LEAKAGE CONTROL AND HYDRAULIC MODELING FOR INTERMITTENT WATER SUPPLY SYSTEMS – GAZA CITY CASE STUDY

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ABSTRACT

The reduction and control of water loss is becoming even more vital in this age of increasing demand and changing weather patterns that bring droughts to a considerable number of locations in the world. The key to developing a leakage strategy for any network is first to ask some questions about the network and how it is operated, and then select the right tools to find the solutions. Network modeling is the tool to give the required answers. The use of distribution network models for leakage control and monitoring of different upgradation or rehabilitation plans for the network with an intermittent supply is a challenging task. In order to develop technical and future strategies for monitoring equity in water distribution as well as identifying and controlling the losses of water network system, district metering principal is suggested to be implemented to achieve the target goals. Objective of this paper, therefore, is to present a technique of leakage monitoring for intermittent water system. It requires the installation of flowmeters at strategic points throughout the distribution system, each meter recording the flows into a discrete area with a defined and permanent boundary. Such an area is called a District Meter Area (DMA). It also unfolds various characteristics of the intermittent hydraulic model that has been developed to simulate the real time conditions in the distribution system and calibration procedures adapted using specialized software. The approach has been discussed in details along with its application and a case study of Gaza City Water network.

KEYWORDS: Hydraulic Model, Intermittent Supply, leakage Control, District Meter Area (DMA)

1. INTRODUCTION

How to reduce leakage in water distribution network is a great challenge which the water distribution network management is facing to. Water network leakage not only causes great waste of energy, but also impacts on the quality of the water distribution service seriously[1]. It is important to distinguish between total water loss (sometimes referred to as ‘unaccounted-for water’ (UFW)) and leakage. Total water loss describes the difference between the amount of water produced and the amount which is billed or consumed. Leakage is one of the components of the total water lost in a network, and comprises the physical losses from pipes, joints and fittings, and also from overflowing service tanks. These losses can be severe, and may be undetected for months or even years. The larger
losses are usually from burst pipes, or from the sudden rupture of a joint, whereas smaller losses are from leaking or “weeping” joints, fittings, service pipes, and connections. The volume lost will depend largely on the pressure in the system, and on the “awareness” time, i.e. how quickly the loss is noticed and dealt with. It also depends on the leak detection and repair policy of the water supply company. The other components of total water loss are non-physical losses, e.g. meter under registration, illegal connections, and illegal or unknown use.[2]

How much leakage is allowed to occur in a system is directly attributable to the water service provider policy, and the influencing factors can be grouped under four categories: resources, infrastructure, institutional attitude, and leakage control policy.

The availability of resources is clearly crucial to the volume of leakage. Where water is plentiful, leakage is viewed and tolerated differently to where it is scarce. Financial resources and manpower resources are also significant factors.

The condition of the infrastructure, and the renewal or rehabilitation policy, is perhaps one of the main reasons for the variation in leakage across the world. The choice and quality of materials, and their laying techniques, particularly in aggressive soils, influence the life-span of the network. Although the age of the network itself is not always a factor, it almost certainly becomes one when combined with the other factors. It follows that a company’s policy for replacing or rehabilitating the pipe network is a major influence on the condition of the infrastructure and therefore leakage.

The institutional policy largely centres on the perception of, and attitudes to, leakage. These in turn affect the capital and staffing that are applied to controlling it. The attitude of governments, national and local agencies, municipal authorities and the community all influence the organization and the operation of the network. Political influences can also be significant—serving the community by developing a new source or building a new treatment works is more “high profile” than initiating a leak detection policy.

Finally, the leakage control policy itself determines the level of activity and the level of leakage in a network. Policies can range from those of very low activity, like repairing visible leaks only, to those which depend on monitoring flows into discrete zones to pick out areas of high leakage.

Of the many factors that affect leakage, it is only pipe pressure that can be controlled once pipes have been laid. Hence, it is recommended that where pressure reduction is feasible and cost effective it should be applied on its own or in conjunction with other methods of leakage control (e.g., passive control, routine or regular sounding, district metering, waste metering, and combined district and waste metering). The objective of any pressure control strategy should be to minimize excessive pressure as far as possible, while ensuring that sufficient pressures are maintained throughout the network to make sure that consumer demands are satisfied at all times. The idealized objective of such a strategy would be to always maintain a head profile in the network such that the pressure at each node is just
sufficient to provide the corresponding demand. This is referred to as an optimal head profile (Sterling and Bargiela 1984) or the target pressure level. However, owing to the head-flow relationships in the network, target pressure levels can only be achieved by few nodes of the network while in the others the operational pressure remains higher. As the complexity of a distribution system grows, the task of achieving the target pressure level becomes more difficult and the average overpressure tends to increase.[3]

In traditional hydraulic models, leakage is equally distributed with the demand, in general as a factor that increases all demands (Assuming that there is a lot of leakage where is a lot of consumption) However, this assumption might not be true for all water networks. A more flexible implementation of leakage is therefore desirable.[4]

2. **District Meter Area (DMA)**

2.1 **The DMA Concept**

The technique of leakage monitoring requires the installation of flowmeters at strategic points throughout the distribution system, each meter recording the flows into a discrete area with a defined and permanent boundary. Such an area is called a District Meter Area (DMA).[5]

The design of a leakage monitoring system has two aims (Figure 1):

1) To divide the distribution network into a number of zones or DMAs, each with a defined and permanent boundary, so that night flows into each district can be regularly monitored, enabling the presence of unreported bursts and leakage to be identified and located.

2) To manage the pressure in each district or group of districts so that the network is operated at the optimum level of pressure.

It therefore follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flowmeters. In some cases the flowmeter incorporates a pressure-reducing valve. District metering has the additional advantage of showing management how the system is working.[6]
2.2 DMA DESIGN

Several factors should be taken into account when designing a DMA, such as:

1. The required economic level of leakage;
2. Size (geographical area and the number of properties);
3. Variation in ground level;

2.2.1 Economic level of leakage

Each water service company will have its own criteria for setting economic levels of leakage and for setting leakage targets for each DMA. These will determine the type of active leakage control policy in the future, the size and number of DMAs, and staffing policy. In a small DMA the operator will be able to:

1. Identify when bursts occur more quickly, reducing “awareness time”;
2. Identify smaller bursts (e.g. a single supply pipe burst);
3. Find bursts more quickly, reducing “location time”;
4. Maintain total DMA leakage at a lower level.

2.2.2 DMA size

Generally, DMA size is expressed in the number of properties. The size of a typical DMA in urban areas varies between 500 and 3000 properties (ref. Managing leakage: Report J—Techniques, technology and training). However some DMAs, designed around old “waste meter zones”, are smaller than 500 properties and others, designed around reservoir zones or in rural areas, are larger than 3000 properties. The size of an individual DMA will vary, depending on a number of local factors and system characteristics, such as:
1. The required economic level of leakage;
2. Geographic/demographic factors (e.g. urban or rural, industrial areas);
3. Previous leakage control technique (e.g. ex-waste meter districts);
4. Individual water company preference (e.g. discrimination of service pipe bursts, ease of location survey);
5. Hydraulic conditions (e.g. limitations of closing valves in the current network, and the need to maintain standards of service).

2.2.3 Water quality considerations
Creating a DMA involves closing boundary valves. This creates more dead-ends than would normally be found in a fully open system. Consequently complaints of poor water quality may occur, both during valving-in a DMA and during later operation. The greater number of valves in a DMA, the greater is the likelihood of this happening. The problem can be partly alleviated by a flushing programme.

2.3 THE DMA ESTABLISHMENT METHODOLOGY
The adopted methodology consists of a sequences of stages in order to design and implement the DMAs. The methodology is clarified in Figure 2. It is consisted from the following stages:
1. DMA Planning and testing
2. Site Survey
3. Detailed design
4. Implementation and verification of DMA performance.

![Figure (2): Typical DMA establishment approach](image-url)
3. CASE STUDY

This study is applied as one of the tasks that required to be fulfilled by the Costal Municipal Water Utilities (CMWU) which aims to manage and control the loss of supplied water to the Municipality of Gaza (MoG) districts, moreover the project shall be part of the total equity plan aiming at insuring the equity of water distribution in the different areas of Gaza Strip localities starting with Gaza city.

The use of bulk water meters at various points on a water distribution network can help in identifying problem areas, i.e. those zones where leakage or other problems are greatest. This allows those areas with the greatest apparent loss to be given highest priority. In order to develop technical and future strategies for monitoring equity in water distribution as well as identifying and controlling the losses of water network system, district metering principal is suggested to be implemented to achieve these target goals.

3.1 Study Area

The MOG is composed of 15 administrative districts. It has an approximate rectangular shape of about 7.5 km long, and its width is about 6 km. The population record is about 496,410 people (in year 2007 – (PCBS, 2008 - Census 2007 Preliminary Findings (Population, Buildings, Housing Units and Establishments). Figure 3 presents the MOG districts.

Figure (3) : Municipality of Gaza Districts (source: MoG, Planning department, 2005).
The only water source for Gaza City is groundwater. This source is currently deteriorating in terms of its quantity and quality. The CMWU/MoG operates 63 wells distributed over Gaza City and Jabalia Town categorized as main wells’ zones and local wells. The last monthly record shows that the total production is 32.5M cubic meter at year 2011(MoG records, 2011).

The total length of the water network pipes in MoG is approximately 450 km with pipe diameters ranging from 2-inch to 20-inch. Large and medium diameter pipes are made of steel and asbestos cement, but many smaller pipes are UPVC, HDPE and galvanized steel. The case study covers the whole MoG network.

Due to infrastructure and water resources limitations where there are no operating water tanks and all water supplies is directly pumped into the networks, it is not possible to provide a 24-hour supply to all areas of the city. Two areas of higher ground elevations, to the south (El Sabra area) and south-east (El Shijaeia area) of the city respectively, are therefore supplied on alternate days by daily manipulation of a number of valves, where mode of operation is illustrated in Figure (4). The network is operated by using manual valves (major valves are about 150 valves) located at many places on the main pipe feeders, especially on the transmission mains and main branches of the system. Each well has a specific operation time in summer and winter.

![Figure (4): operation scheme for Shijaeia / Sabra cycle days 1 and 2](image)

Water network in MoG is composed of about 41 operation zones as shown in Figure (5) varying in size, complexity, topography and source management. These zones are allocated based on the current supply sources and sequence where each has its supply sources of each zone and main operating valves related to these zones.
3.2 Results
DMA Planning and Model development

The authors developed an extended period simulation (EPS) calibrated intermittent hydraulic model for MoG water network. The Model was developed using WaterCAD software (V.6) consisting of 5000 nodes and 36 intermittent operation schemes controlled by more than 130 control valves programmed with operation schemes similar to operation practices by MoG water department. A provision for considering pressure dependent consumption, in an intermittent supply system, the network operation may shift from pressure dependent consumption to demand controlled consumption, both in space and time [8].

The intermittent hydraulic model was created using the following steps
1. Data Collection: infrastructure, resources quality & quantity, system efficiency and Unaccounted-for-Water (UFW), operation schemes, topographical data, related study
2. Network skeletonization: skeleton the network and to define the main feeders and nodes.

Figure (5): MoG Water Operation zones
3. Demand calculation and allocation: This include defining the baseline demand which cover both customer demand (domestic and non-domestic) and UFW

4. Time varying demands establishment: Diurnal curves are important input for Extended period simulation EPS. However, in this study, the diurnal curves (for each operation zone) present a supply-driven demand under intermittent operation conditions. Therefore, the demand pattern presents actually the supply feeding period for each operating scheme. The pattern is modeled as a horizontal straight line with a multiplier equal to 24 hours divided by the supply time for each area. For each operating scheme, one diurnal curve is developed. (Figure 4)

5. Physical data input for network infrastructure

6. Model run for 72 hours which cover the largest intermittent operation scheme in MoG water network.

The model was calibrated using field data collection (pressure & flow) by installing Data loggers at several control points in all operation zones. The EPS model calibration was solved in a progressive manner, optimizing model parameters plus engineering judgments using Darwin Calibrator software. Calibration methodology used is illustrated in the Figure (6). Calibration accuracy approached 93%. This model is updated during this case study to consider new infrastructure, operation schemes, sources and valves operation schemes. The updated hydraulic model is used as first step in DMA planning and testing to get flow and pressure data at the inlet of DMA[9].

Figure (6): Hydraulic model calibration process
Site Survey
In this study, revision, analysis and documentation of the existing water distribution system/facilities and current intermittent operation schemes were achieved by installing data loggers on the proposed monitoring points as shown in Figure (7). The locations of data loggers were selected based on the updated hydraulic model to simulate the current operation intermittent schemes.

Field assessment campaign is organized for 10 days. This period was enough to consider the existing major and local intermittent operation schemes with a considerable contingency margin [10]. 113 tapping points are prepared for field measurements campaign. The 108 instruments were set-up and uploaded using Radcom software to be installed on the main and local supporting wells (41 stations) and on main trunk and distribution pipelines (67 stations). Due to installation normal problems, minor changes are considered and only 106 instruments are installed, collected and downloaded (40 stations on wells and 66 stations on pipelines). The analysis of the field measurements covers: results coherence with current intermittent supply schemes, observation on the water distribution status all over MoG in terms of working pressure, pressure range distribution in MoG where the most suffering areas in terms of working pressures are presented, pressure profile analysis for main trunk and distribution pipelines, pressure pattern analysis in term of supplying period and uniformity, comparing the results with the measurements of similar campaign in MoG that was carried out in April 2005 by Palestinian Water Authority. This information is used to verify the existing intermittent operation schemes which was used as input data to develop the DMAs development scheme.

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<th>Installed on water well feeders</th>
<th>Data Logger results</th>
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<td>Figure (7): Data logger installation and results</td>
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Once the districts (distribution zone) were identified and documented along with their source points and locations, a plan for each DMA was prepared showing the location of district meter and how it will be supplied, and the district boundaries.
Figure (8) illustrates the DM components for 10" flow meter size with dimensions of internal mechanical components at 20" pressure line. Figure (9) shows an existing working DM for 4in pipe line in MoG.

According to the above mentioned components, the DM chamber size is 1.5m width x 4.0m length x 1.8m height for flow-meter size above 4" and 1.5m width x 2.0m length x 1.8m height for flow-meter size 3" - 4".

13 DMAs were developed within Gaza city water network with close coordination and feedback from CMWU- Gaza department technical staff. These DMAs (including DM and boundary valves locations) are described in the following paragraph. Figure 9 illustrates the developed DMAs.
4. RESULTS SUMMARY

1. Hydraulic Model for intermittent supply condition was successfully developed using Water cad Software (Vr.7) with 93% calibration result. Despite that the used software is utilized mainly for continues supply, the authors manage by introducing valve control schemes and intermittent supply patterns and peak factors for each operation zone to overcome such limitation in the hydraulic modeling software.

2. The calibration process for intermittent hydraulic model used in this study involved a series of field tests during which pressure was recorded at strategic locations in the water networks. This was followed by office work during which the model parameters were manipulated in a reasonable range to adjust the model pressure and flow values to the field values The Darwin Calibrator software from Haestad was used in the calibration process where final result lead to 93% model accuracy.

3. DMA developed scheme for MoG resulted in 13 DMAs within water network with close coordination and feedback from MoG and CMWU using the calibrated intermittent hydraulic model for the networks. These DMAs are illustrated in Figure (10).

Figure (10): The developed DMAs within MoG water network.
The installation stage was not completed for DMAs due to blockade over Gaza and fund shortage. Installation stage should consist of several tasks: 1) Supervising the awarded contractor in the fields and monitor the construction of DMs. 2) Install the data loggers in the new monitoring points. 3) Run the data loggers for at least 4 weeks period to verify DMAs efficiency.

4. CONCLUSIONS

This case study has provided a practical context for using DMA as a tool for leakage control and the approach to follow in developing DMA scheme for intermittent water supply network. A comprehensive approach of utilizing calibrated hydraulic model for DMA planning and testing and to be followed by network actual data collection (pressure and flow) using data logger technique is recommended for DMA scheme development.

5. RECOMMENDATIONS

1. The DMA design validation through updated hydraulic model to operational level is preferable to increase the level of confidence of the performed design and assess the hydraulic performance of these DMAs.
2. DMAs management and maintenance plans are needed to be developed. This includes dealing with DMA boundary management and the maintenance of equipment. It also includes record management to ensure that DMA data are accurate and meaningful.
3. DMAs response plan should be created to assess any change in supply and distribution schemes within the system which may influence the operation of a DMA. Potential changes in the system are: change in zone boundaries, new supply conditions new change in operation.
4. It is recommended that any new installation of flow-meter in the network (wells, tanks and pipelines) should be of the type that can be connected to data logger.
5. At the installation stage, it is worthy to bear in mind the requirements for remote meter readings.

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