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Water Losses and the Potential of Reducing System Pressure: A Case Study in Trinidad

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Abstract: *Non-revenue water (NRW) is a concern for the Water and Sewerage Authority of Trinidad and Tobago (WASA), as it is estimated at about 45%. Although WASA has introduced District Metered Areas (DMAs), a low priority has been given to pressure management, which may be resulting in significant water losses, poor service and increased operational costs. This paper analyses the minimum night flow measurements to estimate NRW. The results show that at Maloney and Maraval, NRW is estimated at 37% to 57 %, respectively. By simulating pressure reductions in the DMAs such that at least 20m of pressure is achieved at the highest elevations in the DMAs, it is considered possible to reduce NRW by over 70% and at the same time reduce the frequency of burst pipes by over 40%. The water saved in both districts would provide water to more than 1,000 additional customers. Greater emphasis on pressure management through the implementation of DMA would mean that more water would be available to the Water and Sewerage Authority, and this water would be able to generate revenue.*

Keywords: *Non revenue water, district metered areas, pressure management*

1. Introduction

Globally, freshwater demand is rising and such water resources are diminishing. Water is vital to human survival, health and dignity and it is a fundamental resource for human and economic development. The availability of fresh water is directly linked to the welfare and prosperity of nations. The lack of access to water could lead to starvation, disease, political instability and even armed conflict; and failure to take action could have broad and grave consequences (Rogers, 2008). Water crises, long seen as a problem of only the poorest, are increasingly affecting some of the world's wealthiest nations (WWF, 2006). It is expected that water scarcity would become more commonplace, mainly because the world's population is increasing, the standards of living are improving and global climate change is exacerbating aridity and reducing supply in many regions (Dickie, 2006; Rogers, 2008).

The 2010 drought in the Caribbean showed how quickly drought conditions and water shortages could become an emergency. The problems associated with these drought conditions are exacerbated by the underground damage to water distribution systems that go mostly undetected. Therefore, large volumes of clean water are lost daily through a failing distribution system of old and leaking pipes. These losses which form the main component of non-revenue water (NRW) do not only increase the severity of water shortages resulting from the loss of millions of gallons of water that have been treated to high drinking quality standards, but could also damage surrounding properties and create public health and safety issues. Further, these losses result in reduced revenues for water utility companies and ultimately translate to higher operational cost per unit of water produced by these companies. Additionally, such losses result in energy wastage, since a considerable amount of energy is used to extract, treat and pump potable water. Consequently, there are negative impacts on the efforts by countries and utility companies to adequately respond to minimising the carbon footprint of water supply and to the overall strategy for positively adapting to climate change.

Water loss problems are experienced in both developed and developing countries throughout the world. In many countries, water utility companies are not able to account for large portions of the water they deliver – in some places even above 50%. In the USA, the American Water Works Association estimates that 18% of drinking water is lost each day through leaking pipes and broken water mains. In many older systems, even higher amounts are lost and water efficiency is desperately needed. In Italy, NRW levels range from 15-60% of total system input volumes (Fantozzi, 2009). Overall, over 30% of total water produced for urban uses is either lost through leaks and ruptured pipes occurring in water distribution systems, or is not included in revenue and financing systems (Mounce et al., 2010; Nazif et al., 2010).

In developing Caribbean countries, the challenges to delivering a safe and regular, potable water supply are many—inadequate infrastructure, poor sanitation, and intermittent drought. In some water supply systems in Jamaica NRW ranges from 0% to 80% (Lupo and Erout, 2011), while in Trinidad and Tobago, the Water and Sewage Authority (WASA) estimates that 45% of water is lost annually as NRW (Balkaran and Wyke, 2003). Estimates of NRW in developing countries are placed at about 35% (Kanakoudis and Tsitsifli, 2012). Reducing the high water losses is critical to these countries meeting the Millennium Development Goals on water and sanitation.

The current global water scarcity has the attention of public leaders who are demanding changes to create a sustainable water infrastructure system that protects this valuable resource. The need for efficient use of water resources and reducing water losses cannot be overemphasized. Many strategies have been used in the past to address the issues associated with NWR. The traditional approach for providing adequate water supply has been to invest more in the water sector to increase the production of water, and not to generate programs to reduce the water losses. Consequently, water loss management and leak detection have been treated as an afterthought in network operations.

Currently, water loss strategies have become central to the operation of distribution networks. This has resulted from a combination of global water shortages, privatisation and regulations that make water companies increasingly accountable to customers, shareholders and regulators. The paradigm shift recognises that the most economic and ecological solution is to reduce the water losses in the distribution systems and not permanently increase the water production.

In applying a solution that seeks to increase production, the structure of the pipeline system, originally designed for much smaller output volumes, remains the same, further contributing to damages in the underground system. In particular, the valves which have to regulate flow and pressure to maintain a constant supply of potable water cannot function adequately. If those valves cannot be controlled exactly, this will lead to high pressure differences in the piping system, to pipe bursts, and, ultimately, to a complete collapse of the entire distribution system.

In Trinidad, WASA constantly advises customers on the importance of saving water. WASA invests in public education and awareness through the media. Customers are advised on ways that they should save water and how to prevent water losses. However, WASA needs to also invest in other strategies to reduce water losses.

An important step in addressing this major problem of NRW is to install adequate measurement tools that could show where the underground problems are located and how conditions of the distribution system are changing. This is facilitated through the use of District Metered Areas (DMAs) which are used for pressure control. In 2002 under the Severn Trent Management, WASA reorganised its Water Loss Control Department and introduced the DMA concept. In 2005, the Maraval and Maloney DMAs were conceptualized and established. The reduction target was set by the Authority for moving from NRW from 55% in 2007 to 45% by 2011. To date, the target has not been achieved.

The paper reports on the potential of DMA and pressure management at the Maraval and Maloney sites using a template from GTZ-VAG-Public-Private-Partnership (2009). The paper estimates NRW for these sites using minimum night flow analyses and the potential benefits of pressure management in burst pipe and the accompanying reduction in water losses, by applying the pressure leakage relationship by Lambert (2001) and considers potential savings to WASA.

2. Leakage management and District Metered Areas

All water supply distribution networks suffer some leakage. While zero leakage is the ultimate goal, it is generally accepted that it is not technically possible, or economically viable, to achieve zero leakage. Water utility companies, however, need to implement water loss control systems which would allow them to provide accountability in their operation by reliably auditing their water supplies and implementing controls to minimize system losses. In designing and implementing water loss control systems, water utility companies should set targets based on achieving or maintaining a sustainable economic level of leakage (SELL).

During the past three decades, significant progress has been made in the management of system leakage in an attempt to address the problem of NRW. Ideally, consideration should be given to a holistic approach to leakage control, by considering the components of leakage and selecting appropriate policies (CIWEM, 2012).

In the United Kingdom (UK), a concept DMA management was introduced in the water industry in the early 1980's as documented in "Report 26 Leakage Control Policy and Practice" (UK WAA, 1980). A DMA is defined as a discrete area of a distribution system, typically created by the closure of valves or a complete disconnection of pipe networks in which the quantities of water entering and leaving the area are metered (see Figure 1). Using this set-up, the flow could be analysed in order to quantify the level of leakage particularly through the use of night flow minimums which allows for greater sensitivity in determining if consumption has progressively or suddenly increased, thereby indicating undetected leakage or a rupture (Loveday and Dixon, 2005). Several studies (Hunaidi and Brothers, 2007; Loureiro et al., 2010; Karadirek et al., 2012) have measured and analyzed night flow and pressure of residential DMAs, so as to evaluate NRW level and losses in water distribution networks. Minimum night flow analysis is based on a principle that residential demand generally decreased at night, and the maximum decrease was observed from 2:00 am to 4:00 am (Tabesh et al., 2009; Karadirek et al., 2012). Good flow metering also helps the management of the utility company to understand NRW.

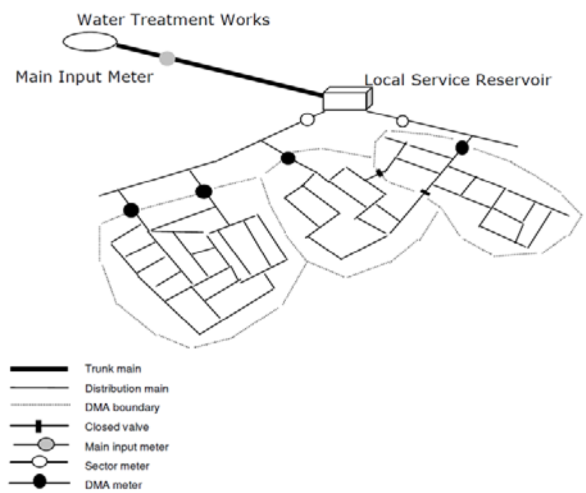

Figure 1. Typical DMA
Source: IWA (2007)

Lowering pressure in a DMA to reduce the amount of water lost in burst pipes has been understood for some time (IWA, 2007). However, high leakage also lowers pressure--a phenomenon that is less understood. The pressure, flow and leakage relationship is therefore not simple. Pressure rises when leaks are repaired and increases the risk of new leaks forming. IWA (2007) proposes as a solution, the installation of a pressure reducing valve that compensates automatically for increase in pressure, and which ensures that lower leakage levels could be maintained in the future. In any case, pressure reducing values should be set to ensure a pressure head of 15m at the house connection.

A systematic reduction of pressure in the main water supply system enables the utility companies to reduce their water loss to sustainable economic levels. Although there has been a substantial degree of research into methods of determining current and future SELL, there is still insufficient clarity as to the methodologies for deriving SELL, in both the short and longr term, for them to be approved for utilisation in the UK (CIWEM, 2012).

Implementation of DMA and pressure management has produced many success stories. In a recent case study in Italy, in which 93% of a 4850Km water mains and network was tested, the infrastructure leakage index was reduced from 3.9 to 3.0 over the period of 2005 to 2008 while there was a reduction in water consumption of 16% and a 20% reduction in the number of repairs to burst pipes (Fantozzi, 2009). In one case in the Metro, Manila, Philippines, with a population of 9 million, using a holistic approach driven by DMAs and pressure management, a utility company was able to reduce NRW from 66% to 42%, and provide water for an additional 1.8 million people over a 4-year period (Miya Arison Group 2012). In England and Wales, DMA management has reduced leakage significantly, and in one case nearly 50% reduction has been recorded over a 10-year period (Morrison and Tooms, 2007). While it must be acknowledged, that pressure management is not the answer in every case, it is often one of the most cost effective measures to reduce leakage and wastage (Mckenzie and Wegelin, 2009).

In many developing countries, the concept of DMA and pressure management has been implemented by foreign specialists through external institutions. Typically, the success is short-term as with the departure of the specialists, maintenance of the system is poorly carried out resulting in unsustainability of DMAs (Loveday and Dixon, 2005). Long-term success of DMAs and pressure management is constrained by institutional factors (such as weak governance and lack of political will), policy issues (such as low tariffs; financial constraints), and technical factors (such as gaps in the technical capability of operators; insufficient and inappropriate technology; and insufficient and misdirected training).

3. Study Methodology

3.1 Site Description

The schematics of the two DMA sites at Maloney and Maraval are shown in Figures 2 and 3. Overall, WASA manages for approximately 6000 km of underground pipes. On average, over 30,000 leaks are repaired and approximately 100 km of water mains are replaced annually. The basic characteristics of the DMAs are shown in Table 1. The night time residential allocation of 6 L/p/h is the value used by WASA in estimating losses. However, if this value is too low, then the losses in the system would be exaggerated. Figures 2 and 3 show the schematic of Maloney DMA and the Maraval DMA, respectively.

Table 1. Characteristics of DMAs

	Maloney	Maraval
No of residential properties	2,954	2,865
No of non-residential properties	0	10
Night time residential allocation (L/p/h)	6	6

3.2 Methods

The DMAs were evaluated for their potential in implementing pressure management using the suggested guidelines of GTZ-VAG-Public-Private-Partnership (2009). GTZ, a German Government owned enterprise, is involved in international cooperation for sustainable

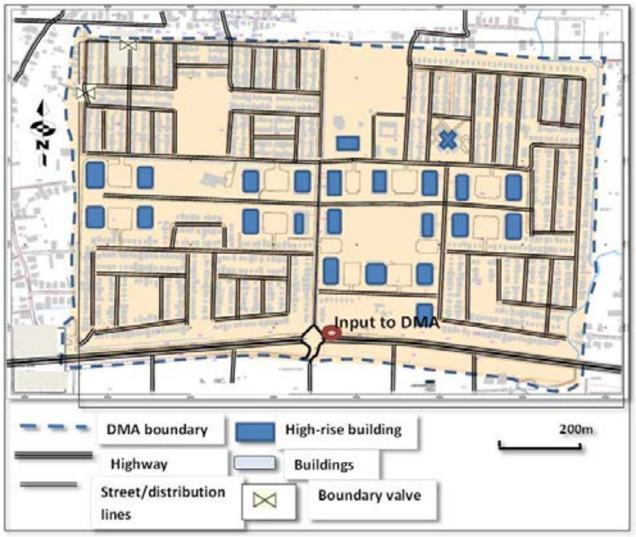

Figure 2. Schematic of Maloney DMA

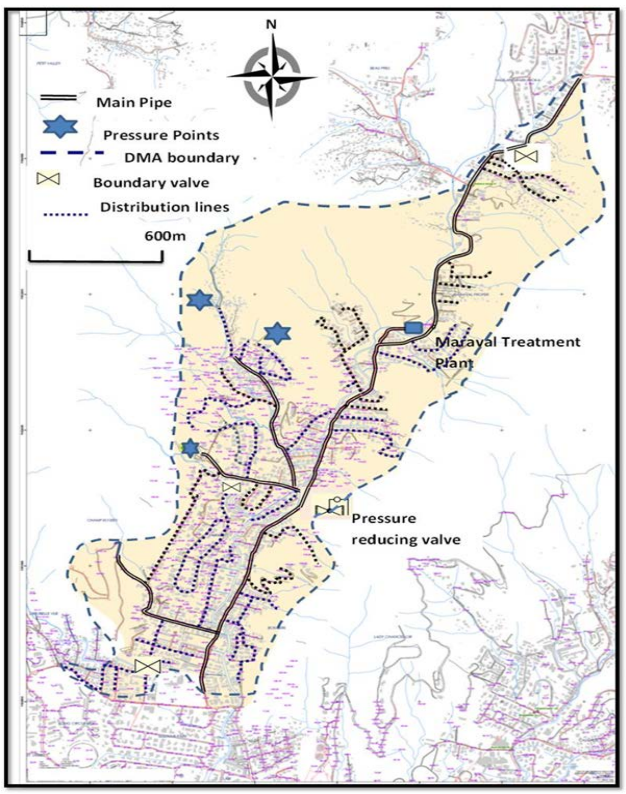

Figure 3. The Maraval DMA (shaded)

development with worldwide operations: As such, the guidelines were developed for use in developing countries, hence the guidelines are assumed to have relevance to Trinidad and Tobago. Further, the UN-Water Decade Programme on Capacity Development (UNW-DPC), which is involved in worldwide training on water loss reduction, supports this approach (GFMECD, 2011).

The integrity of the DMA was verified by ensuring that the boundary valves functioned properly. Flow and pressure were monitored every 15 miutes for four day periods. Automatic and continuous monitoring were achieved through the implementation of DMA management using Radcom flow data loggers at the entry points of the Maraval and Maloney District Metered Areas. Average minimum night flows were determined for the months of March, August and September 2013 by considering flows during 2.00pm and 4.00pm. The minimum night flow is the lowest into a DMA on each night and in most cases consists of leakage, with relatively small quantities of consumer use.

Average NRW was estimated in each DMA using the minimum night flow data and the characteristics of the distribution network. Background leakage in the DMAs was estimated using the model by Lambert et al. (1999). This value is important to estimate recoverable leakage. NRW is the difference of the flow entering the system (entry point of District Metered Areas) minus the total demand (domestic metered, domestic unmetered, non-domestic metered properties).

Topographical maps were used to develop a hydraulic profile of the systems. The highest elevations in the Maraval and Maloney District Metered Areas with the minimum pressure at those points were recorded. Radcom Pressure loggers which were installed at the entry point and at the highest elevation in the Maloney DMA and the two highest points in the Maraval DMA were programmed to collect data at 15 minute intervals. Radwin software (UK) was used to download pressure data.

The potential reduction in losses was computed using the pressure-leakage relationship by applying the pressure leakage relationship by Lambert (2001), as shown in Equation 1.

$$L_1/L_0 = (P_1/P_0)^{N1} \quad \text{.... (1)}$$

Where,
L = leakage,
P = pressure and
N1 = an exponent that influences reliability of leakage.

The N1 values were estimated using pressure readings and estimated losses from the minimum night flow values. The reduction in the number of bursts is estimated using the work of Thornton and Lambert (2006)

4. Results and Discussions

Table 2 shows a summary of the status of DMAs at Maloney and Maraval based on a suggested evaluation requirement list (GTZ-VAG-Public-Private-Partnership 2009) for the potential of pressure management. At both DMAs, based on the GTZ-VAG criteria, pressure management is likely to be economically efficient. Satisfying the GTZ-VAG criteria should be considered a

Table 2. Conditions at DMAs for good potential for implementing pressure management

Condition	Requirement	Maloney	Maraval
Max pressure less min pressure (m)	>10	31.6	63.3
Max inflow/min inflow	<10	2.92	2.95
Available water resources	Water distribution with fully pressurized pipes	yes	yes
Management	Clear commitment and political will	yes	yes
House connections	>2000	2954	2865
Average age of pipelines (years)	>15	>40	>40
Frequency of burst pipes	regular	regular	regular
Real water losses	>15%	>15%*	>15%
Losses (L/day/connection)	200	587	1834

preliminary check as economical and ecological cost/ benefit analyses must also be evaluated.

Since in both study sites all customers are not metered, estimates based only on water balances are not likely to be reliable. Therefore, assessment of leakage by nigh flow measurements is important. Figures 4 and 5 show samples of pressure and flow readings at the entry to the DMAs, respectively. It is observed that the highest pressures occurred during minimum flows, hence an assumption that the greatest leakage is during the minimum night flow period is applicable. During early hours of the morning when customer use is at a minimum, system leakage is at a maximum due to higher average pressures.

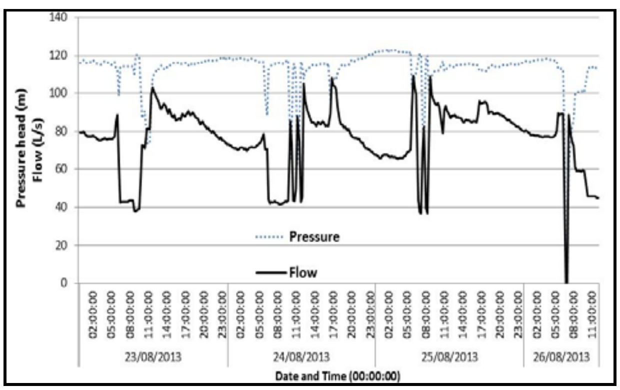

Figure 4. Typical flow and pressure readings for Maraval DMA

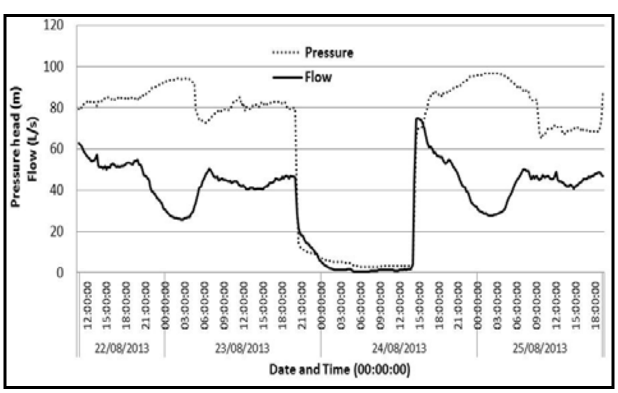

Figure 5. Typical flow and pressure readings for Maloney

Using minimum night flow measurements, taken during the times 1.00am to 4.00am for 3 day periods during the months of March, August and September 2013, the NRW were estimated at 25.7L/s and 61.97L/s for Maloney and Maraval respectively. Based on these estimates, the NRW were estimated at 36.5 % and 56.43% for the Maloney and Maraval DMAs respectively (see Table 3). The estimated NRW includes both a ‘utility leakage’ that is losses up to the delivery point on service connections and a ‘customer leakage’ for losses beyond the delivery point. In the case of the research sites, as metering is absent, all losses are assumed to be utility leakage.

Table 3. The flow and pressure conditions in the DMAs

Conditions in DMA	Maloney	Maraval
Average daily flow measured (l/s)	44.8	67.1
Minimum night flow (L/s)	25.7	61.97
Maximum flow (L/s)	75	109.3
Background leakage (l/p/h)	2.27	4.89
Maximum pressure head at intake (m)	69	122.9
Minimum pressure head at intake (m)	22	15
Average pressure head at intake (m)	83.2	107.7
Average pressure head at highest elevations (m)	40	50-60
NRW (% of supply)	36.5	56.3

As shown in Figure 4, between 5.00 hours and 8.00 hours on August 26, when water supply is temporarily turned off in the Maraval DMA, the readings of pressure and flow are zero. Pressure measurements were taken at the highest elevation (see Table 3) in the DMA to confirm that all customers were receiving water. At these points, it was observed that the average pressure recorded were high and greater than the minimum pressure of 137.3KPa (14m head) stipulated by the Regulated Industries Commission (RIC, 2004).

For practical predictions of pressure-leakage relationships, the equation given by Lambert (2001) was used to develop Table 4. The N1 values for Maloney and Maraval were estimated as 1.05 and 1.03 respectively. As the leakage was found to be high in both DMAs, a value for N1 of close to 0.5 was expected as the distribution network is made up of rigid pipes. The reduction in the level of pipe bursts could be between

70% and 94%, if the pressure heads at the highest elevation in the DMAs are restricted to 20m. These reductions are in keeping with that of Fantozzi and Lambert (2010) who showed that overall average % reduction in burst frequency was 1.4 times the % reduction in maximum pressure. Currently, in Trinidad, WASA is required to provide a water supply with a pressure head of at least 15m to the consumer. Maintaining a conservative pressure head of 20m NRW could be reduced by at least 25% in most cases in the tested DMA. This would allow water to be available for communities with populations of at least 600; reduce the operating costs of the utility; and improve its revenue. A preliminary estimate suggests that the reduction in water losses could provide adequate supply to more than 1,000 new customers.

Table 4. Potential impact on water losses and pipe bursts by pressure reduction

Location	**Maloney**	**Fairways, Maraval**	**La Seiva, Maraval**
Minimum pressures existing at the highest elevation (m)	40	60	50
Desired pressure head at the highest elevation (m)	20	20	20
Lambert's N1	1.05	1.03	1.03
Reduction in losses (%)	37	25	30
Reduction in break frequency (%)	70	94	84

In estimating system losses, WASA used 6 L/p/h for customer night consumption. This practice is based on doubling the amount used in the UK. The practicet started in 2002 under the Severn Trent Management who provided leadership for WASA's reorganisation of its Water Loss Control Department. Accurate customer night consumption is important, as inaccurate data will result in leakage levels being wrongly assessed and would lead to erroneous assessment of the potential of pressure management. An analysis of the impact of the assumed night use per capita, during minimum night flow, shows that by doubling of the assumed value customer night consumption currently used by WASA results in the reduction of NRW by 10.7 % and 6.0 % in Maloney and Maraval, respectively.

5. Conclusions

Notwithstanding the worldwide advances made in leakage management, Trinidad and Tobago still operates at a rudimentary level, while recognising the importance of leakage. Using basic methodologies, shared in this study, useful estimates of water losses could be made which would inform decisions at the preliminary stage of water leakage management.

The potential for pressure management in both the Maloney and Maraval DMA seems good. All the conditions proposed by GTZ-VAG-Public-Private-Partnership (2009) were met. While these conditions suggest that there is the potential for the implementation of pressure management, they must be supported by adequate economic and ecological costs-benefits analyses; and technical and managerial resources.

In this study, NRW is over 35% in both DMAs. While it is impossible to prevent all losses, the study shows that WASA could benefit from investing in DMA pressure management systems. Pressure readings in both Maraval and Maloney DMAs have shown that during the study pressure head has been as much as 27m higher than recommended. Reduced system pressures would result in a reduction of the frequency of pipe ruptures and a reduction NRW. The extra water that is being lost could be used to serve more customers and generate more income for WASA. Reduction in pressure could result in savings in the use of power, reduce the costs of repairs and increase the quantity of water available for distribution.

Some important points to note are:

1. The approach taken to implementing pressure management depends a number of national factors like the level of economic development, environmental consciousness, political priorities and cultural habits which would all influence the dynamics of water management. Some of these conditions are more conducive to pressure management than others. However, ultimately, WASA must approach any pressure management programme such that leakage does not compromise a reliable consumer supply nor the economic viability of the utility.
2. To improve the level of commitment, WASA should invest in capacity building by developing operational guidelines at the levels of management, planning and design, implementation and general operations.
3. WASA should seek to sensitize its staff to the problem of NRW, and the financial and environmental benefits to be derived from implementing an appropriate programme to reduce water losses, particularly in the context of carbon foot printing.
4. WASA should implement a pressure management program in Maraval and Maloney to confirm the benefits of the DMA pressure management systems.

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Ken Damian Balfour *is a Project Engineer at the Water and Sewerage Authority (WASA) in Trinidad and Tobago with over ten years experience. His areas of expertise include the water and wastewater operations, plant maintenance and design, planning and implementation of projects. Mr. Balfour graduated from The University of the West Indies in 2007 with his Bachelor's degree in Mechanical Engineering and completed his Master of Science in Environmental Engineering in April 2014. In 2013, aspects of Mr. Balfour's M.Sc. thesis titled "An Assessment of Pressure Management System to Reduce Non-Revenue Water in Trinidad and Tobago" were presented at the Caribbean Water and Wastewater Association (CWWA) Conference in Barbados. Mr. Balfour is a qualified lifeguard with Trinidad and Tobago Life Saving Society and a black belt holder with Black Hawks Martial Arts Academy International. In 2013, he founded Soriak International, a Christian based outreach ministry.*

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