Leveraging Asset Management Data for Energy Recovery and Leakage Reduction

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Abstract Excess pressure and increases in pressure within water distribution systems correlate directly to increased water losses from pipe leakages. Pressure management in water distribution systems, is one of the most influential, most important and most cost-effective interventions that can be implemented in order to reduce leakage. Excess pressure available in water distribution systems can be used as a renewable, low cost clean energy alternative for energy production with no significant environmental impacts. Similar to the use of PRVs, hydraulic energy recovery devices can be used to reduce excess pressure in a water network, but with the added benefit of converting the excess pressure into electric power rather than to dissipate the energy. Asset management systems, inclusive of asset management plans and asset registers, provides unabridged information on water distribution systems with regards to spatial, technical, operational and financial data. Analysis of this data with respect to energy recovery highlights the hidden opportunities. The energy consumption in urban water supply and distribution systems represents 7% of the world's energy consumption. The paper investigates and proposes the leveraging of asset management data for optimizing pressure management to enable maximum energy recovery and reduce the leakage rate from the system. Energy recovery decreases the carbon foot-print of the water distribution system while simultaneously either generating a stream of revenue for the operator or resulting in an energy cost saving. This increase in revenue or cost saving impacts on the dynamic of an asset management plan and provides for a more sustainable system.

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1 Introduction

The four widely excepted fundamental management practices for leakage reduction (LR) or the constraint of physical losses from water distribution systems (WDS) are pressure management, speed and quality of repair of existing leaks, active leakage control (ALC), and asset management (AM) (Samir, et al., 2017). This paper demonstrates the potential of leveraging the asset management data (AMD) to identify areas in which to implement pressure management through conduit hydropower installations. The conduit hydropower installation not only serves as a pressure management practice but recovers energy from the WDS.

The South African Water Services Act (WSA) requires every municipality to have an asset management plan (AMP). Both the Department of Water and Sanitation (DWS) and the Institute of Municipal Engineering of Southern Africa (IMESA) have developed practices to assist municipalities to compile and comply with the AM requirements of the WSA (Van Zyl, 2014). Similarities in the steps of AMP development as proposed by DWS and IMESA is described in Table 1.

Table 1- Development of an AMP as proposed by DWS and IMESA (Van Zyl, 2014).

Phase	**DWS**	**IMESA**
Technical assessment	1. Asset register	1. Asset register
	2. Condition Assessment	2. Condition Assessment
		3. Remaining Useful Life
Financial assessment	3. Current & future needs	4. Levels of service & demand
	4. Costing analysis	5. Valuation & Life cycle cost
		6. Business risk exposure
Asset management practices	5. Operational plan	7. Operation & Maintenance plans
		8. Capital investment validation
	6. Maintenance plan	9. Future expenditure model & Funding
		10. AMP to suit budget

In 2014 the ISO 5500x series of standards were published and ushered in a new era for AM. Soon after the South African Bureau of Standards followed suit and published SANS 5500x (Boshoff & Childs, 2016). ISO 5500x defines AM as the coordinated activity to deliver value from assets. Using energy recovery (ER) from WDS for pressure management delivers value from assets through direct energy cost savings and economic and socio-economic benefits resulting from LR. ER should therefore form part of AMPs where viable potential within the WDS exists.

Since the late 1970s it has been widely recognised that pressure has a fundamental influence on average leakage rates within WDS and that leakages can be reduced by limiting operating pressures. Increasing energy costs has guided pressure management controls in water networks from using pressure reducing valves (PRVs) towards incorporating hydro turbines to utilize pressure dissipation as a mechanism for ER from the system. Tricarico et al. (2014) highlights the potential revenue or cost saving from ER while simultaneously reducing leakages with the WDS.

Each step in the AMP development process from Table 1 provides data that can be leveraged to obtain a model for ER within the WDS. The method in which this data is processed to identify potential pressure management zones suitable for ER; the potential LR from pressure management through ER in these zones; and how ER improves the reliability of the WDS, is described below.

2 Asset management data

The concept of leveraging AMD centres on the utilization of existing, measured and documented data to add ER and LR potential to the AMP value chain. The flow of AMD in the ER and LR process is shown in Figure 1.

Spatial data of linear and point components within the AR forms the layout of the hydraulic model for the specific section under investigation. Data from the AMP with regards to customer profiles and levels of service (LOS) populates the flow requirements within the hydraulic model. The variables that influences the hydraulic behaviour of the system are derived from data extrapolated from the condition assessment of the components within the AR as outlined in the AMP. AMD relating to a specific section is thus consolidated into a hydraulic model, which can calculate potential excess pressure within a system (or section thereof) and highlight an opportunity for ER as explained in Section 4.

The condition assessment of the section under investigation in terms of unaccounted for water (UFW) is used to calibrate a leakage model. Additional information on system hydraulics such as pressure and flow can be obtained through installed telemetry used in preventative maintenance regimes described within the AMP. Additional information from telemetry increases the confidence rating of the leakage model. Pressure and flow output from the hydraulic model relating to ER potential is used in conjunction with the calibrated leakage model to calculate the potential for LR from ER, as discussed in Section 3.

3 Leakage reduction

The International Water Association (IWA) and the American Water Works Association (AWWA) recommend the Infrastructure Leakage Index (ILI) as the most detailed performance indicator for nonrevenue water (NRW) and real operational losses. The ILI is the dimensionless ratio between the current annual real losses (CARL) and the unavoidable annual real losses (UARL) within a system. The UARL is the lowest technically achievable annual real losses and can be calculated using Equation 1 (Samir, et al., 2017).

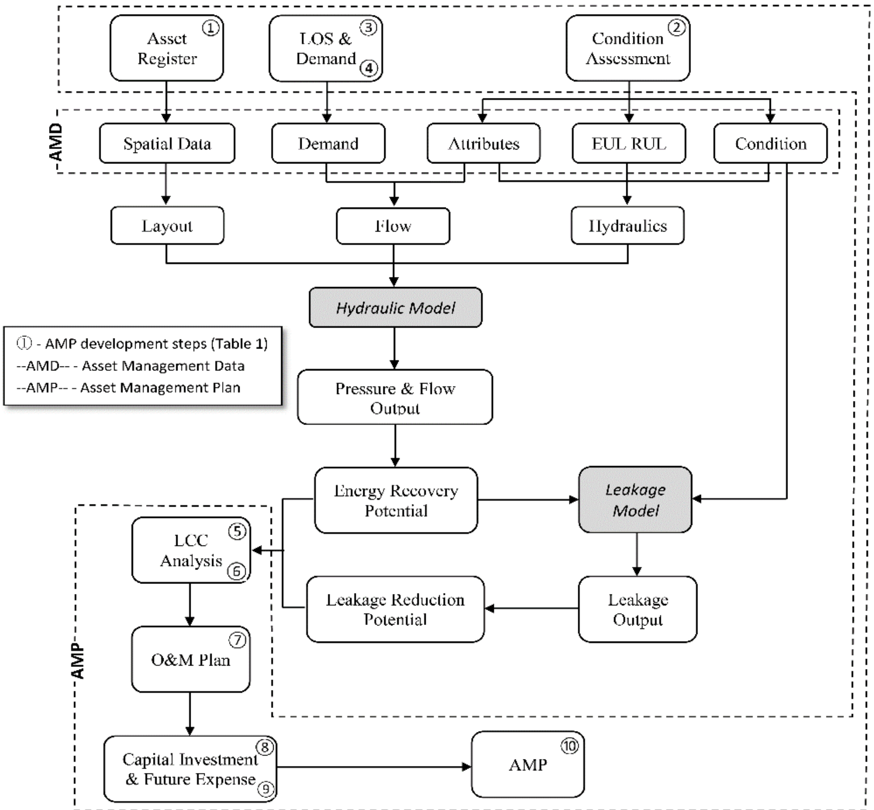

Figure 1 - The flow of asset management data in the ER and LR process.

$$UARL = (18L_m + 0.8N_c + 25L_P) \times H \qquad \textit{Equation 1}$$

Where L_m = mains length (km); N_c = number of service connections; L_p = the total length of underground pipe between the edge of the street and customer meters (km); H = average operating pressure (m).

Liemberger (2010) developed a physical losses assessment to classify leakage levels in both developed and developing countries into 5 categories as shown in Table 2. Pressure has a fundamental influence on average leakage rates within WDS as leakage is, to an extent, driven by pressure. Leakage volume and new leakage frequency is reduced through the reduction and stabilization of pressure within a WDS. Equation 2, known as the FAVAD equation, is the preferred relationship between leakage and pressure (Kabaasha, et al., 2016).

$$Q = C_d\sqrt{2g}(A_0h^{0.5} + mh^{1.5}) \qquad \textit{Equation 2}$$

Where Q = leakage rate (m^3/s); C_d = discharge coefficient; g = gravitational acceleration (m/s^2); A_0 = initial leak opening without any pressure in the pipe (m^2); h = pressure head (m); m = slope of the pressure area line (m)

The FAVAD equation is used to estimate the leakage from a WDS for any given pressure within the system. The total LR in a WDS is difference in between the current leakage (base scenario) and the estimated leakage after a change in system pressure. The change in pressure for the purposes of this paper refers to the pressure head associated with the ER from the WDS.

Table 2 – Physical Loss Assessment (Liemberger, 2010)(Adapted)

Category	ILI	Description
A1	< 2	Potential for further NRW reductions is small
A2	2-4	Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs
B	4-8	Potential for marked improvements
C	8-16	Poor NRW record
D	> 16	Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority

4 Energy recovery potential

In both a pumped and a gravity WDS, pressure in the system must be lower than the prescribed limit to prevent water losses through leakages and pipe bursts (Gaius-obaseki, 2010). In addition, too little pressure will cause unsatisfactory levels of service to consumers and therefor WDS have limitations for pressure. Leakage volume is reduced though a reduction in pressure within a WDS. The maximum LR potential therefore exists when the pressure within a WDS is reduced to the minimum acceptable operating conditions. Any pressure within a WDS over and above the minimum acceptable operating pressure is potentially excess pressure which could be converted into energy through ER. The residual pressures within South African WDSs should be within the limits shown in Table 3 or specific local authority requirements.

Table 3 - Residual pressure in South African WDS (CSIR, 2005)

Types of Development: Dwelling houses	Minimum head under instantaneous peak demand (m)	Maximum head under zero flow conditions (m)
House connections	24	90
Yard taps + yard tanks	10	90

The typical approaches to pressure control within WDS are to install pressure reducing valves (PRV). Energy dissipated in WDS can be recovered by replacing PRVs with hydro turbines. In South Africa there are 257 municipalities which all own and operate WDSs which can be equipped with hydro turbines for ER and supplement or reduce the requirements for PRVs (Van Dijk, et al., 2012). Whenever excess energy is present within a WDS, hydro turbines can be installed for ER.

To calculate the potential ER from a WDS, the available excess pressure head, along with the associated flow is used. The flow and head available is used in Equation 3 to calculate the ER capacity in certain scenarios. Total potential ER is calculated as the product of the ER capacity and the period over which it occurs.

$$P = \rho g Q H \mu \qquad \textit{Equation 3}$$

Where P = power output (watt), ρ = density of fluid (kg/m^3), g = gravitational acceleration (m/s^2), Q = flow rate (m^3/s), H = available pressure head (m) and μ = turbine system efficiency.

5 Case study – Ext 47, Ekurhuleni, South Africa

The concept of ER and LR through leveraging AMD was tested through a desktop study conducted on a section within the Ekurhuleni Metropolitan Municipality in South Africa, called Extension 47. From the asset register (AR) of Ekurhuleni and Ext 47 data was extracted to construct the layout of the hydraulic model. A combination of data from the condition assessment of assets pertaining to the water supply at Ext 47 were used in calculating the hydraulic characteristics of the model.

Ext 47 is a residential suburb consisting of a development of 107 retirement units. The type of development is classified by the Guidelines for Human Settlement Planning and Design (CSIR, 2005), as dwelling houses (residential zone 1), and has a theoretical annual average daily (AADD) water demand of between 600 and 1200 litres/day based on an erf size of less than 400m^2. The actual demand of Ext 47 was measured during the month of June 2107 and extrapolated to estimate an AADD of 518ℓ/day and correlates closely with the standard guidelines for residential zone 1.Figure 2 shows an extract of the flow measurements recorded at the supply inlet pipe to Ext 47 during the month of June 2017. These measurements along with billing information and estimates within the AMP were used to set up the flow conditions within the hydraulic model.

Figure 2 also indicates a minimum night flow of approximately 0.76m^3/h which is indicative of possible water leakage. This indicative leakage flow along with the NRW calculations within the AMD of the AMP, were used to calculate the ILI of Ext 47 as well as to calibrate the leakage model. Figure 3 shows the graphical representation of the hydraulic model for Ext 47 set up in Epanet, using AMD.

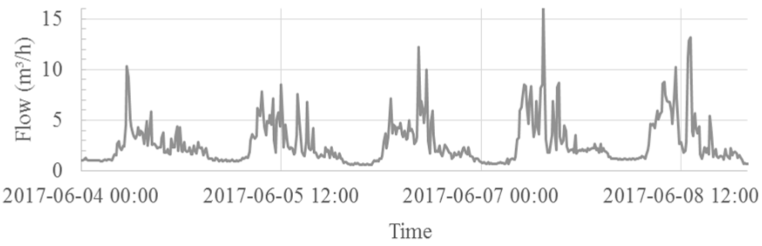

Figure 2 - Ext 47 - Flow measurements - June 2017

6 Results

The UARL and CARL for Ext 47 was calculated as 79ℓ/day/connection and 122ℓ/day/connection respectively, resulting in an ILI of 1.5. According to Table 2 this places Ext 47 in category A1, and highlights that potential for reduction in NRW is small.

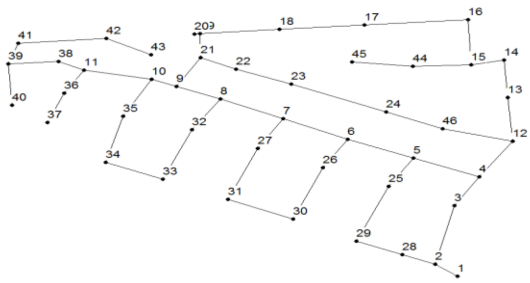

Figure 3 –Ext 47 - Hydraulic Model – Epanet

From the hydraulic model it was evident that the minimum pressure in the system exists at node 43. Reduction in system pressure is therefore limited by node 43. Due to the small extent of Ext 47 the optimum scenario for ER was modelled using a singular location at the main inlet pipe to Ext 47 at node 1. In larger sections a combination of several locations may have the largest impact. The available flow for ER was calculated as the total flow at the main inlet pipe to Ext 47 minus the accumulated leakage rate of 0.76m^3/h. Figure 4 shows the available pressure head and flow for ER for a 24h period as per the average demand pattern calculated from the June 2017 flow data. This graph is an output from the hydraulic model as was used to calculate the total daily ER potential as 5.2kWh.

The leakage model was calibrated using the CARL and the flow and pressure results from the hydraulic model. The leakage model was run using the pressure both before and after potential ER. Results from the model showed an average reduction in leakage from 122ℓ/day/connection to 31ℓ/day/connection. This constitutes a 74% reduction in UFW within Ext 47 when ER is used for LR. The ER and LR for Ext 47 as per the study amounts to an average annual saving of R61 650, based on electricity and water unit tariffs.

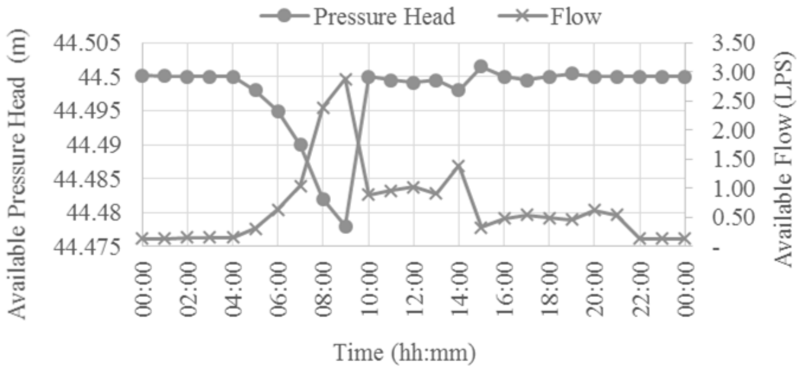

Figure 4 - Total available pressure head and flow for ER from Ext 47

7 Conclusions

The following conclusion and recommendations emanated from the study:

- AMD can be leveraged to highlight opportunities for ER and LR in municipal environments.
- By combining LR and ER, a more sustainable system can be obtained, recovering 5kWh of energy from the WDS in Ext 47 and a 74% reduction in UFW.
- The ER and LR is not one directly a product of the other, but linked through the dissipation of excess energy in the system.
- It is recommended that larger areas be included in the study to investigate the impact of higher demands on ER and LR.
- It is recommended that the study be developed into an add-in tool to identify and spatially report ER and LR through existing AM software.

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