 3: Obtained Values of the Leakage Emitter Coefficient

Node	Emitter Coefficient (L/s/(m H2O)^n)
J-685	0,35
J-598	0,24
J-350	0,20
J-97	0,04
J-700	0,03

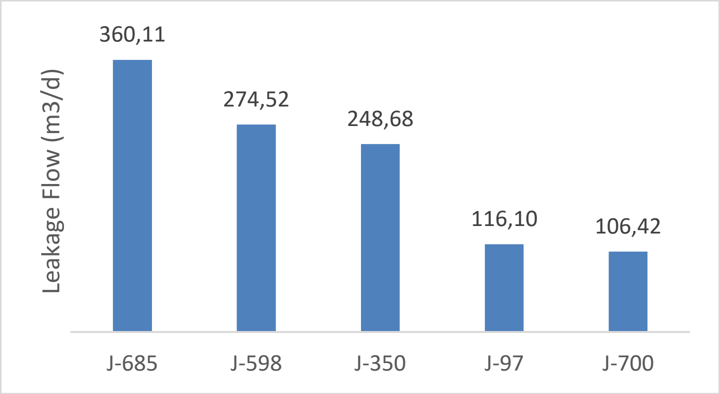


Figure 18: Magnitude of Leakage in the Detected Nodes

Implementation of Pressure Reduction Valves

Throughout the network we can observe high pressure values specially in the low zones of the model, ranging from 63 mH2O maximum and the lowest 48 mH2O. This situation and pressure gradient can be seen in the pressure contour map below, on the left side maximum pressure and on the right minimum pressure.

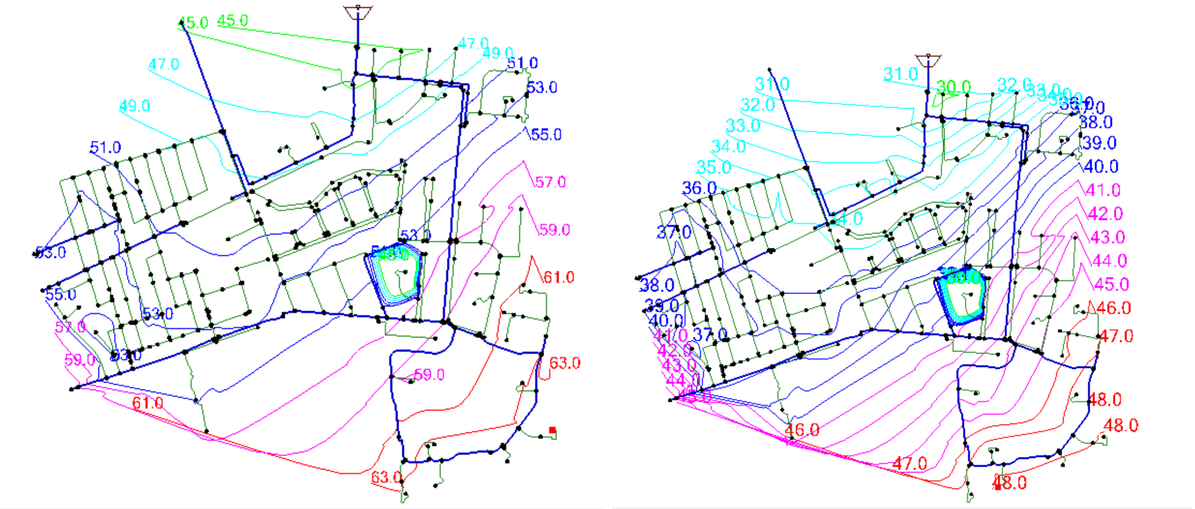


Figure 19: Pressure Gradient without the PRV (left: Maximum Pressure, right: Minimum Pressure in mH2O)

To reduce the risk of new leaks and to have a more consistent pressure throughout the day, 2 PRVs were installed. One located north of the map and close to the water main, and a second one to regulate the pressures in the south of the map where the low zones can be found.

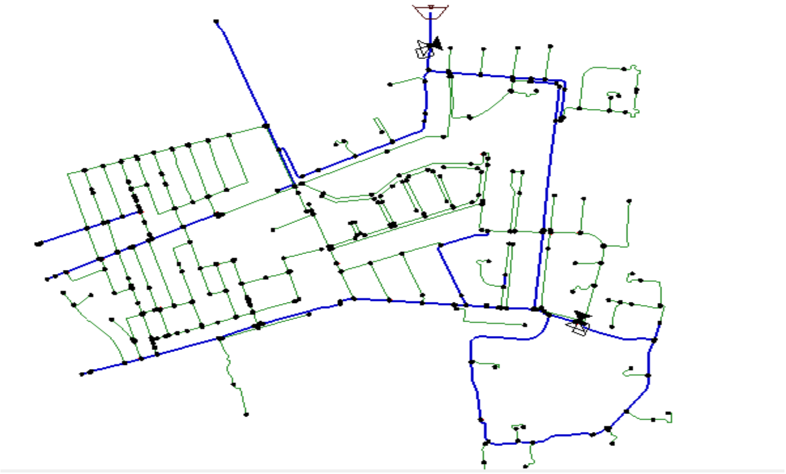


Figure 20: Localization of PRVs

A pressure reduction of at least 20% was desired, therefore the correspondent pressure setting was given into the system in the model via Trial-and-Error approach to find the initial Pressure setting.

Table 4: PRV Information

	Diameter (Valve) (mm)	Minor Loss Coefficient (Local)	Hydraulic Grade Setting (Initial) (m)	Pressure Setting (Initial) (kPa)
PRV-1	184	0,32	115,48	250
PRV-2	76	0,5	83,26	100

After setting up the PRV and indicating the desired pressure a new simulation was started, and the results are shown in the pressure gradient. The maps show a significant reduction from the original value, reducing the maximum pressure from 63 to 45 mH2O and the minimum from 48 to 43mH2O.

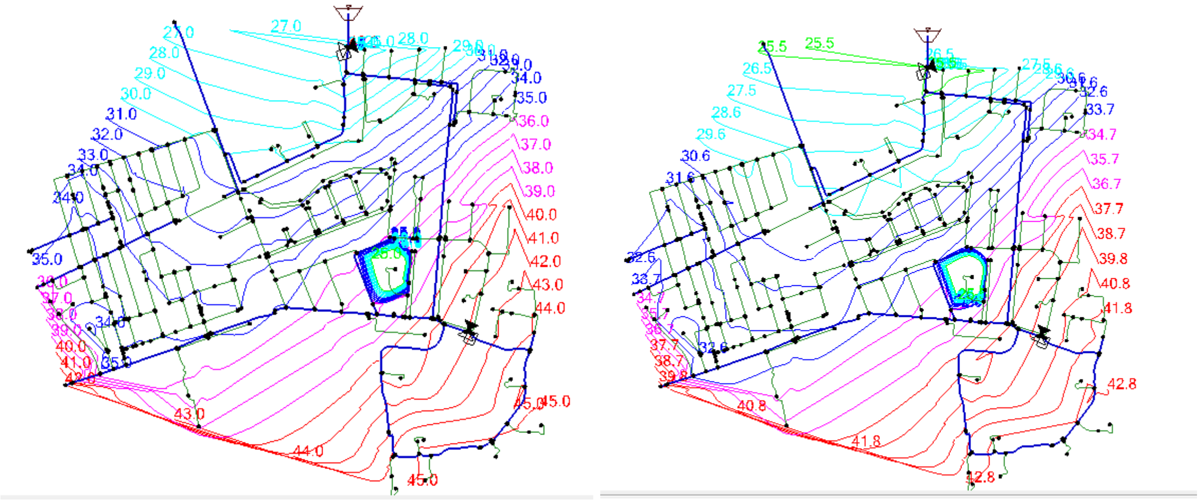


Figure 21: Pressure Gradient with PRV (left: Maximum, right: Minimum)

This implementation allowed for a pressure profile in the nodes without strong fluctuations during the period of the simulation.

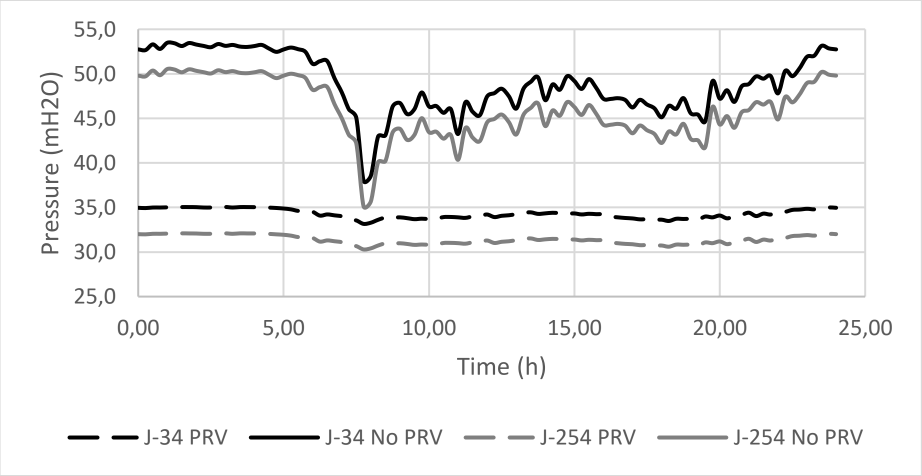


Figure 22: Comparison of Effect of PRV-1 on Selected Nodes

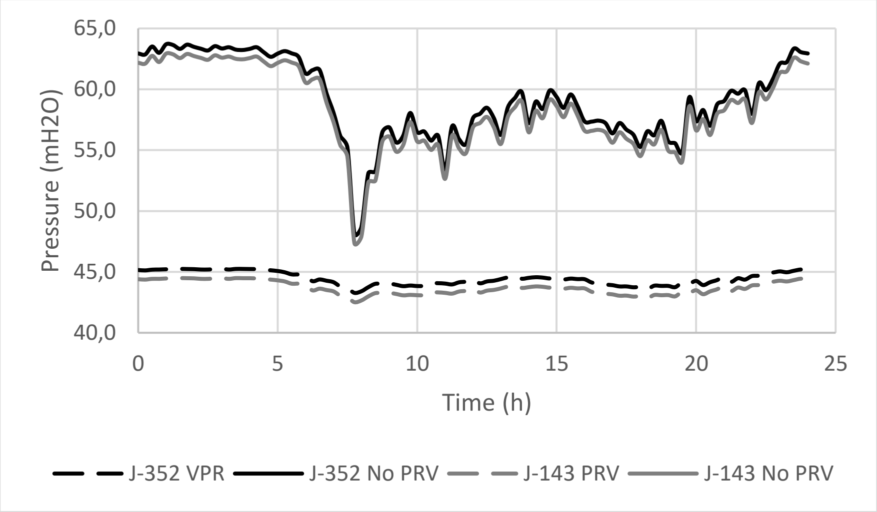


Figure 23: Comparison of Effect of PRV-2 on Selected Nodes

Flow in a leak is pressure dependent, therefore a reduction of the leakage flow is also observed after the implementation of the pressure reduction valve.

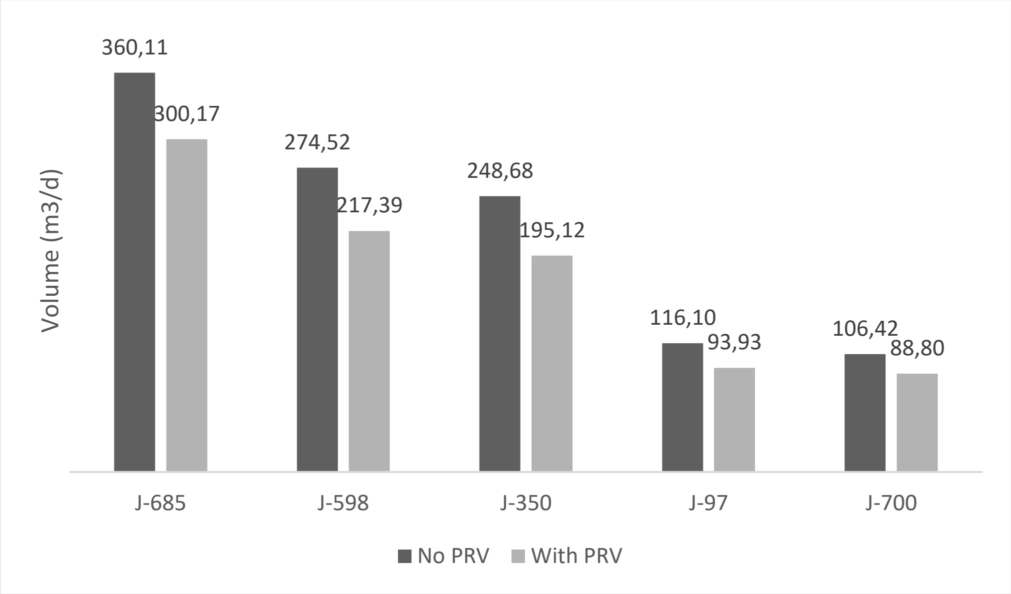


Figure 24: Effect of Pressure Reduction

Questions

1. What time period of field data is good for leakage detection?

Within an established DMA it is better to analyze the Minimum Night Flow, it is the time where urban water demand is at its lowest point and usually occurs between 12:00 and 04:00 am. Water demand would be at its lowest value, therefore a significant percentage of the inflow to the DMA represents water loss volume (leaks). The difference between the Minimum Night Flow and the actual night consumption, helps quantify how much water is being lost by undetected and unreported water leaks. In this case study we will conduct the initial detection at 03:15.

2. Which type of demand adjustment operation is used for leakage detection?

The demand adjustment using optimization models can be effective despite the recognized challenges of model calibration and the physical measurement limitations from the pressure and flow surveys also referred to as field tests. Using Darwin Calibrator can predict the location and size of the water loss. Once detected the leakage nodes are found, use the Criticality tool to repair the leaks or Pressure Dependent Demands to minimize the leaks in the system.

The method is effective at being applied for hydraulic conditions that occur in the early hours of the morning, often on water networks with excess design capacity and where hydraulic gradients are slack and loggers may sometimes be working close to their limits of accuracy.

3. What sitting to adjust when the detected number of leakage nodes is the same as the prescribed maximum number of leakage nodes?

It is recommended to perform a new leakage detection run and increase the number of Leakage Nodes to provide the model with a bigger range of nodes to test. Every simulation run took in average 5 – 10 minutes.

4. What is likely expected for the fitness values of optimized solutions when increasing the maximum trials?

It is likely to be expected that the fitness value decreases due to the increment of maximum trials. This allows the software to further perform calculations and evaluate the solutions while evaluating how close the model results match the observed data. Increasing the number of trials also increases the computation time of the model.

5. How is affecting the final solutions when using a smaller value of Flow per Fitness Point for flows and Head per Fitness Point?

By using a smaller value of flow per Fitness Point Value it will create weighting or prioritization in the calibration to affect solutions. A note to be reminded that these values should be set in a way that the head and flow have unit equivalence and that the larger flow carries more weight in optimization compared to less flow.

6. What to export for a leakage detection run? What not to export for a leakage detection run?

For a leakage detection run it is important to export the Emitter Coefficients obtained and neither the roughness nor the demand are imported for a leakage detection run.

7. Which type of demand adjustment operation should be used for optimizing the pattern at low demand hours?

The goal of the calibration in water networks modelling, is to figure out the physical and operational properties and attributes of the network, so that the model can produce results that are accurate and fit the real solution. Typical parameters used for calibration are roughness, pump operations and in this case, the operation performed is the Demand Pattern Calibration. This process helps to achieve more accurate results, as water demands in an urban area tend to differ (domestic, industrial, comercial, etc.)

8. Why should roughness and demand be optimized at the same time for a high demand time step?

They should be optimized, so that excessive amounts of head loss can be avoided. Additionally, the Water Distribution Network sizes make deployment and maintenance of sensors at all joints unfeasible. Also, it is known that as pipe age increases, the roughness increases as well and generates waterhead losses due to the increased friction & pressure changes. Hence, computational frameworks are also used to optimize roughness and demand for deployment of sensors in WDNs thereby significantly reducing computational costs.

9. What should be exported to a scenario for the roughness and demand optimization at a high demand hour?

The scenario and the calculated roughness need to be exported and not the status nor the demand.

10. Which scenario should be used as representative for optimizing the demand only at the high demand hours after roughness is calibrated?

The scenario used is the scenario that takes into consideration low and high demand hours, that scenario is the Leakage Detection at 3,15 + 10,0.

Conclusions

Water losses are present in every water distribution system. A sustainable reduction of water losses requires permanent and intensive work, as new water leaks will be detected, and the existing infrastructure increases and ages. Therefore, it is recommended that once a year, the IWA water balance and indicators are recalculated and evaluated to achieve an economical level of leakages in the system. Water losses do not disappear; they simply keep occurring; therefore, water loss requires continuous solutions to a multifaceted problem.

There is a basic approach which can help to make demand adjust operation: accurate calculation of non-revenue water (NRW). The kind of leakages can be controlled by using passive and active operations and by implementing appropriate water pricing policy. When water is scarce and there is a lot of competition among the water users (industry; agriculture; household) then active leakage policy will be apt to use. The active leakage policy depends upon the marginal ratio: marginal cost = marginal revenue. Passive leakage control policy can be used in a response to the situation which deals with unacceptable visual leakages (reported by water supplier companies and departments).

A key solution for the reduction of NRW is the implementation of a Water Loss Reduction Program. It compiles several activities.

- Water Balance Method (IWA)
- Water Metering
- More Effective Leak Detection and Repair
- Network Substitution

The model calibration/optimization runs proved to be successful by improving the model results and closely matching the observed flow values. Further calibration to improve the model robustness is always possible, however it could lead to over-parametrization, meaning that further changing and tuning of the parameters to obtain a better model fit can lead to a set of parameters that are unrealistic and do not represent the real values found on the field.

Modelling activities must deal with uncertainty of the available data and parameters, this uncertainty usually propagates into the model results. In our case data such as water demand and pressure measurements were used. There is an inherent uncertainty in the measurements. Therefore, to achieve a reduction of uncertainty and to have more reliable model results, more data can be collected.

The effectiveness of the Pressure control measures (in this case the installation of the 2 PRVs) was demonstrated with the reduced values for the pressure throughout the network and in the reduction of the leakage flow, proving to be also a cost-effective solution when dealing with reduction of water losses.

Proposed Solutions and Recommendations

With the obtained model results and possible locations of the leaks within the network, it is possible to send the Leak Detection crew to perform acoustic leakage detection during the low demand hours, to validate these results.

As indicated before, Water Pressure is one of the fundamental causes of real losses, and pressure control is one of the measurements that produces results in a very short time. Several strategies could be applied to this case study in order to control the excessive pressures caused during periods of low water demand.

When the pressure is reduced water loss will also be reduced from existing leaks and number of new pipe bursts. Please note the tradeoff between high and low pressures. Water suppliers want to provide acceptable but not excessive pressure. This can be accomplished using pressure management. Pressure reducing valves (PRV) can help to set target points for variable speed pumps or adjusted pressure zone boundaries.

A first measurement would be to further sectorize the network into DMAs. By isolating the different areas of the network this measure not only helps with the pressure control, but also facilitates the water metering and accounting.

To better regulate and operate the network, the installation of Control Valves can be considered in any of its variations: Pressure Reducing Valves (PRV), Pressure Controlling Valves (PCV) and Pressure Sustaining Valves (PSV). A PRV aims to reduce the excessive pressure in pipes downstream of the valve. A similar concept is used by a PCV, it is used to control the pressure in zones of low elevation within the DMA. A PSV keeps the pressure constant to avoid significant pressure fluctuations throughout the day.

In the elevated areas of the water network, pressure boosters can be used to maintain the pressure constant and avoid effects of Water-Hammer and significant pressure fluctuations that can have a detrimental effect on the infrastructure.

Infrastructure management consists mainly in the reduction of leak occurrence or the reduction of leaks in zones where pipe bursts are more frequent. If the life cycle of the pipes is close to an end, and its state of deterioration is advanced, it is also recommended to replace elements of the network in a sustained but planned manner, since these network interventions tend to be high cost. Usually a cost-benefit analysis is also needed to support these pipe changes. Of all the measures aimed at pressure control, this is the most expensive.

Since the model is well calibrated, the impact of the suggested measures and the hydraulic response of the network can be analyzed and simulated before its physical implementation, it would also provide the possibility of evaluating different scenarios, such as increased population, planning of pipe replacement, installation of control valves, etc.

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