Journal of Water Supply: Research and Technology—AQUA | 59.8 | 2010

Using performance indicators as a water loss management tool in developing countries

H. Mutikanga, S. Sharma, K. Vairavamoorthy and Enrique Cabrera Jr.

ABSTRACT

Water utilities in developing countries are facing the challenges of substantial water losses in their water supply systems. In order to deliver water to their customers more efficiently and effectively, utilities must be able to measure and assess the performance of their water supply systems against set management objectives. However, water loss assessment is still not widely practised in developing countries. The task of measuring and evaluating performance is accomplished by performance assessment systems through well-defined performance indicators (PIs). Most PIs currently used are often not applicable in developing countries. This paper presents an eight-step participatory methodology for the selection of indicators and highlights challenges of integrating a PI culture in developing countries. In total, 25 PIs have been proposed as part of a standardized water balance methodology and so far 16 PIs have been tested successfully. The other nine PIs have not been tested, as the costs of generating and collecting reliable data outweigh the added benefits. In addition an appropriate water loss performance indicator computational tool has been developed to promote use of standardized water balance and performance measures by the utilities of developing countries.

Key words | developing countries, indicators, performance assessment, water losses

H. Mutikanga (corresponding author)
National Water and Sewerage Corporation,
PO Box 7053, Kampala, Uganda
E-mail: *harrison.mutikanga@nwsc.co.ug*

H. Mutikanga
S. Sharma
K. Vairavamoorthy
UNESCO-IHE Institute for Water Education,
Westvest 7, 2611 AX Delft,
The Netherlands

H. Mutikanga
K. Vairavamoorthy
Faculty of Civil Engineering & Geosciences,
Delft University of Technology,
Stevinweg 1, 2628 CN, Delft,
The Netherlands

K. Vairavamoorthy
University of Birmingham,
School of Civil Engineering,
Edgbaston, Birmingham B15 2TT,
UK

Enrique Cabrera Jr.
ITA-Universidad Politecnica de Valencia,
Camino de Vera, s/n 46022 Valencia,
Spain

INTRODUCTION

One of the major issues affecting water utilities throughout the world is the considerably high level of water losses in distribution systems. This problem is more pronounced in the developing countries with ageing infrastructure and inadequate resources for effective asset management. Kingdom *et al.* (2006), in their analysis of more than 900 utilities in 44 developing countries using the World Bank database on water utility performance (IBNET, the International Benchmarking Network for Water and Sanitation Utilities), found that the average value for non-revenue water (NRW) levels in developing countries is around 35%. They further estimated that every year about 16 billion cubic metres of treated water physically leak from the urban water systems of developing countries while over 10 billion cubic metres are delivered to customers for zero revenue. National Water and Sewerage Corporation (NWSC-Uganda) is among the utilities that submit data to IBNET. In Ugandan towns and cities, NRW ranges from 3 to 80% of the water supplied (SPR 2007). In order to understand why water is being lost, where it is being lost, how much is being lost and to be able to reduce these losses and improve system performance in a more sustainable manner, scrutiny using assessment systems that are consistent, transparent and auditable is a prerequisite.

During the last decade, there has been an increasing desire and need to measure and report different aspects of performance in the water industry. While a number of water suppliers worldwide have well-defined performance assessment systems (PAS) for evaluating water losses in distribution systems, this is not the case for most water utilities in the developing countries.

doi: 10.2166/aqua.2010.066

Like most water utilities in the developing countries, NWSC-Uganda has been using performance measures as a result of external and internal pressures to improve service delivery. However, the current performance measures are biased in favour of commercial and financial aspects with little focus on technical aspects. The most frequently used technical performance indicator (PI) for assessing water losses and target setting is percentage NRW (% NRW). This PI is very basic and inappropriate for assessing the efficiency of managing water supply distribution systems (Lambert & Hirner 2000). While use of percentage NRW is recommended as a basic financial indicator (Alegre *et al.* 2006), it discriminates against utilities with low consumption and higher than average pressures (Farley & Trow 2003).

The increasing demand on our water and wastewater utilities to run their businesses more efficiently and effectively has resulted in numerous studies and publications on PAS over the last 5–15 years. The most relevant PI systems developed for water supply and wastewater systems are those promoted by the International Water Association (IWA) (Matos *et al.* 2003; Alegre *et al.* 2006; Cabrera Jr & Pardo 2008), the Asian Development Bank (ADB) (McIntosh & Yniguez 1997; ADB 2007), the World Bank (Yepes & Dianderas 1996; World Bank 2006), the American Water Works Association (AWWA) (AWWA 2003; Crotty 2004; Brueck 2005), the 'Six Scandinavian Cities Group' (Helland & Adamsson 1998), the UK Office of Water Services (OFWAT) (OFWAT 2004), the Association of Dutch Water Companies (VEWIN) (VEWIN 2007), the international standard ISO 24500 (ISO 2007*a*,*b*,*c*) and recently by the African Water Association (AfWA) (WSP 2008, 2009). While each of these efforts has made a contribution to the body of knowledge on performance assessment for water and wastewater utilities, most of these studies have focused on developed countries. Performance measurement in water utilities of developing countries has received less emphasis and is therefore not very well understood.

Olsthoorn *et al.* (2001), in their paper on standardization of environmental indicators, states that: 'Decision-making and management of complex issues requires methods for representing these issues by simple units of measure. These are called indicators–condensed information for decision-making'. A water supply system is a typical example of such a complex issue for which there is need for appropriate indicators. PIs are typically expressed as ratios between variables; these may be commensurate (e.g. %) or non-commensurate (e.g. $ m^{-3} or litres per service connection) (Alegre 2004).

Over the years, performance indicators (PIs) have been developed for water supply services without specifically focusing on water losses. In the drinking water sector, performance assessment has been carried out in the areas of drinking water production (Vieira *et al.* 2008), rehabilitation of water networks (Alegre 2006), water quality (Coulibaly & Rodriguez 2004) and environmental sustainability (Lundin & Morrison 2002).

The increasing demand for water distribution systems performance evaluation has led to the development of sector-specific water loss performance indicators (WL PIs). Out of the 170 PIs in the IWA manual of PIs for water services, NRW and its components account for 15 (9 operational, 4 water resources and 2 financial) (Alegre *et al.* 2006). This manual sets a good foundation for adopting and customizing PIs depending on local circumstances. The IWA Water Loss Task Force (WLTF) was also initiated as part of the global initiative to develop PIs for water losses among others (McKenzie & Lambert 2004), but their work has mainly concentrated on the physical losses (leakage) in well-managed systems of developed countries. Little work has been done on the apparent (commercial) water losses component until recently (Thornton & Rizzo 2002; AWWA 2003). The IWA WLTF has been working for the past few years on apparent water losses and progress is being made to bring it to par with real loss component-based analysis and interventions (Rizzo *et al.* 2007).

This paper aims to contribute to these developments by building methods and tools that enable water utilities in developing countries to develop and implement a PAS using NWSC-Uganda, a public utility, as a case study. The eight-step participatory methodology for the selection of indicators is presented. A new balanced set of indicators specifically relevant and tailored for assessing water losses in Kampala city have been proposed. In total, 25 PIs (with 13 new specific PIs) have been defined and structured in six groups: namely, operational, asset serviceability, meter management, illegal use, human resources, economic and financial resources. The challenges of integrating a PI culture in developing countries are also presented. In addition, an appropriate WL PI computational tool has been developed to promote use of PAS by water utilities in developing countries.

OBJECTIVE AND SCOPE OF THE STUDY

The main objective of this research was to develop appropriate methods and tools for water loss assessment in developing countries using NWSC-Kampala city's water supply system as a case study. To achieve the objective, the research was conducted in three main steps: literature review on existing and applicable performance assessment frameworks; pilot testing of performance measures in five utilities of NWSC-Uganda; and refining the performance measures based on pilot results and lessons learned.

The water supply system (WSS) typically consists of transmission and distribution. The ultimate function of the WSS is to deliver water to its customers. However, not all water input into the system reaches the customer because of water losses in the system. Therefore, the scope of this study is defined as the most relevant operational PIs for assessment of the WSS's efficiency (i.e water and revenue losses between the water treatment plant (WTP) and the customer metering point). Water losses within the WTP are excluded.

METHODOLOGY FOR PI DEVELOPMENT, DEFINITION AND SELECTION

The eight-step participatory methodology followed in the development, definition and selection of PIs for water loss assessment (WLA) is presented in Figure 1. This methodology refers to the development of the PI system for general use and can be followed by any water supplier willing to implement a PI system. The methodology starts with defining objectives based on the utility strategic plan and ends with using PIs in daily operations. This methodology is consistent with Water Environment Research Foundation (WERF), Water Research Foundation (formerly AwwaRF) and IWA's recommendations of moving from objectives to indicators (Brueck 2005; Alegre *et al.* 2006). It is also consistent with the PDCA approach (Plan Do Check Act) and the ISO 24500 standards (ISO 2007*c*).

ESTABLISHMENT OF A PI SYSTEM

The establishment and implementation of a PI system that uniquely suits WLA was the core objective of this study. The next step was to develop new PIs based on literature guidelines and the IWA-PI concept. A list of relevant indicators was also selected from the existing PI systems, mainly the AWWA/IWA-PI system. A total candidate list of 62 PIs (20 new ones and 42 selected) was assembled and made ready for review by the PI team. This was followed by establishing and appointing a PI team by the managing director (MD) of the water utility in August 2008. The team comprised 24 members of staff from the utility top management, senior managers, middle managers and operational staff. A PI team leader was appointed to coordinate the whole exercise. This was then followed by circulation of relevant literature to the PI team members to stimulate their thinking. Three workshops were then conducted to provide forum for discussions, learning and articulating relevance of each indicator. To enhance speed the team was split into four main working groups (physical losses, commercial losses, NRW and computational tool development). The final outputs were realized after 4 months with a final PI listing of 25 indicators, 51 variables and a PI computational tool. Complementary to the IWA-PIs, there are 14 newly established PIs suitable for WLA in the water utilities of developing countries with little or no relevance to water utilities in developed countries (e.g. leakage handling efficiency, illegal use fines recovery efficiency and inactive accounts ratio). Detailed characterization of some selected PIs (objective, definition, processing rule, units of measurement, data required, results analysis, etc.) is presented in Table 1. The final step was pilot testing the feasibility of the adopted PIs and developed computation tool.

This participatory methodology was preferred to draw continuing support from the operational staff who will provide input data and the top decision-making managers who are the users of the PI information in setting targets and assessing performance for continuous improvement. This approach of involving employees in the process creates ownership and ensures sustainability of the PAS.

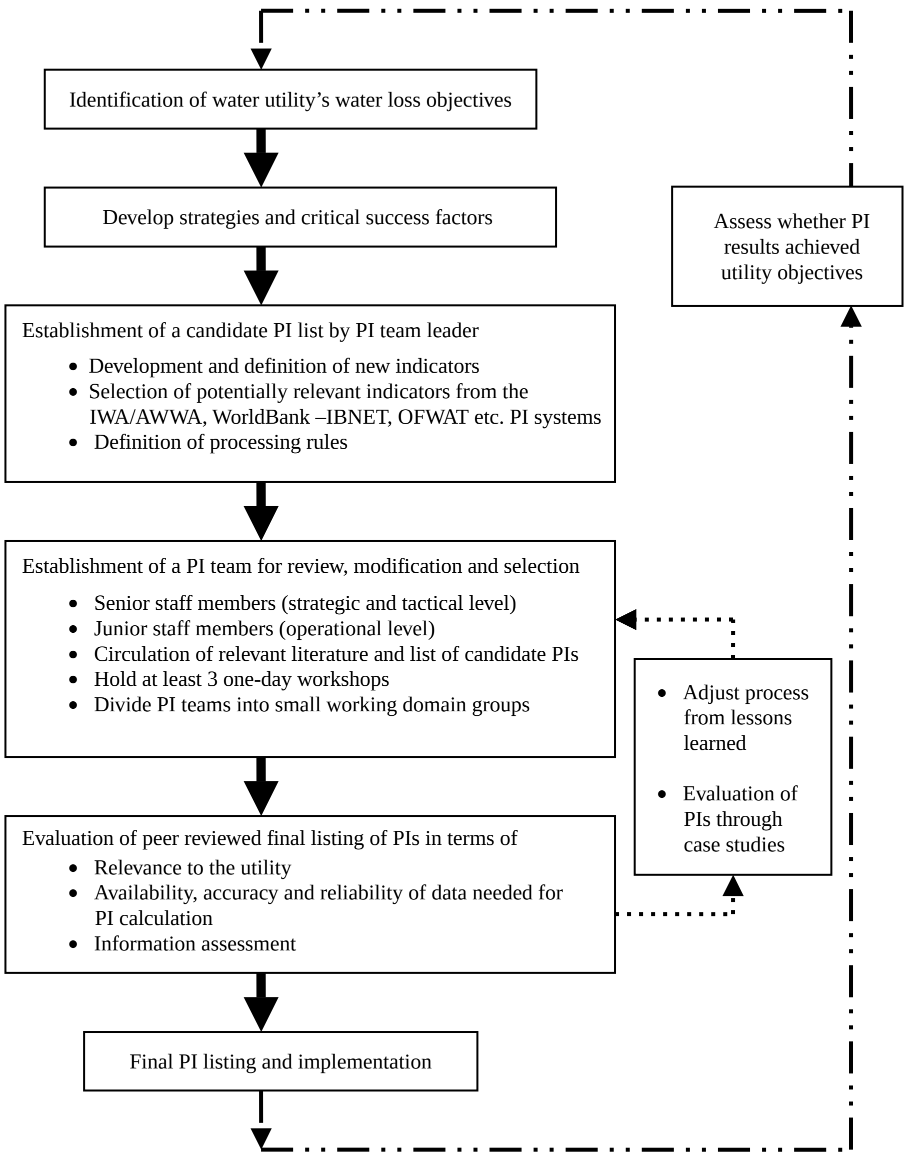

Figure 1 | Methodology for PI development, selection and definition.

APPLICABILITY OF INFRASTRUCTURE LEAKAGE INDEX (ILI) IN DEVELOPING COUNTRIES

During the peer review, one commonly used PI in developed countries was found inappropriate by the team for use in NWSC-Uganda. The proposed PI for real losses, ILI (Lambert *et al.* 1999), was not considered in this study as it did not fulfil some of the basic requirements for PIs (Alegre *et al.* 2006) and required detailed data that was difficult and costly to obtain.

The convenience of ILI for the Ugandan case was dubious, especially considering the costs involved in its calculation and the fact that recent results of ILI assessments from around the world have indicated that it is not always appropriate for comparing systems from different countries, especially developed countries with well-managed systems and developing countries with intermittent supply and low pressure systems (McKenzie *et al.* 2007). In addition, it is of little significance to start thinking of unavoidable annual real losses (UARL) in most water

Table 1 | Some of the developed performance indicators

OpWL1: Leakage handling efficiency (%)

Number of reported leaks and bursts repaired within the target period/total number of reported leaks and bursts

OpWL1 = (D2/D1) × 100

D1 = Total number of leaks and bursts reported during the assessment period

D2 = Total number of recorded leaks and bursts repaired within the target period

Objective of PI: To measure and improve response time to repair of reported leaks and burst

Comments: Very useful for developing countries with no sectorized water distribution networks and district metered areas (DMAs) but with administrative operational business units responsible for repairing leaks among others. Relevant for utilities with so many visible leaks that take days to be repaired

AsWL11: Service connection failures (No./1,000 connections/year)

(Number of service connection failures during the assessment period × 365/assessment period)/number of service connections × 1,000

AsWL11 = (D4 × 365/F1)/C4 × 1,000

C4 = Service connections (No.)

D4 = Service connection failures (No.)

F1 = Assessment period (day)

Objective of PI: To measure utility operational sustainability and asset management with respect to service connections

Comments: Relevant to developing countries where service connection lines are often the forgotten asset

OpWL3: Real losses per connection (l/connection/day when system is pressurized)

Real losses during the assessment period × 1,000/(number of service connections × number of hours system is pressurized during the assessment period/24)

OpWL3 = A12 × 1,000/(C4 × F2/24)

A12 = Real losses (m^3)

C4 = Service connections (No.)

F2 = Time system is pressurized (hour)

Objective of PI: To measure the efficiency of the water supply system

Comments: Adequate for urban distribution systems and systems subject to intermittent supply. Real loss is divided by equivalent number of days when system is pressurized (wsp), rather than 365 days. Useful for target setting and comparisons between systems

IlWL17: Illegal use detection efficiency (%)

(Number of illegal use cases reported, investigated and confirmed/total number of reported and investigated illegal use cases during the assessment period) × 100

IlWL17 = (D13/D12) × 100

D12 = illegal use cases reported and investigated (No.)

D13 = illegal use cases confirmed (No.)

Objective of PI: To assess managerial efforts to proactively manage illegal water use

Comments: Relevant for developing countries where illegal use of water is endemic

distribution systems of the utilities in developing countries where reported visible leaks are still significant and take days before they are repaired. Detailed PIs could be used sequentially in future as more data becomes available and technology evolves in line with IWA's recommendation of a step-by-step implementation.

RESULTS: THE PI SYSTEM FOR WATER LOSS ASSESSMENT

The final listing consists of 25 PIs but only 16 indicators are being used, although some others included in the larger set of 25 may be relevant to other utilities. Owing to space limitations, only four PIs have been presented in this paper as shown in Table 1. The PIs were structured and arranged into six main groups as shown in Figure 2. For performance assessment to become part of utility culture, it helps to identify the purpose of each PI and the final user within the utility.

Operational indicators (OpWL)

In this group, PIs are intended to assess the performance of the utility as regards operation and maintenance (O&M) activities. Utility managers need to pay much attention to O&M activities as the efficiency of the water utility can be lost or improved by these activities.

Asset serviceability indicators (AsWL)

In this group, PIs are intended to assess the long-term performance of the utility's assets in order to continue providing an acceptable level of service to its customers. There is normally a tendency for utilities to reduce asset

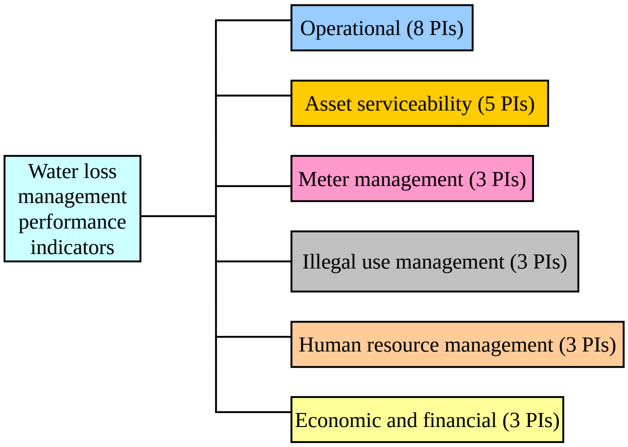

Figure 2 | Performance indicators structure for water loss management.

renewing and operating cost to ensure short-term financial and economic sustainability, especially in developing countries.

Meter management indicators (MeWL)

In this group, PIs are intended to assess the utility's water meters' functionality to accurately measure flows and safeguard against revenue losses. Choosing the right meters, keeping them in good operating mode or even the time to replace them present major challenges to utilities in developing countries and managerial efforts in this respect are assessed.

The other PI groups, illegal water use indicators (IlWL), human resource (personnel) indicators (PeWL) and economic and financial indicators (FiWL), were generated using the same approach and reasoning.

In order to assess the selected PIs, utility data is required. The PI system input variables are structured in seven main domains (water volume, personnel, physical assets, operational, customer, time, economic and financial data) the same as those adopted in the IWA-PI system to ease usability of the system. The final PI system input data totalling 51 variables have been defined. For meaningful diagnosis and decision-making, the PI system is supplemented by relevant utility context information and explanatory factors. To promote transparency of the system procedures and accuracy of the data used, NWSC towns are now ISO 9000:2001 certified and use of balanced score cards and total quality management systems (TQMS) is in practice. In addition the Uganda Government Auditor General appoints external auditors of international reputation to audit NWSC data before publication of performance annual reports. The annual reports are made public and can be freely downloaded on the NWSC website (http://www.nwsc.co.ug).

THE WATER LOSS PERFORMANCE INDICATOR (WL PI) TOOL

Within the scope of this study, an appropriate computational tool consisting of an MS Excel® spreadsheet application has been developed to promote use of the performance measurement system and assist utility managers using the standard water balance. The framework is user friendly as highlighted on the homepage user interface (screenshot in Figure 3(a)); some computed PIs from input variables are depicted in the screenshot in Figure 3(b). The tool can be accessed from either NWSC-Uganda or UNESCO-IHE Institute for Water Education, Delft, The Netherlands on request.

During the past decade, several efforts have been made to develop similar but more costly (typically priced from US$50,000 to 100,000) water balance software tools. Surely, these tools are beyond the reach of most cash-strapped water utilities in developing countries and have hindered use of the IWA standardized water balance methodology. They include Aquafast software developed for AwwaRF (Fanner *et al.* 2007), Aqualibre developed by Bristol Water Utility (UK) (Liemberger & McKenzie 2003) and SIGMA developed by Instituto Tecnologico del Agua (ITA) of the Universidad Politecnica de Valencia, Spain (Alegre *et al.* 2006).

CASE STUDY PILOT TESTING

In order to test the robustness of the PAS and the developed WLA PI tool, a pilot implementation was carried out in five water utilities of NWSC-Uganda using preliminary data for calendar years 2007 and 2008. The feasibility of the PIs was assessed using available data within the utility and additional easy-to-measure and less expensive data to

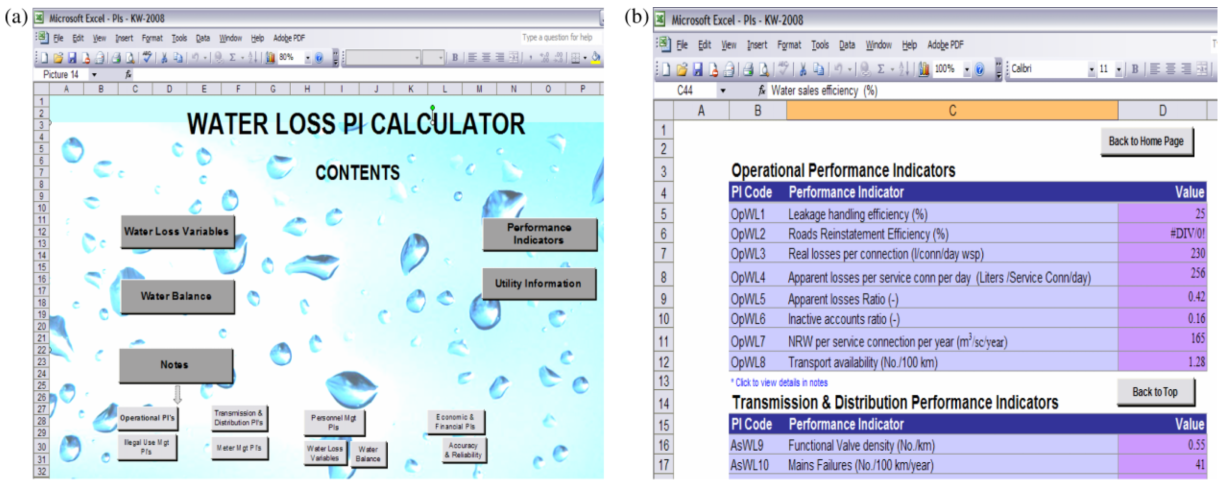

Figure 3 | Screenshots of the PI computational tool for WLA (WL_PI_CALC.xls).

collect but of much significance as a preliminary step. As a result of this, 16 PIs out of 25 proposed PIs were successfully tested. The details of the pilot results have been published in Mutikanga *et al.* (2009).

BENEFITS OF USING PERFORMANCE MEASURES IN NWSC-UGANDA

Using performance measures has yielded benefits and a few are highlighted below:

- Performance gaps have been identified in asset management and renewals, such as mains failures (41 No./100 km/year), service connection failures (133 No./1,000 connections/year) and mains replacements (0.5%/year).
- PIs have promoted better understanding of the water system. For instance, the low frequency of meter replacement (0.5%/year) in a very old network with poor infrastructure and frequent reported cases of defective customer meters probably explains the high apparent losses (256 litres/service connection/day).
- Gaps in data accuracy and reliability for input variables for the water balance have been identified and appropriate measures (e.g. the checkers' system) are being put in place to minimize errors. Using the in-house checkers' system (auditing), it was discovered that, in one of the towns, low NRW figures were being reported using poor and manipulated data in order to win cash incentives and please utility top management that often wanted to see only good performance results irrespective of how they are generated.
- PIs have stimulated in-house benchmarking across utilities and operational branches in Kampala. Data has been generated against which progress towards set targets is assessed. This has helped to improve performance by learning from successes, identifying good performers and learning from their operational tactics to improve the performance of others.

CHALLENGES AND LESSONS LEARNED IN INTRODUCING A PI CULTURE IN NWSC-UGANDA

In the process of establishing and implementing a PI system, the following challenges and key lessons have been learned:

1. The main challenge was getting people from different towns (utilities) to work together on a project that demanded a lot of time and input from staff members over and above their routine work. The burden of additional paperwork and data collection, created fear and resistance among team members and this influenced the decision on number of final PIs adopted. Instilling this culture at all levels of management and effective data collection will take time and deliberate efforts from top management.

2. Some team members were travelling about 300 km from Kampala city, the venue of the workshops. A lot of time was lost as a result of starting most sessions late.
3. Strong leadership commitment is required to see the whole process through. The active participation of the managing director who is the top executive in the water utility made more team members buy-into the process. Despite this strong leadership, about 50% of the PI team especially senior managers were not actively participating in the process in the last two workshops. More effort is required from the utility leadership to change the mind-set of the managers to recognize that water loss reduction is a compelling issue that requires active participation of all stakeholders.
4. Unstructured water distribution networks in some of the utilities and insufficient metering coupled with limited use of standardized WLA procedures still pose a big challenge and casts doubts about the reliability of estimates on water loss components. When networks are poorly structured and maintained, it is very difficult to carry out water audits and this hinders selection and implementation of appropriate water loss reduction strategies. Utilities in the developing countries should progressively work towards reconfiguring and rezoning their networks for effective water loss control.
5. Unlike financial performance measures, water loss measures are data and labour intensive. Some data required purchase of new equipment (e.g. flow and pressure data loggers) and technology support in data acquisition. In the first few weeks about €5,000 was spent on purchase of a few data loggers in Kampala city which is the largest town in NWSC. In the smaller towns where resources are limited, it is still a major problem to obtain reliable and accurate data and a compromise had to be made on the number of measures to be made and indicators to be generated.
6. For effective water loss reduction, there is need to perform a cause and effect scenario to avoid recurrence. This new data requirement needs more time and patience and has been met with a lot of resistance by the field staff. For example, previously a plumber would just repair a leak and close his job but now he has to assess cause and provide additional information (size and age of main, pipe material, type of failure, cost of repair, duration of leak, estimated flow rate, pipe depth, etc.). Unless the existing incentive framework is revised to reward these efforts, workers will continue to perceive the process as being like a library–depositing data in an archive and not seeing the usefulness of more data generation.
7. The utility has moved from measuring one PI (%NRW) to over 10 PIs, creating a situation where data management is no longer an insignificant need but a pressing issue. However, the increased use of PIs has not been matched with corresponding institutional structures for effective data collection and management. The main advantage of moving from one main PI to a few key individual PIs is that most hidden details have started emerging and are aiding management decision making. For example the recruitment of an engineer to head the meter testing laboratory has improved significantly the quality of meter testing data and analysis. Leakage handling efficiency has also improved from an average of 67% to 88% in the past year (2009) because of increased accountability of utility branch operations in Kampala city.
8. Performance measures and the feedback they provide are only as good as the database and the underlying analysis from which they are derived and are subject to manipulation by some utility managers especially if their pay is performance based. Managers need to be convinced that the generated PIs are there to help them improve performance in service delivery and not to penalize them. Otherwise, utility managers will often corrupt data and produce the numbers they are asked to deliver.
9. Though periodic reviews and refinements of PIs are recommended, there is need to balance continuous improvement with stable, older PIs to support historical trends and analysis.
10. The '100-days' results syndrome of utility leaders is often very unrealistic for improvement of some performance figures. It is not unusual to suggest a reduction of NRW in Kampala city by 10% in 100 days. There is need for utility leaders to appreciate the fact that certain improvement measures (e.g. asset renewal) take time to produce an improvement in performance figures. Unless performance measures are looked at in the

spirit of continual improvement, misunderstandings and wrong decisions are likely to arise.

11. Careful selection of trusted, competent key PI team leaders is critical as the development of PIs require knowledge of the business, a lot of thought, patience and commitment. In addition, the process is lengthy and iterative. A PI team not exceeding 10 members is recommended for maximum productivity. Like the old adage of 'too many cooks spoil the soup', likewise use of many PI members often encourages gossip rather than work.
12. There is need to review the utility organizational set-up and include a dedicated unit with a mandate to efficiently collect and integrate data from various sources for successful implementation of a PAS. The various management information systems in NWSC-Kampala (GIS, customer billing database, customer call centre, etc.) need to be updated and integrated to attain flexibility and maximum benefits of using a PAS. The new water loss PAS is slowly being integrated in the NWSC internally delegated management contracts (IDAMCs) reporting framework to ease monitoring, reporting and feedback.
13. Explaining to utility employees the relevance and interrelationships of computed PIs and how they are aligned to global utility goals and objectives, individual inputs and cash incentives earned is vital for successful implementation.
14. It is important to link employee incentives to performance measures as a way of continuously providing feedback on target attainment and encourage continuous performance improvement. This is now the case for all executive and senior managers in NWSC. However, if targets are not set realistically and are hardly attained by staff, they can be a demotivating factor.
15. Having a balanced set of well-defined PIs that are very well aligned to the utility's strategic plans is critical for the successful implementation of a PAS. For example NWSC-Uganda has excelled in commercial operations with high levels of revenue collection efficiency (>95%) and good customer care. But because its performance measures focused less on technical aspects, the utility's NRW of over 40% remains one of the highest on the African continent.
16. Frequent reviews (quarterly in the case of NWSC-Uganda) of performance measures in conjunction with internal benchmarking are fundamental to implementing a PAS. In NWSC, reviews are held in workshops with full participation of all the 22 NWSC towns (utilities) and results are presented highlighting 'pace-setters' and 'laggards'. Cash incentives and trophies are presented to winning utilities and 'naming and shaming' is done to laggards. This has proved to be a good benchmarking tool for driving performance and ensures sustainable continuous improvement in service delivery. The cash incentives are shared among staff in accordance with the partner's deed of the IDAMCs.
17. There is no cookie-cutter blueprint for a PAS; each utility must examine its own operational processes and practices, infrastructure, organizational culture, supporting data and technology and develop performance measures most appropriate for their local working environment.

Utilities trying to establish a PAS will encounter some of these challenges and it is good to be aware of them in order to minimize repetition. Further challenges and how to overcome some of the misunderstandings have been recently outlined in Alegre *et al.* (2009).

CONCLUSIONS

This paper introduces a new participatory methodology for establishing a performance assessment system using the IWA-PI concept. Appropriate specific indicators for water loss assessment have been developed. The PI system is suitable for reporting 'in accordance' with the IWA guidelines, thus enabling performance benchmarking of different utilities and regions.

The authors are confident that the established performance measures together with the developed computational tool (WL PI) will promote use of the standard water balance methodology for better assessment of water losses in utilities of developing countries.

ACKNOWLEDGEMENTS

This study is partially funded by the Netherlands Fellowship Program (NFP) and by NWSC-Uganda. The authors also acknowledge GTZ–Uganda for making it possible for the WL PIs to be incorporated in the global PI system (SIGMA-ITA) for the Ugandan water sector; these water loss PIs among others will be further tested and reported for a long period of time as part of the ongoing urban water reforms. The authors also wish to thank the PI team, especially the area managers and engineers who contributed much time and effort to this study. We also wish to acknowledge the material support provided by Maureen Hodgins of Water Research Foundation (formerly AwwaRF). These contributions all led to the body of knowledge and lessons presented herein.

REFERENCES

ADB 2007 *Benchmarking and Data Book of Water Utilities in India*. Asian Development Bank, Manila.

Alegre, H. 2004 Performance indicators as a management support tool. In: Mays, L. W. (ed.) *Urban Water Supply Management Tools*. McGraw-Hill, New York.

Alegre, H. 2006 The use of the IWA PI system to support the rehabilitation of water networks. In: Alegre, H., Babel, M. S., Cabrera, E. Jr., Cubillo, F., Duarte, P., Hirner, W., Merkel, W. & Parena, R. (eds) *Performance Indicators for Water Supply Services*. IWA Publishing, London, pp. 71–79.

Alegre, H., Baptista, J. M., Cabrera, E. J., Cubillo, F., Hirner, W., Merkel, W. & Parena, R. 2006 *Performance Indicators for Water Supply Services, IWA Manual of Best Practice*, 2nd edition. IWA Publishing, London.

Alegre, H., Cabrera, E. Jr. & Merkel, W. 2009 Performance assessment of urban utilities: the case of water supply, wastewater and solid waste. *J. Water Supply Res. Technol.–AQUA* **58**(5), 305–315.

AWWA 2003 Committee report: applying worldwide BMPs in water loss control. *J. Am. Water Works Assoc.* **95**(8), 65–79.

Brueck, T. M. 2005 *Developing and Implementing a Performance Measurement System*. IWA Publishing, London.

Cabrera, E. Jr. & Pardo, M. A. 2008 *Performance Assessment of Urban Infrastructure Services*. IWA Publishing, London.

Coulibaly, H. D. & Rodriguez, M. J. 2004 Development of performance indicators for small Quebec drinking water utilities. *J. Environ. Manage.* **73**, 243–255.

Crotty, P. 2004 *Selection and Definition of Performance Indicators for Water and Wastewater Utilities*. AWWA Research Foundation, Denver, Colorado.

Fanner, P., Thornton, J., Liemberger, R. & Sturm, R. 2007 *Evaluating Water Loss and Planning Loss Reduction Strategies*. AWWA Research Foundation, IWA, Denver, Colorado, London.

Farley, M. & Trow, S. 2003 *Losses in Water Distribution Networks: A Practitioner's Guide to Assessment, Monitoring and Control*. IWA Publishing, London.

Helland, B. & Adamsson, J. 1998 Performance indicators: benchmarking between six cities in Scandinavia. *JWSRT-AQUA* **47**(6), 284–288.

ISO 2007*a* ISO/FDIS 24510:2007 (E)–Activities relating drinking water and wastewater services–Guidelines for the assessment and for the improvement of the service to users.

ISO 2007*b* ISO/FDIS 24511:2007(E)–Activities relating to drinking water and wastewater services–Guidelines for the management and for the assessment of wastewater services.

ISO 2007*c* ISO/FDIS 24512:2007(E)–Activities relating to drinking water and wastewater services–Guidelines for the management and for the assessment of drinking water services.

Kingdom, B., Liemberger, R. & Marin, P. 2006 *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. How the Private Sector Can Help: A Look at Performance-Based Service Contracting*. World Bank, Water Supply & Sanitation Sector Board, PPIAF, Washington, DC.

Lambert, A. & Hirner, W. 2000 Losses from water supply systems: Standard terminology and recommended performance measures. *The Blue Pages, the IWA Information Source on Drinking Water Issues*. IWA, London, October 2000.

Lambert, A. O., Brown, T. G., Takizawa, M. & Weimer, D. 1999 A review of performance indicators for real losses from water supply systems. *JWSRT–AQUA* **48**(6), 227–237.

Liemberger, R. & McKenzie, R. 2003 Aqualibre: A new innovative water balance software. *IWA Efficient 2003 Conference*, Tenerife, 2–4 April 2003.

Lundin, M. & Morrison, M. G. 2002 A life cycle assessment based procedure for development of environmental sustainability indicators for urban water systems. *Urban Water* **4**, 145–152.

Matos, R., Cardoso, M., Ashley, R., Duarte, P., Molinari, A. & Schulz, A. 2003 *Performance Indicators for Wastewater Services*. IWA Publishing, London.

McIntosh, A. C. & Yniguez, C. E. 1997 *Second Water Utilities Data Book: Asian and Pacific Region*. Asian Development Bank, Manila.

McKenzie, R. & Lambert, A. O. 2004 Best practice performance indicators: a practical approach. *Water 21*(August), 43–45.

McKenzie, R., Seago, C. & Liemberger, R. 2007 Benchmarking of losses from potable water reticulation systems: Results from IWA Task Team. *IWA Specialised Conference: Water Loss 2007*, Bucharest, Romania, 23–26 September 2007, pp. 161–175.

Mutikanga, H., Sharma, S. K. & Vairavamoorthy, K. 2009 Performance indicators as a tool for water loss management in developing countries. *5th IWA Water Loss Reduction Specialist Conference*, Cape Town, South Africa, 26–30 April 2009, pp. 22–28.

OFWAT 2004 *Updating the Overall Performance Assessment (OPA): Conclusions and Methodology for 2004–05 Onwards*. Office of Water Services, UK.

Olsthoorn, X., Tyteca, D., Wehrmeyer, W. & Wagner, M. 2001 Environmental indicators for business: a review of the literature and standardisation methods. *J. Cleaner Prod.* **9**, 453–463.

Rizzo, A., Vermersch, M., St John, S. G., Micallef, G. & Pace, R. 2007 Apparent water loss control: the way forward. *Water 21* (August) 45–47.
SPR 2007 *Uganda Water and Sanitation Sector Performance Report (SPR) 2007*. Uganda Government, Minstry of Water and Environment, Kampala, Uganda.
Thornton, J. & Rizzo, A. 2002 Apparent losses, how low can you go. *Leakage Management Conference Proceedings*, Lemesos, Cyprus, 20–22 November 2002.
VEWIN 2007 *Reflections on Performance 2006*. Association of Dutch Water Companies, Rijswijk, The Netherlands.
Vieira, P., Alegre, H., Rosa, M. J. & Lucas, H. 2008 Drinking water treatment plants assessment through performance indicators. *IWA World Water Congress*, Vienna, 7–12 September 2008.
World Bank 2006 *IBNET Indicator Definitions*. World Bank, Washington, DC.
WSP 2008 *African Water Utilities: Regional Comparative Utility Creditworthiness Assessment Report*. Water and Sanitation Program (WSP), World Bank, Africa, Nairobi, Kenya.
WSP 2009 *Water Operators Partnerships: African Utility Performance Assessment*. Water and Sanitation Program (WSP), World Bank, Africa, Nairobi, Kenya.
Yepes, G. & Dianderas, A. 1996 *Indicators: Water and Wastewater Utilities*, 2nd edition. TWUWS, World Bank, Washington, DC.

First received 17 June 2009; accepted in revised form 18 February 2010