American Journal of Water Resources, 2017, Vol. 5, No. 1, 1-4
Available online at http://pubs.sciepub.com/ajwr/5/1/1

DOI:10.12691/ajwr-5-1-1

Predictive Leakage Estimation using the Cumulative Minimum Night Flow Approach

Makaya Eugine*

Department of Civil Engineering, National University of Science and Technology, Zimbabwe
*Corresponding author: eugine.makaya@nust.ac.zw

Abstract Several methods have been used in estimating leakages. Although the minimum night flow analysis method has been widely used in leakage estimation, the cumulative minimum night flow method is one method that can yield comparatively good leakage estimates. This paper applies the cumulative minimum night flow method to estimate water leakage in a water distribution system. The cumulative minimum night flow method develops a model from empirical night flows which is used to estimate mean minimum night flows and hence estimate leakages. The result was compared with the South Africa minimum night flow analysis methodology. It was found out that the model developed from the cumulative minimum night flow method yielded good result, (R^2=0.9998). Thus, the cumulative minimum night flow method could be relied on in predicting leakage estimates in water distribution systems. Furthermore, the model could be used in other locations other than that described in this paper.

Keywords: *cumulative minimum night flow, predictive leakage estimation, South Africa minimum night flow analysis, water distribution system*

Cite This Article: Makaya Eugine, "Predictive Leakage Estimation using the Cumulative Minimum Night Flow Approach." *American Journal of Water Resources*, vol. 5, no. 1 (2017): 1-4. doi: 10.12691/ajwr-5-1-1.

1. Introduction

Water is a very important resource whose management should be a key priority for every nation. Although water is a renewable natural resource, it has started to be scarce because of its spatial and temporal distribution world-over. No water utility should allow for unnecessary water losses. Thus, water loss by which ever means, should be minimised to the most economic level feasible.

Many methods have been developed to detect leakage. Some of the methods of leakage detection are direct while others are indirect. With the advent of information and communication technology more robust computational methods are being developed for direct leak detection. However, many water utilities in developing countries have not yet embraced these high-tech tools and methodologies. The reason for that is to do with the cost of acquiring the technology and well as the lack of expertise to operate the technology. The biggest challenge is thus to localise and locate leaking points in a water distribution network.

Leakage is the single largest means by which water is lost in a water distribution system [10]. The way in which a leak flow develops, determines the leakage type and its respective magnitude. There are slow leaks that develop over time and rapid leaks referred to as bursts, which have very high flow rates. Leakage may result from poor workmanship, earth quakes and tremors, lack of maintenance and excessive pressure [1]. Leaks are more difficult to detect than bursts by virtue of their magnitudes.

The subsequent sections of this paper explore approaches and techniques used in leak detection and analysis. These include the district metered area approach, the water balance method, and the night flow modelling approach.

1.1. The District Metered Area Approach

A water balance is a best practice approach that can be used to partition various components of NRW. However, a water balance approach would not be able to forecast leakage as it only gives a general overview of water lost. To be more accurate water distribution systems are divided into isolated metering units called district metred areas (DMA). Each DMA has between 500 and 3000 connections [4]. Leakage from each DMA is monitored by computing the minimum night flow and comparing it with the normal night usage.

When demand is least, pressure will be highest and hence leakage will be highest [4]. The adoption of the DMA approach has simplified complex water distribution networks, characteristic of all water supply systems. Thus, the DMA approach narrows the scope of evaluation of water losses.

1.2. Water Balance Approach

Leakage in a water distribution system can be quantified by a water balance of total water supply against total metered consumption, with reserves for maintenance fire fighting, metering errors and unauthorised or illegal consumption [12] as detailed in Equation 1.

$$\text{Leakage} = \text{TS} - \text{MC} - \begin{bmatrix} \text{MTAllwnc} + \text{FFAllwnc} \\ +\text{MEAllwnc} + \text{ICAllwnc} \end{bmatrix} \quad (1)$$

where TS is total supply, MC is metered consumption, MTAllwnc is allowance for maintenance, FFAllwnc is allowance for fire fighting, MEAllwnc is allowance for metering errors and ICAllwnc is allowance for illegal consumption.

In quantifying network leakage pressure – flow relationships have been extensively explored. However, [16] suggested the following relationship for analysing pressure -burst frequency relationship:

$$\frac{BF_1}{BF_0} = \left(\frac{P_0}{P_0}\right)^{N2} \; or \; \text{N2} = \frac{\ln\left(\frac{BF_1}{BF_2}\right)}{\ln\left(\frac{P_1}{P_0}\right)} \quad (2)$$

where BF_o is burst frequency at initial pressure, P_o; BF_1 is burst frequency at the changed pressure, P_1; N2 is burst frequency exponent.

The determined values were then used to determine pressure management opportunities [8] by computing frequency reduction from possible pressure reduction using the following equation:

$$\Delta BF = \left(1 - \left(\frac{\mathbf{P_1}}{\mathbf{P_0}}\right)^{\mathbf{N2}}\right) x100\% = \left(1 - \left(\frac{\mathbf{P_0} - \mathbf{\Delta P}}{\mathbf{P_0}}\right)^{\mathbf{N2}}\right) \mathbf{x}100\% \quad (3)$$

where ΔBF is burst frequency reduction realized upon pressure reduction; as a percentage.

Leakage management experts somehow agree that all water distribution systems leak to some extent and therefore it is impossible to eliminate real losses from a large water distribution system completely [9,15]. The amount that cannot be eliminated, (threshold amount) part of real losses for well-maintained and well-managed systems is known as unavoidable annual real loss (UARL). System-specific values of UARL can be assessed using a formula developed by the IWA Water Losses Task Force [7]. The data required in assessing UARL are the number of service connections (Nc), the length of mains (Lm in km) and the length of private pipes (Lp in km) between the streets, property boundary and customer meters, and the average operating pressure. According to [6] the general equation for UARL calculations is:

$$UARL = \left(18\ x\ L_m + 0.8\ x\ N_c + 25\ x\ L_p\right) xP \quad (4)$$

where UARL is Unavoidable Annual Real Loss (L/d); L_m is length of mains (km); N_c is number of service connections (from main to the meter); L_p is length of unmetered underground pipe from street edge to customer meters (km); and P is average operating pressure at some zone point.

[6] recommended a revision of the UARL relationships for systems not operating at the standard pressure of 50 m. Thus, they proposed Equation 5.

$$UAL_r = UARL_{50} x \left(\frac{P}{50}\right)^{N1}. \quad (5)$$

The current $UARL_r$ then becomes the revised UARL, while UARL50 is UARL at standard pressure of 50 m, P is operating pressure, and N1 is leakage exponent. The current annual real loss (CARL) comprises of physical water losses from the pressurised systems through to customer water meter, and is normally calculated as the total water lost less the apparent losses [13]. Over and above the UARL approach, network hydraulic modelling plays a pivotal role in leakage assessment.

1.3. The Night Flow Modelling

Utilities utilise a variety of measures to reduce leakage. These range from routine renewal of assets, reduction of service pressures and location of leaks by acoustic methods with active leakage control [3].

The analysis for real water losses is done using flow and pressure data from a DMA. In a DMA leakage is estimated when flow is at its minimum. This typically occurs between midnight and 04:00 hours when customer demand is at its minimum and therefore the leakage component will be at its largest percentage of the system input volume.

The Daily Real Loss Volume (DRLV) is expressed as in Equation (6).

$$DRLV\ F_{nd}\ X\ Q_{mn} \quad (6)$$

where Q_{mn} is the average minimum nightly leak flow rate (m^3/h) and F_{nd} is the night day factor. This relationship supposes that the leakage volume is not constant during day but rather depends on demand dynamics. The F_{nd} is computed by the sum of pressure values acquired during 24 hours in an average DMA representative point by using Equation (7).

$$F_{nd} = \sum_{i=0}^{24} \left(\frac{P_i}{P_{3-4}}\right)^{N1} \quad (7)$$

where P is the average pressure during the minimum nightly consumption between midnight and 04:00 am; N1 is the orifice exponent that can be computed using Equation (8).

$$\frac{Q_1}{Q_0} = \left(\frac{P_1}{P_0}\right)^{N1} \quad (8)$$

where Q_o is the flow rate in association with Po pressure , Q_1, is the flow rate in association with pressure P_1 and N1 is obtained by closing valve usually situated in the system entry. Empirically N1 values are 0.5 for metallic pipes and 1.5 to 2.5 for plastic pipes [7].

Even in night flow analysis, the relationship between pressure and leakage is approximated by orifice classical formulation represented by Equation (9).

$$Q = C_e H^{N1} \quad (9)$$

where C_e is the discharge coefficient of the orifice which depends on the orifice shape and diameter, H is the nodal head and N1 is as defined above [14].

The minimum night flow (MNF) methodology is the best practice analysis and monitoring strategy for water leakage within a District Metered Area [4]. The MNF method puts emphasis on problematic areas with a high percentage of NRW in real time especially if night consumption is expected to be fairly small.

1.4. The South Africa Night Flow Analysis Model

The South Africa night flow analysis model (SANFLOW) is based directly on the BABE (burst and background estimate) and Fixed Area Variable Area Discharges (FAVAD) principles and is written in DELPHI computer language for the Windows operating system [11]. The methodology used in SANFLOW is a very empirical method based on a large number of test results from the United Kingdom and elsewhere in the world [11]. The SANFLOW model requires flow and pressure readings. On top of that, default parameters are needed as inputs, above the infrastructure variables. The default values were empirically developed for developing countries.

Reliance on one method of estimating leakages in water distribution networks is just as unreliable as default values used in SANFLOW models. Thus, the need for robust methodologies which can give more reliable leakage estimates. The objective of this paper is thus to assess the effectiveness of the cumulative minimum night flow method in predicting leakage estimates in a water distribution system. The cumulative minimum night flow method is discussed fully in the methodology section of this paper.

2. Study Area

This paper draws its data from two district metered areas of Harare, Zimbabwe. One DMA, Budiriro, is a high density residential location while the other DMA, Belvedere, is a low density residential area. Budiriro has an estimated population of 57105 connected through 11421 household water meters, while Belvedere has a population of 9495 connected through 1899 meters [2]. Belvedere was installed 70 years ago while Budiriro was installed 35 years back. The map of Harare and the chosen two DMAs is shown in Figure 1.

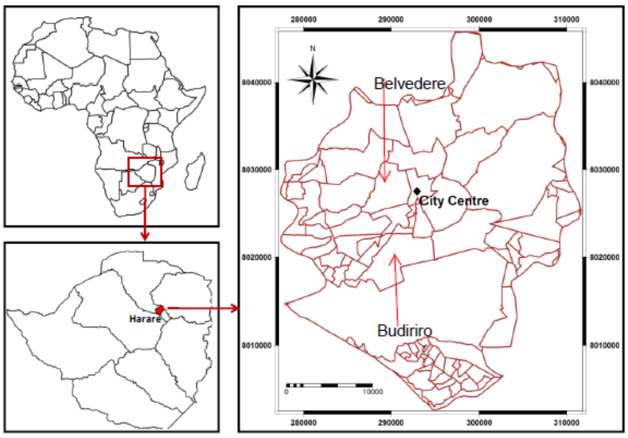

Figure 1. Map of Harare showing Buduriro and Belvedere DMAs

3. Methodology

Flows into each of the two DMAs were logged over a 24 hour period from 22 to 26 April 2012. The SANFLOW analysis model was used to compute the leakage over the sampling period. The results were compared with those obtained using the cumulative minimum night flow method. The method uses the average minimum night flows to compute the cumulative minimum night flow. The average cumulative night flows values are plotted against the night flow times. A model is fitted to the cumulative values and is used to compute the mean cumulative minimum night flow and hence be used to predict leakage estimates in the DMA.

4. Results and Discussion

The characteristics of the two DMAs in terms of population, number of connections, properties and length of the mains are shown in Table 1.

Flows into Budiriro and Belvedere DMAs are shown in Figure 2 and Figure 3 respectively. The figures show the maximum and the minimum flows on each sampling day.

Table 1. DMA characteristics

	Budiriro	Belvedere
Population	57105	9495
Connections	11421	1899
Properties	11421	1899
Mains length (km)	90.17	98.45

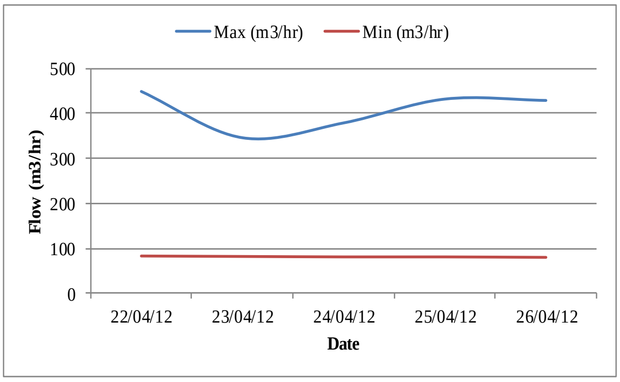

Figure 2. Flow into the Budiriro DMA

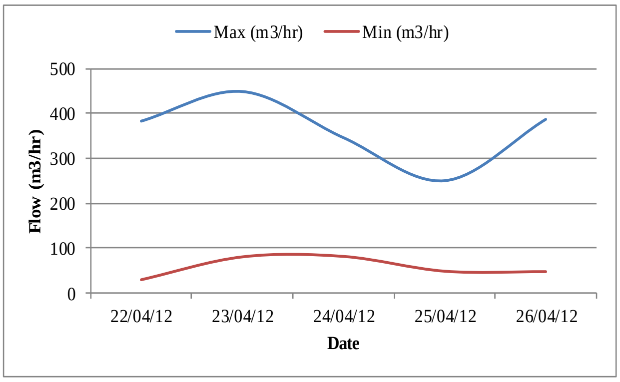

Figure 3. Flow into the Belvedere DMA

Table 2. Water leakage computation using SANFLOW

Water supply area	Average excess night flow (m^3/hr)	Average monthly Leakage (m^3)	Average zone Daily flow (m^3/hr)	Equivalent monthly supply (m^3)	Estimated water leakage		
					% supply	m^3/conn./ month	l/conn./d
Budiriro	156	112,474	586	42,1959	27	9.85	328
Belvedere	64	46,015	181	130,419	35	24.23	808
Average					33	15.30	510

The South Africa minimum night flow analysis (SANFLOW) model was used to compute leakage estimates as shown in Table 2.

The results for the cumulative minimum night flow method are shown in Figure 4. The models of the two DMAs are fitted on Figure 4. The model for Budiriro is perfectly fitted (R^2=1), while for Belvedere the model is near perfect with R^2=0.9818.

Fitted models in Figure 4 show that the mean minimum night flow for Budiriro is 81 m^3/hour while for Belvedere it is 64.1 m^3/hour. The two fitted models are $Y = 81X + 2.6$ for Budiriro and $Y= 64.1X-22.1$ for Belvedere. The gradient of each fitted model represents the mean minimum night flow over the five day period. The Y- intercept for each line represents the flow measuring inaccuracy and background leakages. The magnitude of the flow measuring inaccuracy for Belevere is higher than that for Budiriro. This can be attributed to the age of the infrastructure in place. Compared with the SANFLOW model, it can be shown that the cumulative minimum night flow method can give good (R^2 = 0.9998) minimum night flow estimates, hence leakage estimates.

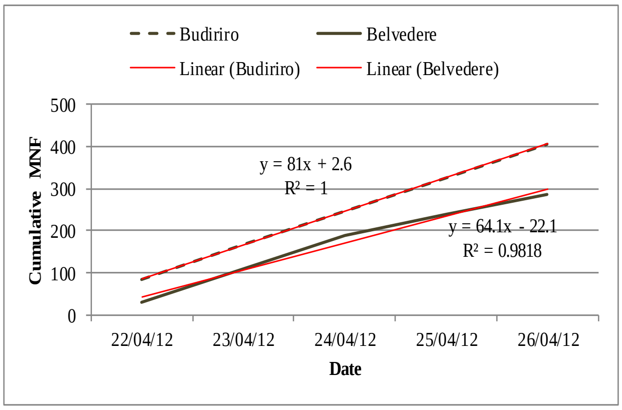

Figure 4. Cumulative minimum night flow

5. Conclusions

The cumulative minimum night flow method is an alternative, indirect way to compute the minimum night flow and the associated water losses that are a result of metering inaccuracies and background losses. The method can be used in conjunction with other minimum night flow analysis methods for better results. Furthermore, extended sampling data can be used to further validate the modelling approach. Further studies could be done to use the model in establishing flow measuring inaccuracies and background leakages.

Acknowledgements

The city of Harare and Mr. Ndunguru are acknowledged for their contributions in this study.

References

[1] Bhaghdadi, A.H.A. and Mansy, H. A. A mathematical model for leak location in pipes. *Applied Mathematical Modelling*, Volume 12, Butterworth Publishers, 1988, 25-30.

[2] CSO. Zimbabwe Population Census Provincial Report Midlands (2012) Zimbabwe National Statistics Agency, Harare, 2012.

[3] Farley, M., Wyeth, G., Ghazali, Z., Istandar, A., and Singh, S. The Manager's Non-Revenue Water Handbook: A Guide to Understanding Water Losses, Washington DC, USA, 2008.

[4] Hunaidi, O. Leakage Management for Water Distribution Infrastructure – Report 1: Results of DMA Experiments in Regina, SK. Canada, National Research Council, 2010.

[5] Lambert, A. Assessing non-revenue water and its components: A practical approach. *Water 21*, IWA Publishing, London, 2003, 51-52.

[6] Lambert, A., and Lalonde, A. Using practical predictions of Economic Intervention Frequency to calculate Short-run Economic Leakage Level, with or without Pressure Management. *Proceedings of IWA Specialised Conference "Leakage 2005"*, Halifax, Nova Scotia, Canada, 2005.

[7] Lambert, A., Brown, T.G., Takizawa, M., and Weimer, D. A Review of Performance Indicators for Real Losses from Water Supply Systems. *AQUA*, Vol. 48 No 6, Dec 1999.

[8] Lambert, A.O. What do we know about Pressure - Leakage Relationships in Distribution Systems? *Proceedings of the IWA Specialised Conference 'System Approach to Leakage Control and Water Distribution Systems Management'*, Brno, Czech Republic, 2001, May 16-18, 89-96.

[9] Liemberger, R. Real Losses and Apparent Losses and the new W392 Guidelines from Germany. Paper presented at the International Water Association Specialist Workshop, Radisson Resort, Gold Coast, Queensland Australia. 24 February 2005.

[10] Makaya, E and Hensel, O. The contribution of leakage water to total water loss in Harare, Zimbabwe, *International Researcher Volume 3 (3)*, 2014.

[11] McKenzie, R. S. Development of a standard approach to evaluate burst and background losses in potable water distribution systems: SANFLOW User Guide, Water Research Commission, South Africa, 1999.

[12] Rizzo, A., Pearson, D., Stephenson, M., and Harper, N. Apparent water loss control: A practical approach. IWA Water Loss Task Force, *Water 21*, 2004, Vol. 6 (3).

[13] Seago, C., Bhagwan, J., and McKenzie, R. Benchmarking leakage from water reticulation systems in South Africa. *Water SA*, 2004, Vol. 30 (5), 25-32.

[14] Thornton J., Sturm, R., and Kunkel, G. Water Loss Control, mcGraw-Hill, New York, 2008.

[15] Thornton, J. Best Management Practice 3: System Water Audits and Leak Detection. Review and Recommendations for Change. Technical Report. California, California Urban Water Conservation Council. IWA Publishing, 2005.

[16] Thornton, J., and Lambert, A.O. Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships. Paper to IWA Special Conference "*Leakage 2005*", September 12-14, Halifax, Canada, 2005.