International Conference on Hydroinformatics

2014

Modeling Of District Metered Areas With Relatively High Leakage Rate. The Case Study Of Kalipoli's DMA

Antonios Bakogiannis

Athanasios Tzamtzis

MODELLING OF DISTRICT METERED AREAS WITH RELATIVLY HIGH LEAKAGE RATE. THE CASE STUDY OF KALIPOLI'S DMA.

ANTONIOS D. BAKOGIANNIS (1), ATHANASIOS D. TZAMTZIS (2),
(1): Senior Civil Engineer, Water Infrastructure Department, Water Supply & Sewerage Company of Athens (EYDAP S.A.), Greece, E-mail: abako@eydap.gr
(2): Project Director, Head of the Water Infrastructure Department, Water Supply & Sewerage Company of Athens (EYDAP S.A.), Greece, E-mail: tzamtza@eydap.gr

The article reviews the modelling of District Metered Areas (DMAs) with relatively high leakage rate. As a generally recognised approach in modelling of leakage does not exist, modelling of leakage by enginners and other researchers usually takes place by dividing the whole leakage rate evenly to all available nodes of the model. In this article, a new methodology is proposed to determine the nodal leakage by using a hydraulic model. The proposed methodology takes into consideration the IWA water balance methodology, the Minimum Night Flow (MNF) analysis, the number of connections related to each node and the marerial of pipes. In addition, the model is illustrated by a real case study, as it was applied in Kalipoli's DMA. Results show that the proposed model gives reliable results.

INTRODUCTION

Several researchers were motivated to develop techniques for the realistical modelling of leakage in Water Distribution Systems. It is more than three decades well known, that leakage is explicitly related to pressure.

Germanopoulos (1985) was among the first to report the relationship betwwen leakage and pressure. He proposed the implementation of the following equation:

$$V_{ij} = CL_{ij}(P_{ij}^{av})^{1.18}$$

where V_{ij} is the leakage flow rate from the pipe connecting nodes i and j, C is a constant depending on the network, L_{ij} is the lenght of the pipe and P_{ij}^{av} is the average pressure along the pipe.

Vela et al (1991) extended the above relationship by incorporating the pipe size and other parameters, as shown below:

$$V_{ij} = CL_{ij}D_{ij}^{d}e^{\alpha\tau}(P_{ij}^{av})^{1.18}$$

where D is the pipe diameter, τ is the age of the pipe, d equals to 1 (for D<125mm) and -1 (for D>125mm), α is a leakage shape parameter, L_{ij} is the length of the pipe, P_{ij}^{av} is the average pressure along the pipe and V_{ij} is the leakage flow rate.

Burrows et al. (2003) proposed another methodology, taking into consideration that the pressure exponent should be variable, as follows:

$$UFW = (C_u)[\Sigma\{\mathrm{N}ci(\mathrm{Pr}\,essure_{node-i})^{N_1}\}_{nodes}]_{MNF}$$

where UFW is the leakage flow at minimum night flow time, Nci is the number of connections related to each node, N_1 is the pressure exponent and Cu is the leakage rate per property connection under pressure of 1m.

Tabesh et al (2009) suggested the following formula in order to calculate the nodal leakage flow ($Q_{L,i}$)

$$Q_{L,i} = \sum_{j=1}^{NK} \frac{L_{ij}}{2} C P_i^N$$

where NK is the number of pipes connected to node i, L_{ij} is the pipe length connected to nodes i and j, C is a coefficient that needs to be calculated and P_i is the pressure value for each node.
Tabesh et al (2009) and Burrows et al (2003) have evaluated their techniques on real case studies in Iran and UK respectively, while the other methodologies have not been implemented on real Water Distribution Networks in order to evaluate their effectiveness.

PROPOSED METHODOLOGY

In this study, the following methodology may be implemented in Discrete Metered Areas (DMAs), which are mainly used for monitoring and leak detection in Water Distribution Systems (WDS).

The first step of the proposed methodology is based on the IWA/AWWA Water Balance (AWWA, 2009), which is a useful tool in analyzing the various components of Non Revenue Water (NRW), real losses, authorized consumption, etc (Table 1). By implementing Water Balance, Water Utilities have the opportunity to gain an understanding of the type of the water loss as well as its magnitude and, if it is used correctly, this will give directions for actions and measures needed to be taken in order to reduce Non Revenue Water.

Table 1. IWA/AWWA Water balance Methodology.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies & Data handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmition or Distribution Mains & Detectable Losses</td></tr>
<tr><td>Leakage & Overflows at Utilities Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the point of Customer Metering</td></tr>
</table>

A brief summary of the main steps needed to perform this specific audit is given below:

1. The amount of water put into the WDS is determined.
2. The authorized consumption is obtained by past experience.
3. Apparent losses are estimated and finally,
4. Real losses are calculated.

For better results, audit process and water balance methodology need to be periodically performed and not only once. Besides, after performing the initial IWA water balance approach, it is observed that some of the above components (especially apparent losses) are estimates with little confidence in their accuracy.

Therefore, in order to assure the real leakage rate in the DMA, the second step of the proposed methodology is to implement Minimum Night Flow Analysis (Farley & Trow, 2003). One of the most important actions that can be taken to identify leakage rate, is the measurement of night flows. By simply observing the minimum night flow, it is possible to identify many unusual situations. The minimum night flow in a water distribution system, usually takes place between midnight and 4.00 a.m. when the consumption is at its lowest. After having calculated the minimum night flow, it is crucial to determine its main components. Minimum night flow therefore consists of the normal legitimate night use which should be calculated and the leakage. The MNF analysis is very practical, as it may be implemented every day, provided that there is continuous audit of inflow in the DMA. Therefore, the measurement of the minimum night flow leads to an alternative way (apart from IWA water balance methodology mentioned above) of identifying the amount of leakage in the DMA.

After having implemented MNF analysis and IWA water balance methodology, the leakage rate is evaluated. Nevertheless, in order to model a water distribution network, the main consideration is how to distribute leakage. As a generally recognized approach in modeling of leakage does not exist, modeling of leakage by engineers and other researchers usually takes place by dividing the whole leakage rate evenly to all available nodes of the model. At first sight, someone should support that distributing leakage evenly to all nodes of the model is not far away from reality, as in practice you have no knowledge of where leakage is located. This method doesn't have a negative impact when leakage rate is below 10% of the System Input Volume entered the DMA, but when leakage rate is above 40%, as in Kalipoli's DMA, consequences are visible as the process of model calibration becomes more complicated. It is obvious that the more the leakage rate increases, the less reliable the above method of distributing leakage evenly is becoming. Therefore, modeling DMAs with high leakage rate needs a different process. Below, a formula is described where the nodal leakage flow is calculated as a discharge through an orifice, taking into consideration that leakage is pressure depended and at the same time leakage is closely related to material of the pipe and the number of connections:

$$V_i = \alpha \Pi^{0,2} C P_i^N$$

where V_i is the nodal leakage flow

Π is the number of connections related to each node

C is a constant, depending on the network

P_i is the pressure of each node during MNF time,

N is the pressure exponent

α is a constant related to the material of the pipes connected to each node and is dimensionless. If the material of all pipes connected to each node is of asbestos-cement, α takes the value of 0,1. If the material of at least one pipe connected to a node isn't of asbestos-cement, α takes the value of 0,05.

After the leakage flow has been calculated for each node, the leakage for the whole DMA is calculated as:

$$V_{Li} = C\sum_{i=1}^{j} a\Pi^{0,2}P_i^N \qquad (1)$$

where J is the number of nodes in the model.

The coefficient C is calculated as follows:

$$C = \frac{V_{Li}}{\sum_{i=1}^{j} a\Pi^{0,2}P_i^N} \qquad (2)$$

A brief summary of the main steps of the proposed methodology is given below:

1. Calculate the leakage by implementing IWA water balance methodology in DMA.
2. Calculate the leakage by implementing MNF analysis in DMA.
3. Compare and evaluate the leakage rates found above.
4. Model the DMA using a Hydraulic Software Solver.
5. Obtain the consumption of each node from the billing records.
6. Initially, spread leakage evenly to all nodes.
7. Run the model for Extended Period Simulation in order to obtain pressures for nodes at MNF time.
8. Calculate a first estimate for the coefficient C, using Equation 2.
9. Calculate leakage for all nodes, using Equation 1.
10. Assign new leakage to all nodes and run the model again to obtain new pressures.
11. Repeat the above process until the new pressures obtained are similar to pressures of step number 10.

THE CASE STUDY OF KALIPOLI'S DMA.

In order to evaluate the above methodology and verify the results, a real case study was carried out in Kalipoli's DMA. Kalipoli's region is situated in the greater area of Pireus in the capital of Greece and is under the authority of the Water Supply & Sewerage Company of Athens (EYDAP S.A.) Kalipoli's water distribution network has a total length of 13 km and 6.441 service connections. Pipe diameters range between 70mm and 250mm. It is mainly an old network, consisting 82% of asbestos-cement pipes, 11% of cast iron pipes, 5,5% of HDPE pipes and 1,5% of PVC pipes. Terrain elevation varies from 30,89 meters to 52 meters above sea level and there are no tanks in the DMA. According to regulations, minimum supply pressure is of 20meters high at the property line. All flow enters the DMA through a Pressure Reduced Valve (PRV) as a single inlet. At PRV, flow and pressure were monitored continuously on a 24hour basis. The PRV was set at 90m during the day and from midnight until 6 a.m. was set at 78m pressure. There are no large industrial or trade night consumers that could affect minimum night flow.

Following the proposed method, at first the IWA water balance methodology was implemented in Kalipoli's DMA, from 20-5-2013 to 22-08-2013, as it is described in Appendix A. The amount of total water losses was found as 100.702m^3. Water losses, expressed as a percentage of the System Input Volume, were calculated as 42%.

Afterwards, Minimum Night Flow Analysis was implemented, as it is described in Appendix B. The minimum night flow from 20-05-2013 to 22-08-2013 was measured with the help of a Supervising Control & Acquisition System. The customer night use has been determined at 2,8 lt/conn.hr and acquired by data records.

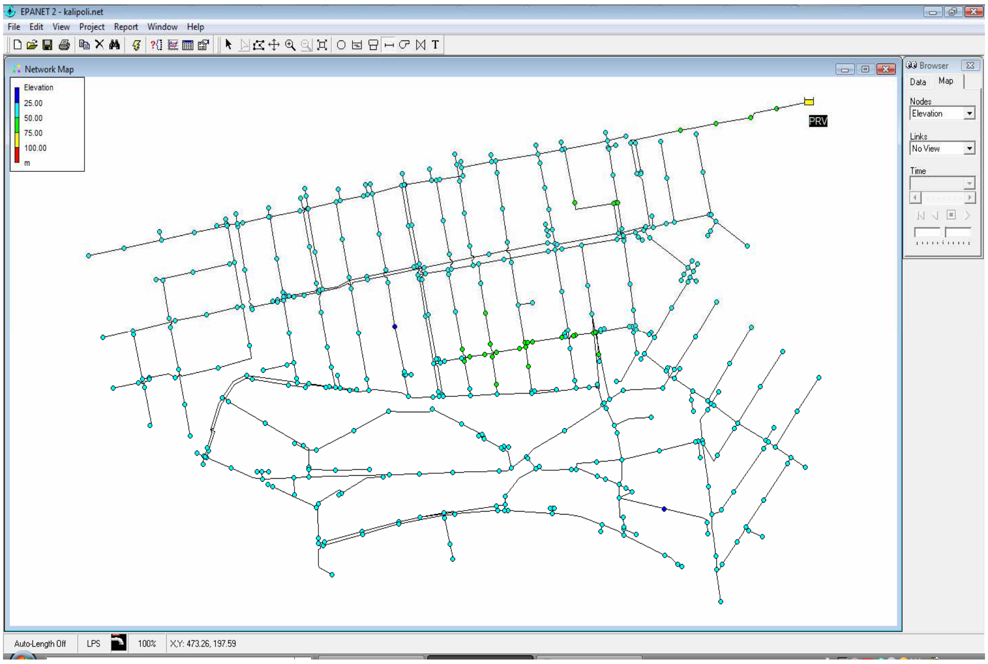

Figure 1.Hydraulic model of Kalipoli’s DMA, using Epanet 2

The MNF analysis showed that the initial estimates and assumptions taken into consideration during IWA water balance methodology were reasonable, as the final results were in close agreement for the two methods.

The case study network model of Kalipoli’s DMA is shown in Figure 1. Epanet 2 hydraulic modeling software was used to model the network that was built using input data for the network assets obtained from the Geographic Information System (GIS) of EYDAP S.A.

Nodal elevations were also estimated with the help of GIS. The Hazen – Williams formula was selected in the model for hydraulic analysis, because of its simplicity. Initially, Hazen – Williams coefficients of 105, 120 and 130 were used for Asbestos-Cement, cast iron, PVC and HDPE pipes, respectively. The hydraulic model consists of a reservoir, 510 pipes and 473 junctions. The model was applied for Extended Period Simulation (EPS), under steady state conditions. A 24-hour diurnal cycle was applied for modeling. In order to enable EPS, hourly demand multipliers derived from the diurnal flow profile at the Kalipoli’s DMA inlet were used for hydraulic analysis. The PRV was simulated by putting a reservoir with elevation adjusted properly.

In the next step, metered billing records were used for each connection, to calculate nodal demands. The Thiessen Polygons method was selected for the distribution of the consumption to the nodes.

Initially, apart from the consumptions mentioned above, the leakage of 100.702m^3 that was calculated by the MNF analysis and IWA water balance methodology was distributed evenly to all nodes of the model. By running the model for Extended Period Simulation, the pressure values for nodes were obtained on a 24hour basis. Afterwards, the application of Equation 2 gave a first estimate for the coefficient C, which is referred to the whole network of Kalipoli’s

DMA. The value of the pressure exponent in Equation 1 was taken as 0,5 as most representations of leaks in models are based on the assumption that the rate of leakage is controlled by orifice (Walski et al, 2006). Then, knowing coefficient C, the leakage for each node was calculated using Equation 1. Knowing the leakage for each node, the model was run again and new pressures were obtained for each node. The above process was repeated three times after which it was observed that the nodal pressures remained approximately steady, confirming that there was no need for more calculations. Finally, it was observed that when total leakage was distributed evenly, leakage at each node was calculated at a rate of 2,24m^3/day, whereas when the proposed methodology was applied, leakage in many nodes was found to be 4,50m^3/day, which represents the real value.

CONCLUSIONS

Results show that when leakage is not distributed evenly to all nodes of the model, but it is calculated using the proposed method, then the pressures at the nodes obtained by the model, were very close to real/field values. Therefore, the proposed methodology helps strongly the process of model calibration, especially in DMAs with high leakage rate. It is obvious that the higher the leakage rate, the more obligatory the use of the proposed process becomes. Nevertheless it has to be stated that the proposed methodology has only been implemented in Kalipoli's DMA, a high populated area with specific characteristics, and therefore it should also be implemented in other DMAs with different characteristics, in order to further verify its accuracy and prove its general applicability.

REFERENCES

[1] AWWA "Water Audits and Loss Control Programs: AWWA Manual M36", American Water Works Association, (2009), USA.

[2] Burrows R., Mulreid G. & Hayuti M., "Introduction of a fully dynamic representation of leakage into network modeling studies using Epanet", In: Maksimovic C., Butler D., Memon A. (eds), Advances in water supply management, Swets & Zeitlinger Lisse (2003) pp: 109-118.

[3] Farley M., & Trow S., "Losses in Water Distribution Networks: A Practioner Guide to Assesment, Monitoring and Control, (2003), IWA Publishing, London.

[4] Germanopoulos G., "A technical note on the inclusion of pressure dependent demand and leakage terms in water supply network models", Civil Engineering Systems, (1985), pp 171-179.

[5] Tabesh M, Asadiyani Yekta A.H. & Burrows R., "An integrated model to evaluate losses in water distribution networks", Journal of Water Resources Management, Vol. 23, (2009), pp 477-492.

[6] Vela A., Perez R. and Espert V., "Incorporation of leakage in the mathematical model of a water distribution network", *Proceedings of the 2nd international conference on computing methods in water resources*, Computational Mechanics Publication, pp 245-257.

[7] Walski T., Bezts W., Posluszny M. W. & Whitman B., "Modelling leakage reduction through pressure control", Journal of AWWA, (April, 2006), pp. 147-155.

APPENDIX A

Table 2. Water balance Methodology applied in Kalipoli’s DMA.

<table>
<tr><td rowspan="9">System Input Volume (227.231m^3)</td><td rowspan="4">Authorized Consumption (126.529m^3)</td><td rowspan="2">Billed Authorized Consumption (125.393m^3)</td><td>Billed Metered Consumption (125.393m^3)</td><td rowspan="2">Revenue Water (125.393m^3)</td></tr>
<tr><td>Billed Unmetered Consumption (Zero)</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption (1.136m^3)</td><td>Unbilled metered Consumption (Zero)</td><td rowspan="7">Non-Revenue Water (101.838m^3)</td></tr>
<tr><td>Unbilled Unmetered Consumption (1.136m^3)</td></tr>
<tr><td rowspan="5">Water Losses (100.702m^3)</td><td rowspan="2">Apparent Losses (5.681m^3)</td><td>Unauthorized Consumption (1.136m^3)</td></tr>
<tr><td>Metering Inaccuracies & Data handling Errors (4.545m^3)</td></tr>
<tr><td rowspan="3">Real Losses (95.021m^3)</td><td>Leakage on Transmition or Distribution Mains& Detectable Losses (76.017m^3)</td></tr>
<tr><td>Leakage & Overflows at Utilities Storage Tanks (Zero)</td></tr>
<tr><td>Leakage on Service Connections up to the point of Customer Metering (19.004m^3)</td></tr>
</table>

APPENDIX B

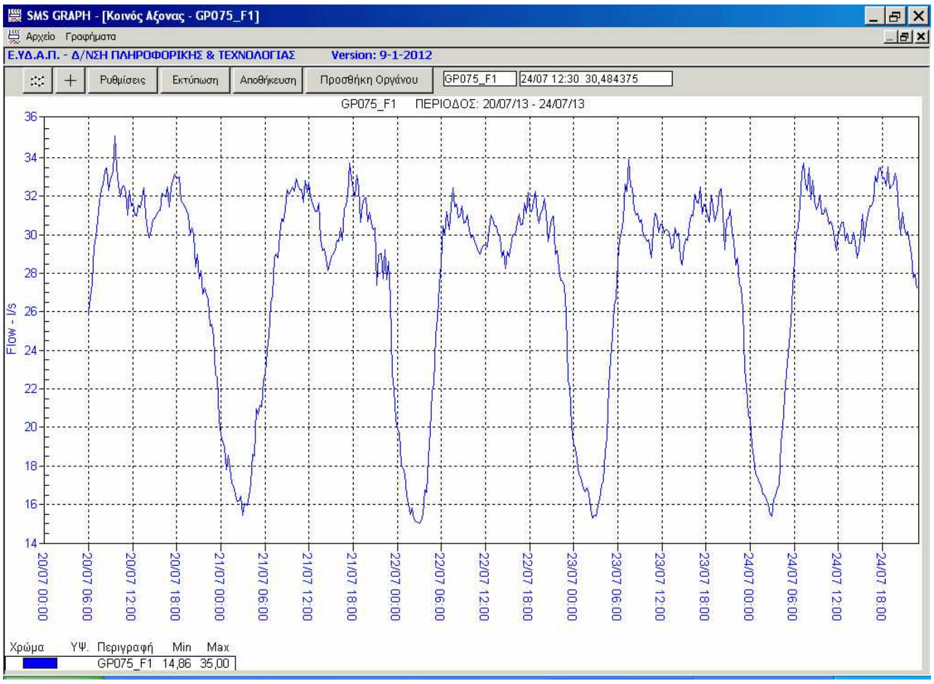

Figure 2. Minimum Night Flow Diagram of the Kalipoli's area by Supervising Control & Data Acquisition System.

Table 3. MNF Analysis of the Kalipoli's area

	m^3/h	Daily(m^3)
Minimum Night Flow* (average measured)	52,56	1.468,58
Customer Night Consumption	16,91	405,84
Exceptional Customer Night Consumption	0,45	10,80
Potential Losses		1.051,93

*The Night Day Factor (NDF) was calculated as equal to 27,94.