Water infrastructure asset management addressing the SDGs through energy recovery

Gideon Bonthuys Pr Eng
i@Consulting
deon@iatconsulting.co.za

Petrus Blom GPr GISc
i@Consulting
petrus@iatconsulting.co.za

Marco van Dijk Pr Eng
Department of Civil Engineering
University of Pretoria
marco.vandijk@up.ac.za

INTRODUCTION

Loots *et al* (2014) stated that "conduit hydropower is the 'low-hanging fruit' in terms of viable renewable energy which could be developed". The study by Loots *et al* (2014) was sparked, like various other studies at the time, by the continuing energy challenge faced by South Africans. The challenge started with rolling black-outs or load-shedding in 2008 (Bonthuys *et al* 2016a) when total electricity demand started encroaching on the current supply capacity, resulting in the construction of Kusile, Medupi and Ingula to add 10 000 megawatts of capacity to the national grid (South African Government 2015). The study by Loots *et al* (2014) indicated that within the City of Tshwane alone, at only the ten most feasible sites, there exists an annual conduit hydropower potential of 10 GWh.

Conduit hydropower, or inline hydropower, is essentially a method of energy recovery from a water supply or distribution system. Excess pressure energy, normally dissipated through pressure-reducing stations, are recovered by installing a hydro turbine which dissipates the excess pressure energy by transforming it to electrical energy. This reduction in excess pressure within the water supply and distribution system also has the potential of reducing background leakages within the system. This potential for leakage reduction is similar to that of conventional pressure release valves (PRVs), but with the added environmental and financial benefits which accompany energy recovery. Leakage reduction has become of critical importance following severe droughts that have plagued areas such as the Western Cape after poor rainfall during the 2015, 2016 and 2017 rainy seasons.

Energy recovery through conduit hydropower has the potential to help lessen the impact of both the energy and water crises in South Africa. Energy recovery and leakage reduction also have the potential to increase the sustainability of municipal infrastructure and therefore address four of the 17 Sustainable Development Goals (SDGs) (Figure 1).

This begs the question, seeing that conduit hydropower or energy recovery is the low-hanging fruit, why then are none of the municipalities feasting?

Although awareness of the potential for energy recovery within municipal water supply and distribution systems exists, there is a lack of knowledge regarding the extent and location of such potential. Municipal infrastructure asset registers (ARs) and asset management plans (AMPs), which contain water supply and distribution system data, should be leveraged to identify preliminary potential for energy recovery and leakage reduction.

ASSET MANAGEMENT

In terms of the Public Finance Management Act (PFMA) and the Municipal Finance Management Act (MFMA), the accounting officer is responsible for managing the assets and liabilities of the municipality, in part by ensuring that the organisation has and maintains a management, accounting and information system that accounts for its assets and liabilities. Central to these systems is the AR, which is a database that contains all the relevant data on all the significant infrastructure assets owned by the organisation. The AR supports an effective AMP.

Every South African municipality is required by the Water Services Act (WSA) to have an AMP for their water and sanitation infrastructure. The Department of Water and Sanitation (DWS) and the Institute of Municipal Engineering of Southern Africa (IMESA) have developed practices to assist municipalities with

Figure 1 SDGs addressed by energy recovery and leakage reduction

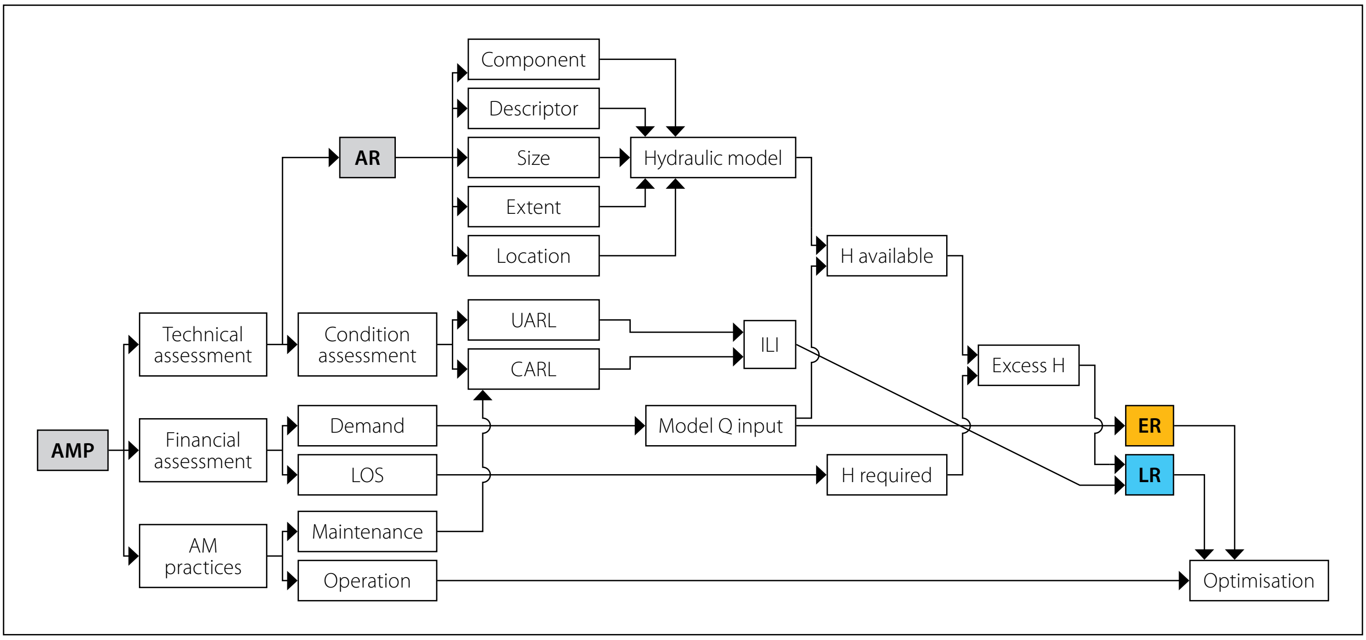

Figure 2 Energy recovery and leakage reduction potential from asset management data

compliance to the requirements of the WSA (Van Zyl 2014). These practices divide the development of an AMP into three phases, namely technical assessment, financial assessment and asset management practices. The technical assessment phase includes the compilation of an AR.

Other than the initiatives by the DWS there are several other national initiatives that can broadly be classed as either regulatory or supportive. The golden thread through all the initiatives, including the focus of asset management for energy recovery and leakage reduction, is the development of a proper AR and AMP.

In 2014 the ISO 5500x series of standards were published. ISO 5500x defines asset management as the coordinated activity to deliver value from assets (Boshoff & Childs 2016). Asset management data contained in both the AMP and the AR is leveraged to identify preliminary potential for energy recovery and leakage reduction (Figure 2). Energy recovery and leakage reduction deliver value from assets through both economic and socio-economic benefits, thereby adding to the asset management value chain.

ENERGY RECOVERY POTENTIAL

Water supply and distribution systems have limits for operating pressures. Too high pressures increase water losses through leakages and have the potential to cause pipe bursts (Gaius-obaseki 2010), whereas too low pressures provide unsatisfactory levels of service to consumers (McNabola *et al* 2011).

Topography, restrictions in the selection of component sizes, and varying demand patterns have the potential to cause excess energy within pressurised water supply and distribution systems (Loots 2013). The conventional control approach is to dissipate excess pressures within the system through installed PRVs. Excess energy, however, can be recovered by installing hydro turbines. Any pressure over and above the minimum operating pressure of a specific system is potentially excess pressure which can be converted into energy through energy recovery.

In South Africa there are 257 municipalities which all own and operate water supply and distribution systems that can be equipped with hydro turbines for energy recovery (Van Dijk *et al* 2012). As an example the City of Polokwane was used for this article. As per Figure 2 the asset management data sourced from the AMP and AR was used to set up a hydraulic model. The hydraulic model in turn is used to perform a preliminary estimation for the excess pressure in the water distribution system of the Polokwane/Seshego regional segment within the Polokwane Local Municipality. Due to the intricacy of the water distribution system within the Polokwane/Seshego regional segment, and to simplify for illustration purposes, a section of the regional segment was isolated as a District Metered Area (DMA) in Polokwane Central. Figure 4 shows the preliminary calculated excess pressure. It is important to note that this pressure is calculated with several assumptions made in terms of the DMA and it is recommended that the model be properly calibrated. From the basic mathematical relationship for the potential energy recovery from hydro-turbines, the two important parameters are pressure and available flow (Bonthuys *et al* 2016b). The calculated excess pressure, above the minimum prescribed operating pressures, along with the associated flows from the hydraulic model, was used to estimate the energy recovery potential from the isolated Polokwane Central DMA with Equation 1 and an algorithm developed by Samora *et al* (2016) (Figure 3). Since the demand is not constant, the excess pressure at any given node will vary in time. The minimum potential for energy recovery and leakage reduction will occur at the lowest excess pressure within the system. For the analysis relating to this article the timestep with the lowest accumulative excess pressure within the system was taken as the steady state on which to base energy recovery and

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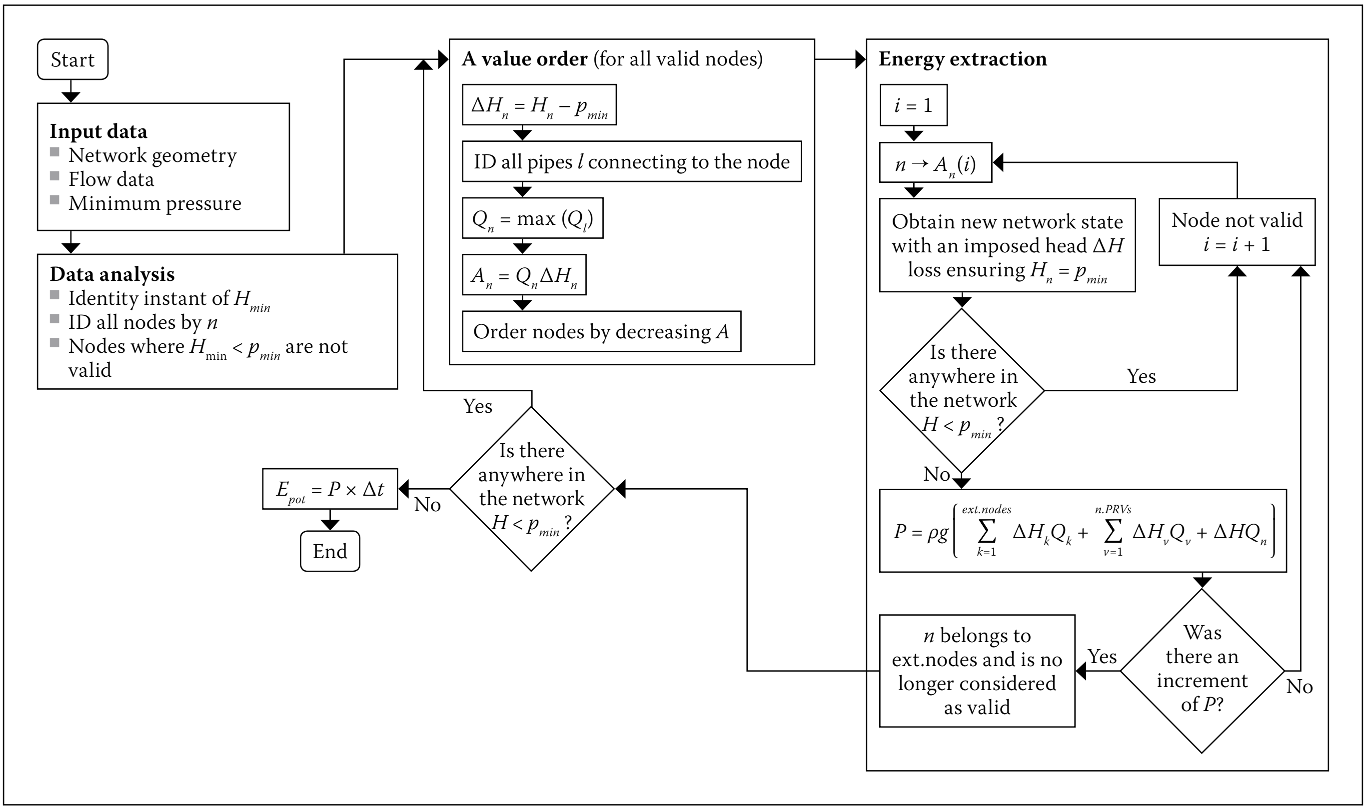

Figure 3 Energy recovery potential algorithm (Samora *et al* 2016)

leakage reduction potential. The turbine system efficiency was estimated at 70%. Figures 4 and 5 show the calculated excess pressure and estimated energy recovery potential from the isolated Polokwane Central DMA after 10 iterations of the proposed algorithm.

$$P = \rho g Q H \mu \qquad (1)$$

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)

μ = turbine system efficiency.

LEAKAGE REDUCTION POTENTIAL

It is widely recognised that leakages depend on and are directly proportional to pressure (Gupta *et al* 2016). Any reduction in pressure, i.e. through energy recovery, therefore results in a reduction in leakages from a system. An equation for the relationship between leakage and pressure is the Fixed and Variable Area Discharge (FAVAD) equation (Equation 2). To utilise the FAVAD equation certain leakage parameters need to be known and can be derived from the Current Annual Real Losses (CARL) of the system.

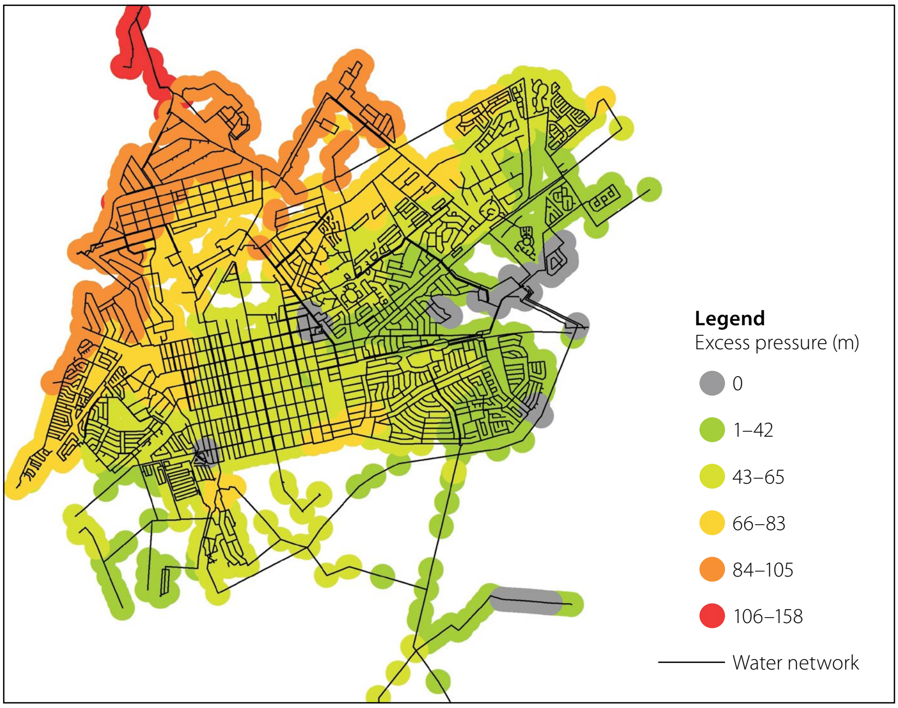

Figure 4 Excess pressure in the Polokwane Central DMA

$$Q = C_d \sqrt{2g}(A_0 h^{0.5} + m h^{1.5}) \qquad (2)$$

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 CARL of a system is the physical water losses from the pressurised system up to the point of customer use and is calculated as the system input less the authorised consumption and the apparent losses (McKenzie *et al* 2002). The CARL, along with the Unavoidable Annual Real Losses (UARL), is used to calculate the International Leakage Index (ILI). The ILI is the dimensionless

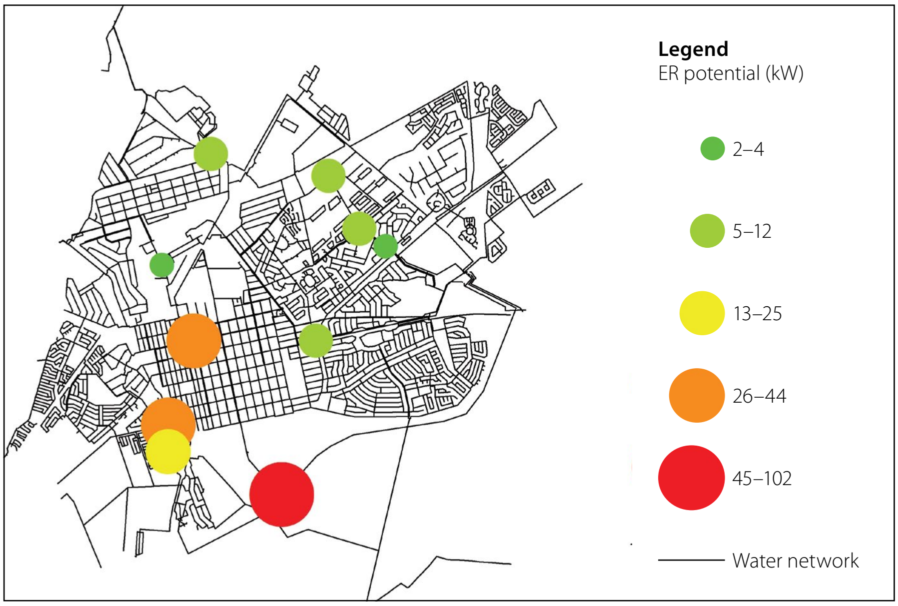

Figure 5 Energy recovery potential in the Polokwane Central DMA – after 10 iterations

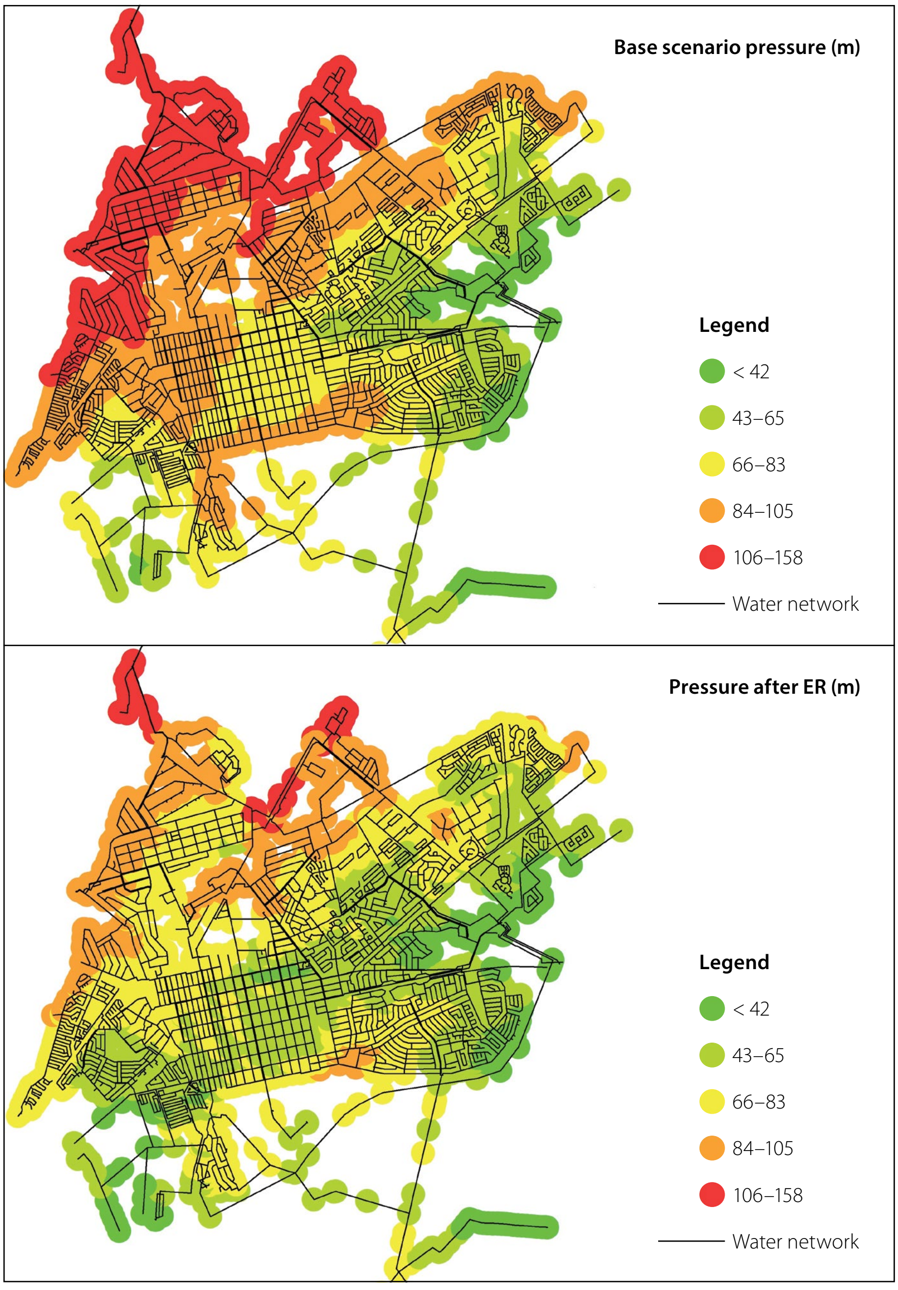

Figure 6 Polokwane Central DMA operating pressure distribution before and after energy recovery

ratio between the CARL and the UARL within a system. The UARL is the lowest technically achievable annual real losses and can be calculated using Equation 3 (Samir *et al* 2017).

$$UARL = (18L_m + 0.8\,N_c + 25\,L_p) \times H \qquad (3)$$

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).

The UARL can be used as a preliminary indication of leakage reduction potential where no further information on the CARL within the system is available. A reduction in the system pressure through energy recovery will cause a reduction in both the CARL and the UARL in the system as they are both pressure-dependent. The UARL of a system is also included in the CARL; therefore reducing the UARL of a system by decreasing the average operating pressure in the system will reduce the CARL.

From Equation 3 the UARL for the isolated Polokwane Central DMA system is calculated as 9.2%. From the Polokwane Water and Sanitation AMP, the UARL and CARL were determined as an average of 8% and 22% respectively between December 2015 and July 2017. The ILI for the Polokwane Central DMA is calculated as 2.4.

Where the parameters of the FAVAD equation can be calibrated using measured data from the system, the estimated losses in the system with flow and head available after energy recovery are calculated and compared to the CARL to show potential leakage reduction. Where UARL is used, the UARL is calculated using available head before and after energy recovery and compared to show potential leakage reduction. Figure 6 shows the isolated Polokwane Central DMA system's operating pressure before and after energy recovery. The average operation pressure before and after energy recovery is 74.5 m and 64.7 m respectively, resulting in a leakage reduction potential, using the UARL as a benchmark, of 14% for the Polokwane Central DMA.

Using the proposed algorithm, along with the developed hydraulic model, showed an energy recovery potential of 264 kW after only 10 iterations, addressing the SDG of affordable and clean energy.

CONCLUSIONS

Using the proposed algorithm, along with the developed hydraulic model, showed an energy recovery potential of 264 kW after only 10 iterations, addressing the SDG of affordable and clean energy.

Analysis of the hydraulic model results before (UARL = 3.5 ML/day) and after energy recovery (UARL = 3.0 ML/day) within the isolated Polokwane Central DMA water supply system resulted in a leakage reduction of 15% based on the UARL.

The UARL as a percentage of the AADD reduced by 1.3% from 9.2% to 7.9%, when comparing the UARL to the modelled AADD of 35 ML/day.

Due to the lack of measured data, the CARL of the system was not calibrated using the FAVAD equation. The CARL for the base scenario before energy recovery was calculated as 22% by the Polokwane Local Municipality. If we assume that the UARL and CARL of the system follow similar patterns, it could be concluded that the energy recovery, as modelled, would also decrease the CARL by 15% from 22% to 19% of the AADD.

This results in a leakage reduction in potable water supply of 3% within the Polokwane Central DMA by implementing energy recovery, thereby addressing the SDG of clean water.

The monetary value of a 3% reduction in water leakages, paired with 264 kW of energy recovery potential, amounts to approximately R6.1 million per annum. This addresses to an extent both the SDG on industry, innovation and infrastructure, and the SDG on sustainable cities and communities

It becomes clear that asset management data contained in both the AMP and the AR of a municipality can be leveraged to identify preliminary potential for energy recovery and leakage reduction. It has been known for a while, and it is undisputed, that energy recovery or conduit hydropower is the low-hanging fruit in terms of renewable energy within local municipalities. It is, however, also true that energy recovery has the potential to reduce leakages within a municipal water supply system. The problem remains the lack of knowledge of the extent and location of this energy recovery and leakage reduction potential. Asset management can bridge this gap.

Following these conclusions, it is recommended that studies be continued in calibrating the CARL of municipal systems like the Polokwane Central DMA to fully understand the effect that energy recovery has on leakage within the system. It is therefore also recommended that procedures be put in place within local municipalities to better measure and monitor flow and pressure within their water supply systems.

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DISCLAIMER

The output of the research conducted and reported in this article is generated from hydraulic models developed from the City of Polokwane's Water Supply Infrastructure Asset Register and Asset Management Plans. These models incorporate assumptions informed by demand modelling and have not been calibrated to any specific time, date or scenario of measured data from the City of Polokwane's Water Supply Networks. This research does not reflect or constitute the views of the Polokwane Local Municipality or any individuals affiliated with the Polokwane Local Municipality. ☐

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