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REVIEW

Performance indicators for small- and medium-sized water supply systems: a review

Husnain Haider, Rehan Sadiq, and Solomon Tesfamariam

Abstract: Water supply systems (WSSs) are one of the most important and expensive core public infrastructures. The primary objective of a water supply utility is to have this valuable asset operate at its maximum possible efficiency with minimum cost throughout its design period. To achieve this objective, the first step is to evaluate the existing efficiency of all the components of the WSS using suitable performance indicators (PIs). Various agencies and organizations worldwide have developed detailed performance evaluation frameworks including several indicators to comprehensively cover all the aspects (e.g., physical asset, staffing, operational, customer satisfaction, economical) of the WSSs. Most of these frameworks and indicators have been developed for large-sized WSSs. Small- and medium-sized water supply systems (SM-WSSs) have specific performance-related issues, ranging from difficulties in collecting the data required to use the available systems of PIs to lack of skilled personnel and financial resources for efficient operations. A comprehensive review of the literature has been carried out to assess the suitability of reported performance evaluation systems for SM-WSSs in terms of their simplicity (easy and simple data requirements) and comprehensiveness (i.e., all the components of a WSS). This review also evaluates the individual PI with respect to its understandability, measurability, and comparability (i.e., within and across utility comparisons). On the basis of this detailed review, a conceptual performance evaluation system for SM-WSSs, consisting of a list of PIs grouped into their respective categories, has been proposed. The proposed system provides a stepwise approach, starting the performance evaluation process with the most significant and easy to measure PIs for small-sized WSSs and moving to a relatively complex set of indicators for SM-WSS depending on the availability of resources and specific operating conditions.

Key words: performance indicators, performance assessment, small-sized water supply system, medium-sized water supply system, water distribution system, water utility.

Résumé : Les systèmes d'approvisionnement en eau (SAEs) constituent les plus importantes et onéreuses infrastructures publiques de base. Le premier objectif d'un service d'approvisionnement en eau consiste à assurer le fonctionnement d'une infrastructure couteuse, à son maximum d'efficacité possible à un coût minimum, tout au long de sa durée de vie. Pour atteindre cet objectif, la première étape consiste à évaluer l'efficacité de toutes les composantes en place du système d'approvisionnement en eau (SAE) en utilisant des indicateurs de performance appropriés (IPs). Diverses agences et organisations partout au monde ont développé des cadres d'évaluation détaillés de performance, incluant plusieurs indicateurs pour couvrir l'ensemble de tous les aspects (p. ex. actif physique, personnel, opération, satisfaction des usagers, économique, etc.) des SAEs. On a développé la plupart de ces cadres et indicateurs pour de grands SAEs. Les systèmes d'approvisionnement en eau de petites et moyennes dimensions (SAE-PD) comportent des questions de performance spécifiques, allant des difficultés (à regrouper les données nécessaires) à utiliser les systèmes disponibles de IPs jusqu'au manque de personnel expérimenté et de ressources financières pour des opérations efficaces. Les auteurs ont conduit une revue de littérature pour évaluer de façon rationnelle l'à propos de l'évaluation des rapports de performance pour les SAE-PD en terme de leur simplicité (besoin en données facile et simple) et complet (p. ex. toutes les composantes d'un SAE). La revue évalue également l'indicateur de performance individuel en relation avec sa compréhension, sa mesurabilité et sa compatibilité (i. e., comparaison interne et entre services d'approvisionnement). Sur la base de cette revue détaillée, on propose un système d'évaluation conceptuel de performance pour les SAE-PD, constitué d'une liste de IP regroupés dans leurs catégories respectives. Le système proposé fournit une approche par étapes, commençant avec le processus d'évaluation de performance avec les IPs les plus significatifs et les plus faciles à mesurer pour les petits systèmes d'approvisionnement en eau, en passant ensuite à un ensemble relativement complexe d'indicateurs pour les SAE-PD, dépendant de la disponibilité des ressources et des conditions spécifiques d'opération. [Traduit par la Rédaction]

Mots-clés : indicateurs de performance, évaluation de performance, petits systèmes d'approvisionnement en eau, moyen système d'approvisionnement en eau, système de distribution de l'eau, service de l'eau.

1. Introduction

Access to safe drinking water in sufficient quantity and at affordable cost is the right of every human being, irrespective of the location and size of their community (WHO 2012). Like all other infrastructure systems, the water sector also faces a number of global challenges in the 21st century, including population growth, uncertain climate changes, socio-environmental issues, limited water resources, and economic crises (Berg and Danilenko 2011). A water supply system (WSS) may face a number of problems associated with its continuous aging process, including low pressure, water loss, and water quality deterioration (Alegre 1999; Alegre et al. 2006). To operate and maintain a WSS at its maximum possible efficiency at a viable cost is one of the prime objectives of any water utility. This goal can only be achieved by adopting rational and optimum main-

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tenance, rehabilitation, and renewal (M/R/R) strategies. Even small-sized water supply systems (S-WSSs) can adopt advanced but sustainable asset management tools to enhance their effective service life by improving the efficiency of all the components of the WSS (Brown 2004).

The first step towards a sustainable WSS is to evaluate the performance of a given WSS, which further provides the basis for detailed investigations (detailed condition assessment and (or) M/R/R strategies). The performance of a WSS can be assessed by selecting suitable performance indicators (PIs) (Coelho 1997, Alegre et al. 2006; Berg and Danilenko 2011; NWC 2012; AWWA 2004; OFWAT 2012; NRC 2010; ADB 2012). The general concept of evaluating the performance of a WSS is to compare its performance with established benchmarks through cross-comparison with similar utilities (Alegre et al. 2000). Cross-comparisons at the international level require wider application of the overall performance evaluation framework, as well as the individual PI. Most of these performance evaluation systems have been developed for large-sized water supply systems (L-WSSs) because they are vulnerable to frequent operational problems (e.g., small leakages to large pipe bursts, loss of amenities during vandalism) (Stone et al. 2002). Moreover, the small- and medium-sized water supply systems (SM-WSSs) are serving fewer people using smaller diameter pipelines, but they are also less involved in management activities owing to the lack of technical and financial resources (Braden and Mankin 2004; Brown 2004). Another reason for being neglected could be that some of these systems are not old enough to have conventional structural deterioration phenomena (Kirmeyer et al. 1994). However, right now a number of SM-WSSs are facing several technical, socioeconomic, and environmental challenges to meet the regulatory guidelines (Dziegielewski and Bik 2004).

A systematic approach is adopted to comprehensively review the reported PI systems, keeping in mind the specific requirements of the SM-WSS. The main components of the overall review process are shown in Fig. 1. Discussion on the major differences between L-WSSs and SM-WSSs will be followed by the review of various PI systems proposed by different organizations. A PI system usually consists of general asset information, baseline data variables, the categorization of given PIs, linkage between data variables and PIs, the formulae or equations to calculate the PI, and the comparison with benchmarks. Appropriate grouping of selected PIs provides an effective mechanism to assess the category-wise performance of the WSS (e.g., personnel, customer service, operational). This categorization further aids decision makers in identifying and then rectifying the weaknesses of the WSS in a more systematic manner. For example, a relatively new system is performing worse than an old system of the same size and socioeconomic conditions because of staff inefficiencies. In this case, the utility management may receive a large number of customer complaints, even though all the other categories might be working efficiently. An extremely complex or comprehensive PI system might not be feasible for the SM-WSS. In this respect, PI systems proposed by various agencies have been evaluated based on the simplicity, comprehensiveness (i.e., all aspects of a WSS are covered), and their potential to be applicable to SM-WSSs. Moreover, the data required to estimate the PIs are either not available or missing in most situations. Suitability of PIs for SM-WSSs is assessed on the basis of their understandability, availability of existing data, and the data that can be frequently collected in future. It is also important for the utility operators and managers to establish the important PIs for which data have to be collected and recorded. The last part of the review consists of a selected list of suitable PIs (with relevant classification) taking into consideration their significance and comparability, and accuracy and reliability of the required data for SM-WSSs.

The main objectives of this paper are to (*i*) carry out a state-of-the-art review of literature on PIs; and then based on this review, (*ii*) propose a system of PIs for SM-WSSs. To meet these objectives systematically, the paper is subdivided into six sections. Section 2 consists of size-based classification of water supply utilities and the main differences between the SM-WSS and the L-WSS. A state-of-the-art review is then carried out in Section 3 of the available performance indicator systems being utilized worldwide by different agencies. The review also evaluates each system in terms of measurability and understandability of the PIs, and the PIs are grouped into various categories. The review further explains the specific objectives and conditions in which these systems were developed and thereby describes their limitations. This section also contains a matrix showing suitability of these PI systems for SM-WSSs. In the next section of this paper, some case studies of different countries having limited data resources for performance evaluation are presented to identify the simplest PIs (though not necessarily the most important ones). Section 5 consists of a proposed system of PIs that provides a step-by-step approach to start and gradually improve the performance assessment (PA) process for SM-WSSs. In this section, selected PIs are proposed category-wise to improve the interpretability of PIs in the decision-making process of the given water utility. In the last section, the main conclusions of the entire review are drawn.

2. Background and classification of water supply systems

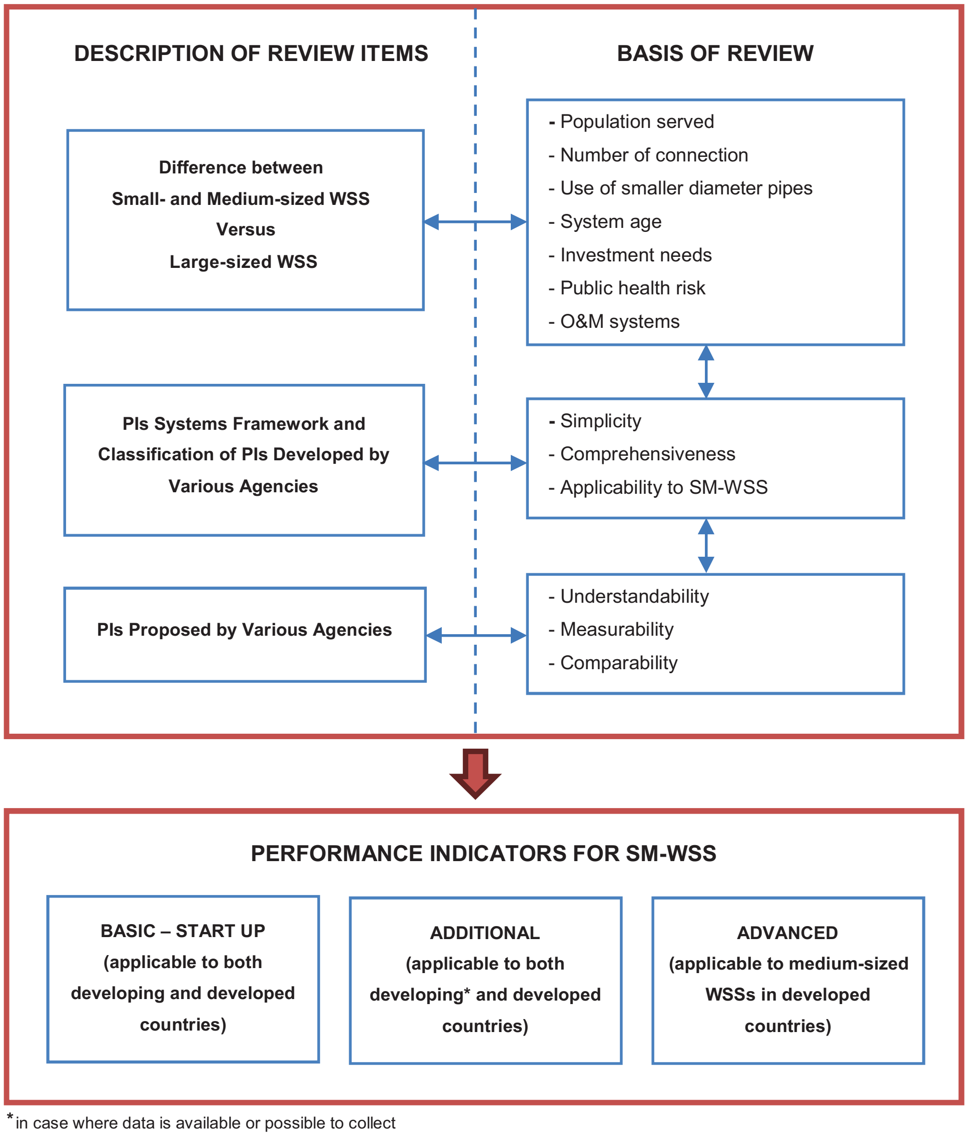
To evaluate the existing PI systems, it is important to understand the difference between SM-WSSs and L-WSSs and how and on what basis these systems have been distinguished from each other in various countries. Water supply systems can be divided into vertical and linear components. The vertical components consist of treatment plants, pumping stations, and storage facilities, whereas the linear components are transmission mains and distributions system pipelines. Generally, linear components are more expansive and their value can be 60%–80% of the overall cost of the WSS (Stone et al. 2002). The components of a WSS greatly depend on the water source (i.e., fresh surface water, ground water, sea water, or saline ground water) as shown in Figs. 2*a*–2*d*. It can be seen in Fig. 2 that the overall water supply scheme could be as simple as Fig. 2*b* (fresh groundwater source) and as complex as Fig. 2*d* (saline surface water source). The selection of suitable PIs depends on type of the source type and water quality. A more detailed framework, including a larger number of PIs, might be required for the same size WSS with a different water source.

Classification of WSSs on the basis of their size and the important factors that differentiate SM-WSSs from L-WSSs are briefly discussed in this section. Although the situation in case of private SM-WSSs (e.g., England and Wales) could be different, the review covers the performance evaluation system adopted for private WSSs as well; however, the main focus is on public sector SM-WSSs.

2.1. Size-based classification of water supply systems

The WSSs are categorized on the basis of their sizes to efficiently perform their organizational, financial, human resources, and operation and management (O&M) activities. The criterion of system size classification varies around the world (Ford et al. 2005) (Table 1). In most parts of the world, including Central and North America, the utilities are commonly classified as small, medium, and large based on the volume of supplied water, number of connections, and population served (Corton and Berg 2009). In New Zealand's and South Africa's water research councils, the basis of size classification is the number of connections (Lambert and Taylor 2010; McKenzie and Lambert 2002). According to the Irish Environmental Protection Agency, the small system is the one that serves less than 5000 people (Ford et al. 2005). British Columbia, Canada, has a tiered classification for small water systems (WSs) based on the number of connections, ranging from 1 connection for a restaurant or resort (i.e., WS4) to more than 20 000 connections (i.e., WS1) (USEPA 2006*a*). Sometimes, one utility is responsible for providing water to two or more WSSs. In

Fig. 1. Framework of approach adopted for critical review. O&M, operation and management; SM-WSS, small- and medium-sized water supply system; WSS, water supply system.



this case, the performance of the WSS should be evaluated separately if the water source, the funding sources, and the management hierarchy (particularly for operation and maintenance) are independent. In this paper, both terms WSS and water utility have been used interchangeably depending on the context of the discussion.

Each classification system presented in Table 1 has its own constraints. For example, there is a large difference between the population served and the number of connection ratio in developing countries as compared with the developed world due to high population densities and larger number of persons per connection, particularly in urban areas (WSP 2009). Secondly, the variations in per capita water consumption are also large enough to relate the community size with the flow requirements due to type of supply and standard of living. Every country or region should characterize the size of a municipality keeping in mind all the relevant factors discussed earlier in the paper. In general, utilities having population greater than 100 000, number of connections greater than 10 000, and demand higher than 50 million gallons per day (MGD) are considered as large municipalities.

2.2. Difference between L-WSSs and SM-WSSs

There are several factors that make the SM-WSS different from the L-WSS, some of which are directly related to the size of the system. Factors specific to the SM-WSS are as follows:

- Relatively new inclusions to developments in the proximity of large cities;
- Pipe sizes are small (thus less costly) due to less water demand;
- Less impact of natural resources due to relatively small water withdrawals; and
- Less production of greenhouse gases (GHG) emissions from energy consumption.

In other cases, factors are site specific and might not be applicable to all SM-WSSs, particularly in the case of privately-operated, organized water supplies in developed countries. These factors may include

- Lack of financial resources;
- Low capital and operation costs (if compared on the basis of same water source type);

Fig. 2. Schematic schemes of water supply systems based on different types of sources: (*a*) fresh surface water source; (*b*) fresh groundwater sources; (*c*) saline groundwater source; and (*d*) saline surface water source. OHR, overhead reservoir; RO, reverse osmosis.

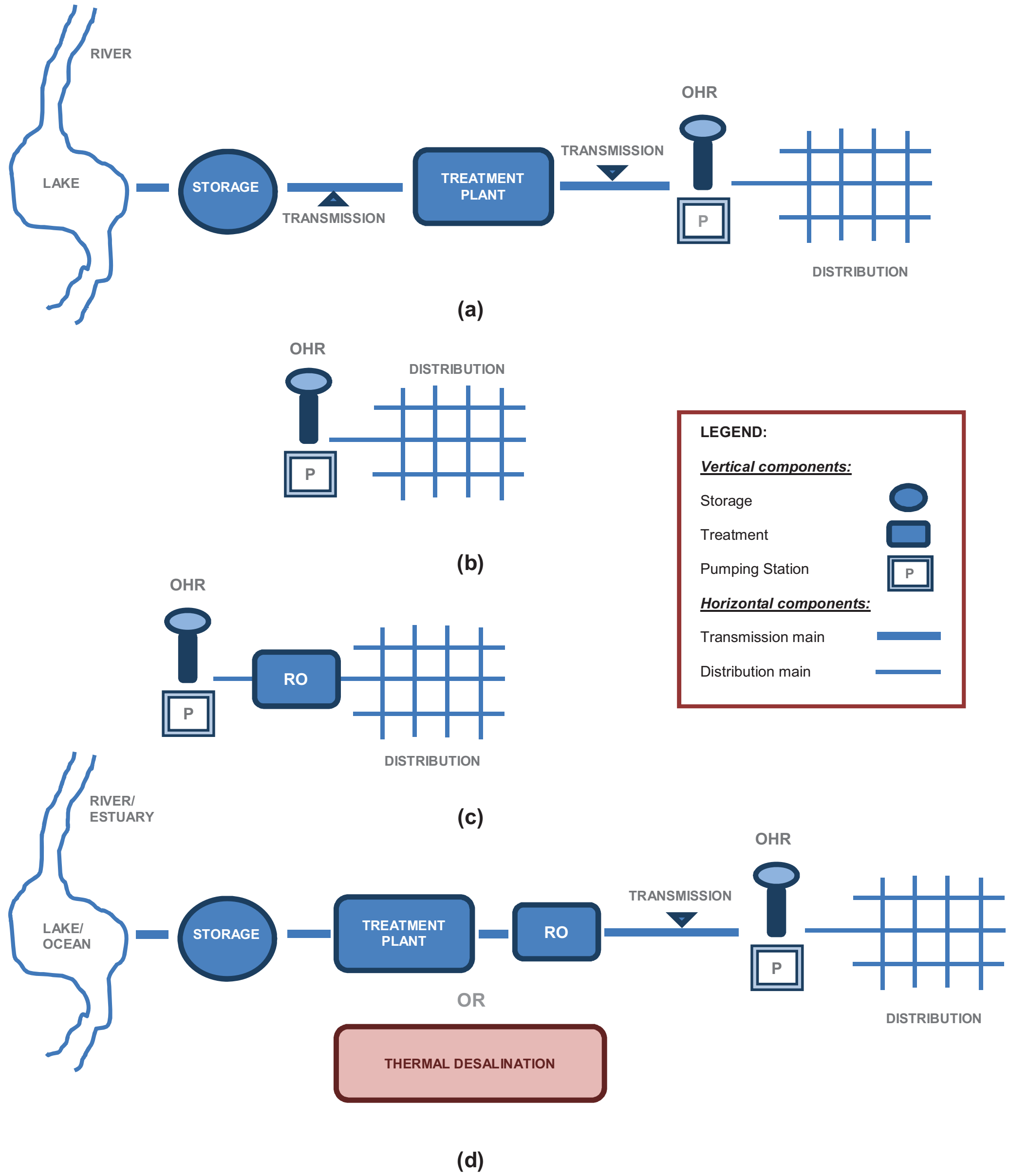


Table 1. Various basis of size-based classification of water utilities.

System size	USEPA (2002) (population served)	USEPA (2009) (population served)	World Bank (2002) (population served)	New Zealand (Lambert and Taylor 2010) (No. of service connections)	SA Water Research Council (McKenzie and Lambert 2002) (No. of service connections)	AWWA (USEPA 2007) (flow MGD)
	Country/agency with basis of classification					
Large	>50 000	>100 000	>500 000	>10 000	>50 000	>50
Medium	3300–50 000	3300–100 000	125 000–500 000	2500–10 000	10 000–50 000	5–50
Small	<3300	<3300	<125 000	<2500	<10 000	<5

Note: AWWA, American Water Works Association; SA, South Africa; USEPA, United States Environmental Protection Agency.

- Lack of technical staff, equipment, and vehicles;
- Lack of awareness and access to recent technologies (true for both public and private water suppliers); and
- Less intention to manage and more to replace and (or) renew the system components.

To qualitatively and quantitatively justify these differences, a detailed inventory of different types and sizes of utilities operating around the globe is required, which unfortunately is not readily available in the literature and (or) might have not been reported owing to lack of attention given to performance evaluation of SM-WSS utilities to date. A notable exception is the periodic reporting for drinking water infrastructure future needs in the United States by the United States Environmental Protection Agency (USEPA). Therefore, a brief review of these reports is presented in the following section as a useful case study to understand the differences between L-WSSs and SM-WSSs.

2.2.1. United States Environmental Protection Agency drinking water infrastructure needs surveys — a case study

The USEPA has been publishing "Drinking water infrastructure needs survey and assessment for next 20 years" reports periodically for the years 1995, 1999, 2003, and 2007, which were published in years 1997, 2001, 2005, and 2009, respectively. The findings of the most recent report, published in 2009 for all types of systems, are shown in Fig. 3. According to this report, the percentages of the population living in S-WSSs and L-WSSs are 9% and 45%, respectively. It can also be seen in Fig. 3 that M-WSS have proportionate (45%) total financial needs for 45% of the total population (USEPA 2009), whereas the S-WSSs account for almost double (18%) of the community's water system financial needs per percentage of population (i.e., 9%) due to low economies of scale.

Financial needs for the year 2007, distributed by component, are presented in Fig. 3; maximum (more than 60%) financial needs have been estimated for improvements of distribution systems, and the remaining 40% is for treatment (filtration, disinfection, and corrosion control) and source (surface water intake structures, drilled wells, and spring collectors). These statistics could be explained by very limited requirements (only plain chlorination practice) in case of a fresh groundwater source (Fig. 2*b*). A shift in trend of the distribution system investment needs for all sizes of WSSs can be seen in Fig. 4. The reason for MS-WSSs having the highest investment needs could be the change in population limits from 50 000 to 100 000 people. It is possible that some L-WSSs may have moved into the M-WSS category since 2007.

According to the USEPA evaluation study on S-WSSs conducted from June 2005 to December 2005, these systems are facing many challenges (as described earlier in the paper) along with regulatory and (or) compliance challenges. Massachusetts officials stated that if the required amount for system improvement is less than $100 000, it is not cost-efficient for a small system to furnish a loan application (USEPA 2006*a*). Moreover, S-WSS lack in economies of scale (lower capital cost but high O&M cost per household) as compared with large systems and thus are likely to be lacking in their technical, financial, and management capacities (USEPA 2001; Dziegielewski and Bik 2004; Brown 2004; Maras 2004; Braden and Mankin 2004).

2.2.2. Source water

The selection and application of different PIs related to various components of a WSS depend on the type of source water, regardless of the size of the system. A small-sized WSS relying on surface water source (Fig. 1*a*) has to consider PIs related to water storage and treatment facilities; on the other hand, performance of a large-sized WSS with a fresh groundwater source (Fig. 1*b*) can be evaluated without such PIs.

2.2.3. System age and pipe size

American Water Works Association (AWWA) conducted a Community Water System Survey in 2000 on 1806 systems of all population sizes provided by the USEPA (2007). A summary of the percentage of pipe per system by age for each size of system (population served) is shown in Fig. 5. It can be observed that most of the pipes (more than 80%) in SM-WSSs are less than 40 years old. Therefore, the operational difficulties related to pipe age of SM-WSSs might be less than those of L-WSSs.

The USEPA (2007) report also included results for an average length (miles) of each size pipe, from less than 6 in. (1 inch = 2.54 cm) to greater than 10 in., in different system sizes; and these results are shown in Fig. 6. From Fig. 6, it can be clearly seen that pipe mains

Fig. 3. Total 20-year financial need by system size and project and (or) component type (in billions of January 2007 dollars) (developed using USEPA 2009 data). L-WSS, large-sized water supply system; M-WSS, medium-sized water supply system; S-WSS, small-sized water supply system.

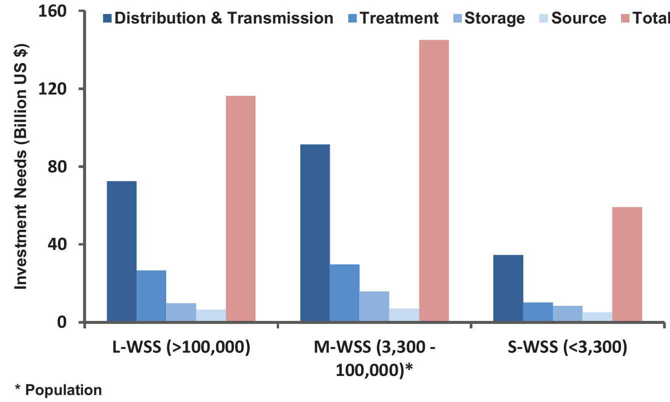
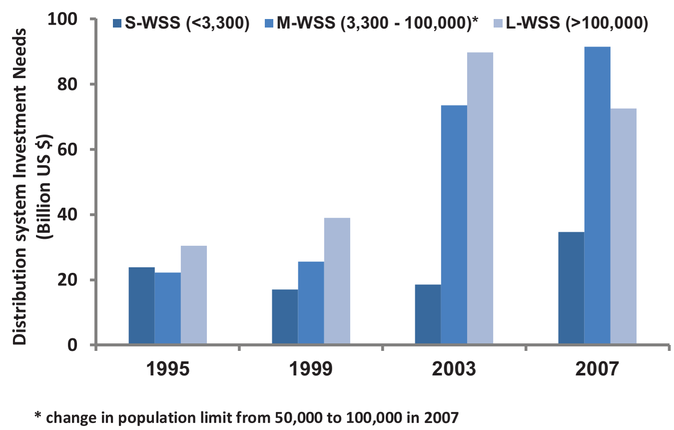


Fig. 4. Variation in 20-year distribution system investment needs by system size from 1995 to 2007, according to USEPA infrastructure needs survey and assessment for United States (developed using USEPA 1997, 2001, 2005, 2009 data). L-WSS, large-sized water supply system; M-WSS, medium-sized water supply system; S-WSS, small-sized water supply system.



having sizes greater than 10 in. exist mainly in L-WSS. Most of the pipe diameters in SM-WSSs are less than 6 in.; therefore, conventional and expansive condition assessment technologies applicable to L-WSSs cannot be applied to SM-WSSs. To make on-time and optimized decisions, rational PIs can play an effective role for such systems.

2.2.4. Public health risk

According to Ford et al. (2005), the public health problems faced by a S-WSS are different than those experienced by large systems. The following reasons for this have been reported in the literature (USEPA 2006*a*; Hamilton et al. 2004):

- Higher exposure of pathogens due to operational issues in chlorination practices;
- Inadequacy of treatment systems to deal with outbreaks;
- Limited financial resources for monitoring and mitigation measures;
- Lack of trained laboratory staff;
- Higher concentrations of nitrates and pesticides in source water due to more farming activities in rural proximity; and
- Overall mismanagement such as lack of preventive maintenance, poorly designed and constructed facilities, and inefficient operation and maintenance.

Fig. 5. Percent of pipe system by age class in different system sizes (developed using USEPA 2007 data). L-WSS, large-sized water supply system; M-WSS, medium-sized water supply system; S-WSS, small-sized water supply system.

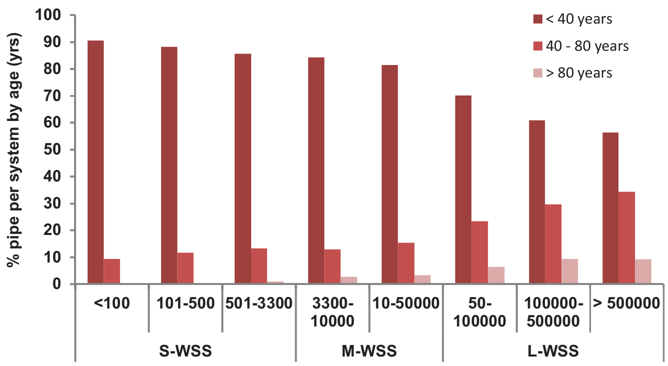
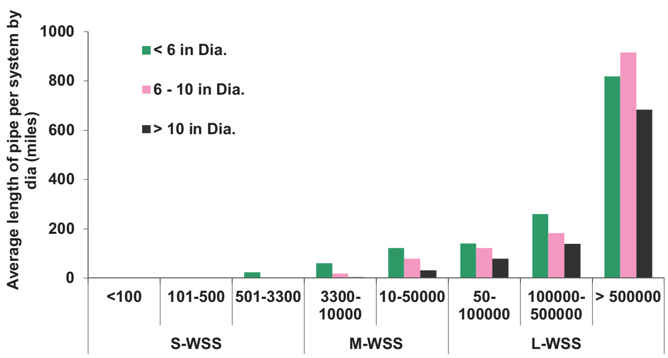


Fig. 6. Average miles of pipe per system by diameter in different system sizes (developed using USEPA 2007 data). L-WSS, large-sized water supply system; M-WSS, medium-sized water supply system; S-WSS, small-sized water supply system.



Meeting drinking water quality standards is most difficult for small systems. USEPA (2006*a*) statistics over the years have shown that noncompliance with drinking water regulations increases as the size of the system decreases because of inadequate resources in terms of both equipment maintenance and qualified operators.

2.2.5. Operation and management systems

Management capacity is one of the most important components of successful operations of a WSS. The main problem particularly with S-WSSs is lack of fully qualified technical individuals (i.e., in many cases, drinking water operations are not their sole occupation). According to Braden and Mankin (2004), many small communities are struggling to evaluate required improvements, generate funds, and manage the more advanced systems required to meet drinking water standards. They also reported that most of the small systems cannot attract and (or) retain officials with the required knowledge because of poor pay scales and low job recognition (Ford et al. 2005). Consequently, they are operating with part-time technical personnel and few staff members to plan, oversee, and manage infrastructure improvements. Moreover, most of the systems do not have effective leadership.

2.2.6. Physical, water quality, and environmental sustainability

In a distribution system, the common problems are associated with loss of water or pressure due to leakage and pipe breaks. There is always a trade-off between the cost of increasing water production and the cost of repair; however, this might not be practical for SM-WSSs facing water scarcity issues or limited capacity at source waters. Another point of view is that it is cost-effective for SM-WSSs to simply fix lines when they break. In Australia, the best risk management approach for smaller systems is focused on responsiveness to pipe failure to reduce the cost per break repair and the time out of water (Cromwell et al. 2001).

Detailed condition assessments of small mains having lower priority risks, using statistical analysis of raw data on certain parameters such as break trends segmented by pipe material and soil type to evaluate overall replacement needs, would not cost as much as other forms of actual condition assessment of specific lines (Sadiq et al. 2010). On the other hand, nondestructive testing (e.g., closed-circuit television (CCTV) cameras) are limited to larger diameter pipe (i.e., typically ≥24 in. diameter in the US) due to high costs involved in testing procedures (Liu et al. 2012). Most condition assessment methods are expensive for SM-WSSs; therefore, only reliable and effective PA can help with decisions regarding their practical application.

Performance indicators related to environmental and socioeconomic sustainability of SM-WSSs should also be considered in the overall PA framework. In any WSS, energy is consumed in several operation and maintenance activities. Moreover, higher water usage not only impacts water resources directly but also generates large wastewater volumes, which eventually leads to huge energy requirements for treatment, reuse or final disposal. Greenhouse gases (GHG) generated by all these activities are responsible for climate and hydrological changes (Parfitt et al. 2012). The components of a WSS shown in Fig. 2 are interdependent; inefficient working of any of these components leads to the loss of either water or energy or both. Therefore, it is important to maintain the efficient performance of all the components of a small- or medium-sized WSS to conserve both water and energy. Sometimes SM-WSSs are located close to each other and rely on the same water source. In this case, sustainability indicators including climate change impact on water availability in source water should also be included in the PA framework. Other environmental concerns such as impacts of chlorinated water on aquatic life due to leakage in a water mains and flushing of pipes passing through or nearby natural water bodies need to be addressed with the help of suitable environmental PIs. In general, the concentration of residual chlorine in water distribution systems ranges between 0.5 and 1 $mg \cdot L^{-1}$; meanwhile, much smaller concentrations can significantly affect fish and other aquatic microorganisms (Donald and Dorothy 1977).

Performance indicators can be used to describe the overall level of service (LOS) including various components (storage, treatment, distribution, etc.) and sectors (physical, customer services, environmental, financial, etc.) of a WSS. Therefore, keeping in view the specific differences between the L-WSS and SM-WSS, an effort is made in the subsequent sections to evaluate the available PI systems to select the most significant, easy to understand and measure, and economically viable key PIs for SM-WSSs.

3. Literature review of performance indicators for water supply systems

Performance is the degree to which infrastructure provides the services to meet the community expectations and it is a measure of effectiveness, reliability, and cost (NRC 1995). The performance of a WSS depends on efficient and reliable working of all functional components including water resources, physical assets, operational activities, personnel, and environmental and financial activities. The performance of a WSS is evaluated to indirectly estimate the conditions and rehabilitation needs to ensure continuous and reliable working of all of these components of a WSS during their entire service life before the occurrence of a failure. Once a failure has occurred, the cost of corrective action is much more than planned preventive action would have been. The difference between the planning and management cost and the cost of corrective actions justifies the need for PA.

There are several methods of performance evaluation of water utilities given in the literature, including PIs, total factor productivity indices, and production frontiers (Coelli et al. 2003). However, for methods other than PIs, more sophisticated data are required, which is difficult to acquire or is sometimes even missing in the case of most SM-WSSs, due to ongoing restructuring and expansions and inadequate information technology. There is no single definition of performance; however, the good performance is the one that satisfies the stakeholder's needs. Review of literature in the following sections starts with a brief overview of commonly used terminology and history of PIs followed by a comprehensive review on recent developments.

3.1. Terminology and historical background of performance indicators

The Canadian Water and Wastewater Association (CWWA) (2009) briefly defined the terms PIs, variables, benchmarks, and target as follows:

Performance indicator. A PI is a parameter or a value derived from other parameters, which provides information about the achievements of an activity, a process or an organization with a significance extending beyond that directly associated with the calculated value of the parameter itself. For example, the average number of litres of water supplied per person per day. Indicators are typically expressed as commensurate or noncommensurate ratios between the variables.

Variables. Performance indicators involve the measurement of data variables generated by analysis of the service performed. The selected variables should be easy to understand; accurately measureable with available equipment, staff, and funds; easily reproducible or comparable; should refer to the geographical area and reference time of the study area; and be relevant to the indicator to be developed. These are basically the baseline data required to determine the associated value of a PI, e.g., number of service connections, population served, total water main length, and annual costs.

Benchmark. This is a numerical point of reference generally for the past or present. For example, in 2008, the average supply of water to residential customers was 350 L·per person per·day. The benchmark values established for the future should be considered as targets.

Target. A target in reference is a determined value for the PI, which is to be achieved over time (future) through the conduct of a program. For example, a target for average water supply would be to reduce average demand to 300 L·per person per·day by 2012.

The International Water Supply Association (IWSA) selected the topic "Performance Indicators" for one of its world congresses during the early 90s, but the concept could not garner much interest. However, 3 to 4 years later this concept was highlighted by a number of senior members of water utilities. A good PI system is one that contains PIs which are fewer in number, clearly defined, nonoverlapping, useful for global application (i.e., wider applicability), easily understandable, refer to a certain time period (i.e., preferably one year), address a well-defined geographical area, and represent all the relevant aspects of water utility performance (Alegre 1999).

The National Civil Engineering Laboratory (NCEL) in Portugal proposed a hierarchical structure of PIs, including four main groups, for the first time in 1993. Each group consists of a number of PIs and a subset of indicators in the upper layer (Matos et al. 1993). Later in 1994 and 1995, the Portuguese Association of Water Resources (APRH) and NCEL jointly proposed a hierarchical structure of LOS into four categories (i.e., organization, engineering, environmental, and capital) (Defaria and Alegre 1996) (Fig. 7). This structure is more efficient, as it provides the basis of PA of the organization staff and also incorporates consideration of environmental impacts on the water resources.

Alegre (1999) carried out a comprehensive review of the development of the conceptual framework and PIs for WSSs. The work done by various agencies and researchers on PA of WSSs before 2000 was covered in that review (NCEL, Portugal, Matos et al. 1993; American Water Works Association Research Foundation, Alegre 1999; APRH, Portugal, Defaria and Alegre 1996; Malaysian Water Association 1996; Water and Sanitation Division, World Bank (WB), Yeppes and Dianderas 1996; Asian Development Bank (ADB), McIntosh and Ynoguez 1997; Dutch Contact Club for Water Companies and The 6-cities group of the Nordic Countries, Van Der Willigan 1997; IWSA, Alegre 1999). The findings of this review reveal that water resources, water quality, and environmental indicators were not given sufficient importance until 1997. One of the reasons could be fewer environmental issues due to relatively lower population and low water demands; moreover, awareness about addressing environmental problems more effectively has also been accelerated during the 21st century. State-of-the-art developments in PIs for WSSs by the major agencies in various parts of the world are presented in the following section.

3.2. International Water Association manual of best practice

According to Alegre (1999), PIs are used to assess the performance of a WSS in terms of efficiency and effectiveness. The efficiency is a measure of the extent to which the resources of a WSS are utilized optimally to provide the service (i.e., ratio between input consumed and output achieved); and effectiveness is a measure of the extent to which the targeted objectives (specifically and realistically defined) of the utility as a whole and its management units are achieved. The first edition of International Water Association (IWA) manual of best practices was published in July 2000. The PI system was developed through close collaboration with international managers, practitioners, and researchers (Nurnberg 2001). This manual was applied for the benchmarking process in many water supply projects around the world, particularly in Europe, including Austria and Germany (Theuretzbacher-Fritz et al. 2005). An overview of the PA studies of WSSs (about 30 large-scale companies, 270 medium- and small-scale utilities, and about 20 bulk supply companies) in Germany was presented in IWA world water congress Berlin 2001, including the legal framework and technical standards. It was observed that all of them were using different approaches for their PA and thus there was a lack of a standardized assessment system. The use of IWA manual of best practice (Performance indicators for water supply systems) for standardized and comparable PA was recommended by the congress (Nurnberg 2001).

The general concept of this manual was based on the concept of a layered pyramid structure, starting from raw data at the bottom, feeding the PIs on the above layers (Fig. 8). This structure consists of a theme of indicators, subindicators, and variables. Alegre et al. (2000) structured more than 150 PIs in six categories (i.e., water resources, personnel, physical, operational, quality of service, and economic and financial). These groups help users identify the purpose of a specific indicator and are given a two-letter code (e.g., "Pe" represents "personnel"). Each group is divided into subgroups for further understanding (e.g., total personnel, personnel per main function, personnel qualification). These subgroups consist of a number of PIs calculated from variables and are expressed in specific units like percentages and ratios. Variables are the baseline data elements consisting of measured or recorded values in specific units. All these measured values are required to be used with certain accuracy and reliability bands to indicate the quality of the observed data (Alegre et al. 2000).

These PIs were further prioritized on the basis of their relative importance as levels 1, 2, and 3. Level 1 is the first layer of indicators that provides a synthetic global overview of the efficiency and effectiveness of the water undertaking. Level 2 consists of additional indicators, which provide a more detailed insight than the

Fig. 7. The concept of the Defaria and Alegre (1996) level of service framework.

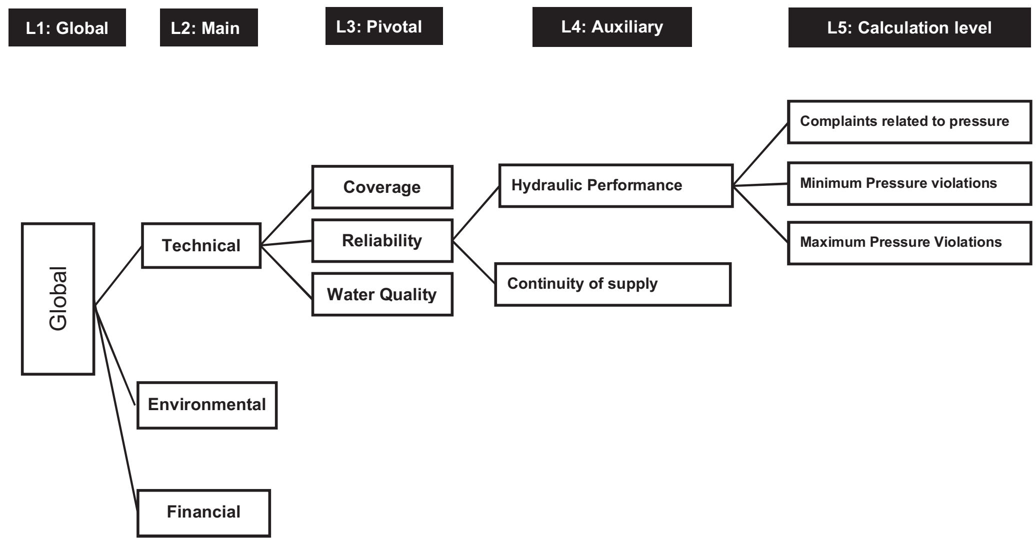
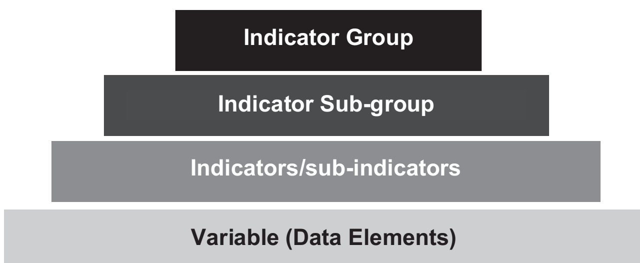


Fig. 8. Concept of layer pyramid used by Alegre et al. (2000) for calculating performance indicators.



Level 1 indicators for users who need to go further in depth. Level 3 indicators provide the referred comprehensive global assessment of the undertaking assessment (Alegre et al. 2000, 2006). This level-based structure can provide a basis to start a performance evaluation process of a SM-WSS having proportionate human and financial resources according to its size with Level 1 indicators. Moreover, in the case of SM-WSSs, it could be possible that Level 3 indicators are not important. The IWA published the 2nd edition of its manual in 2006. In this edition, the total number of PIs increased to 170; however, no changes were made in categories of PIs (Alegre et al. 2006). This reference in this review has been used as IWA (2006) for the purpose of comparison between different agencies. A summary of PIs along with a number of subindicators is presented in Table 2. Detail of subindicators and allocated levels is beyond the scope of this paper. However, it can be seen in Table 2 that the system seems to be well balanced and covers all aspects of a WSS. Indicator subgroups (in each category) provide a way to effectively interpret an indicator; for example, the subgroup of "pressure and continuity" is placed under the category of quality of service. This subgroup further contains eight PIs related to pressure and continuity of supply, such as adequacy of supply pressure at delivery points in terms of percentage and number of water interruptions per thousand connections, respectively. This system of indicators seems to be well structured with wider applicability and provides room to include new indicators as well. Water quality has also been given sufficient importance by explaining aesthetic, physical–chemical, and biological indicators separately. However, more recently identified environmental indicators such as GHG emissions have not been included, though they can be added or calculated separately by the utility. SigmaLite (2.0) software (ITA, Valencia, Spain) was developed on the basis of the framework proposed in the 2nd edition of the IWA manual. Details can be seen at www.sigmalite.com. The software also generates charts to compare the calculated PIs with the benchmark values for PA.

3.3. The World Bank

The International Benchmarking Network for Water and Sanitation Utilities (IBNET) was launched in 1996 under the water and sanitation program of the WB. The IBNET was developed by the Energy and Water Department of the WB with the aim to provide access to comparative information of different utilities and promote best practices among water supply and sanitation providers worldwide. The IBNET provides standardized measurements (i.e., a set of tools) to the water suppliers to assess their own operational and financial performance and against the performance of similar WSSs at national, regional, and global levels. Through the IBNET platform, the water and sanitation utilities from all around the world, including South Asia and Africa, found an opportunity to compile and share the financial costs and the PIs (Berg and Danilenko 2011).

This reference has been used as WB (2011) for the purpose of comparison between different agencies. The IBNET is a toolkit having a set of financial, technical, and process indicators, which provides a gradual approach to utilities having little or no variables in data to calculate the indicators, by providing a "startup kit" to move slowly towards a more advanced performance benchmarking system. In this way, this could be a useful option to use for PA of SM-WSS facilities having less available data and resources in developing countries. However, the toolkit does not cover a large number of indicators that have been used by water supply agencies in developed countries, irrespective of the community size, such as IWA (2006).

The IBNET categorizes 80 selected PIs into 12 groups as presented in Table 3 (Berg and Danilenko 2011). Along with the categories mentioned in Table 3, the manual also address eight normalizing factors (e.g., the operating cost, staff, revenue, and system failure indicators use one or more of population, number of connections, volume, and network length). This is the general data related to the asset and is used in quantification of other indicators as well. Indicators of water production and consumption are addressed in volume of water consumed by one person in a day or month, which is the measure of volume supplied and consumed by the community and depends on the availability of water and other factors affecting water consumption. These units ($L \cdot person^{-1} \cdot day^{-1}$) are system variables and might not be a measure of the system's performance. However, the ratio between them (water supplied and consumed) can be used to deter-

Table 2. International Water Association manual of performance indicators for water supply services (IWA 2006).

Indicator category	Indicator subgroup	Description of subgroups with number of PIs in each subgroup*	Total No. of PIs in each indicator category
Water resources	2	• Water resources availability (2) • Usage efficiency and reuse (2)	4
Personnel	7	• Personnel data (2) • Personnel per function (7) • Technical services personnel per activity (6) • Personnel qualification (3) • Personnel training (3) • Personnel health and safety (4) • Overtime work (1)	26
Physical	6	• Treatment (1) • Storage (2) • Pumping (4) • Transmission and distribution (2) • Metering coverage (4) • Automation and control (2)	15
Operational	9	• Inspection and maintenance of physical assets (6) • Instrumentation calibration (5) • Electrical and signal transmission equipment installation (4) • Mains, valves, and service connection rehabilitation (5) • Pumps rehabilitation (2) • Water losses (7) • Failures (6) • Water metering efficiency (4) • Water quality monitoring (5)	44
Quality of service	6	• Coverage (5) • Public taps and standpipes (4) • Pressure and continuity of supply (8) • Quality of supplied water (5) • Service connection and meter installation and repairs (3) • Customer complaints (9)	34
Financial and economic	13	• Revenues (3) • Costs (3) • Composition of running costs for type of costs (5) • Composition of running costs per main function of the water undertaking (5) • Composition of running costs per technical function activity (6) • Composition of capital costs (2) • Investments (3) • Average water charges (2) • Efficiency indicators (9) • Leverage indicators (2) • Liquidity (1) • Profitability (4) • Water losses (2)	47
Total	**43**		**170**

*Only the types of indicators are described with number of subindicators in parentheses.

mine the water losses. Service coverage is taken as a separate category in IBNET, whereas in IWA (2006) the coverage indicators are considered in the quality of service category. Water losses are taken up as nonrevenue water. The IBNET system assesses the network performance in terms of number of breaks per kilometres per year; this indicator along with other water loss indicators is considered under the operational category in the IWA manual. Network performance is not only a function of pipe breaks, but other indicators associated with water quality and aesthetic issues also dictate the performance of a pipe network. Therefore, this indicator essentially provides information only about structural failure of a water distribution system (WDS). In the IBNET system of PIs, only metering is considered amongst all the physical components of the WDS, whereas other important indicators including pumping, valves, hydrants, treatment, and storage are not addressed. Other categories mentioned in Table 3 (i.e., operating costs and staff, billing and collections, financial performance, and assets) are mainly financial and (or) economic indicators and could be addressed under one category with subdivisions to simplify the overall structure of the system. However, affordability could be an important indicator for future investment planning in the water sector, particularly in developing countries. In water quality parameters only residual chlorine is considered, and overall impacts on water resources and environment (e.g., drought, GHG emissions) are also missing. Overall, the IBNET system appears to be suitable for cross-utility and cross-country performance comparisons in developing countries.

3.4. National Water Commission, Australia

The Australian Government's National Water Commission (NWC) has developed a national performance framework (NPF) for performance evaluation of both urban and rural water utilities in Australia.

Table 3. International Benchmarking Network for Water and Sanitation Utilities system of performance indicators (World Bank 2011).

Indicator category	Total No. of indicators	Performance indicators*
Process indicators	19	• Utility planning description (1) • Management of utility including training strategy, appraisal setting, etc. (5) • Higher management (1) • Types of financial resources (4) • Level of services offered by the utility (4) • Utility's procedures to assess customer satisfaction (4)
Service coverage	3	• Percentage of population covered with easy access (1) • Population coverage per household connection and per public point (2)
Water consumption and production	11	• Water production and consumption per person per day (2) • Water production and consumption per connection per month (2) • Water consumption subdivided into customer type categories, etc. (4) • Residential water consumption per person per connection, etc. (3)
Non-revenue water	3	• Non-revenue water as a percentage; volume per kilometre per day; and volume per connection per day (3)
Meters	2	• Metering level • Volume of sold water to metered connections
Network performance	1	• Pipe breaks
Operating costs and staff	12	• Operational costs of water produced and sold (4) • Staff per 1000 connections, and per 1000 persons (5) • Percentage of labour cost as total operational cost (1) • Percentage of energy cost as total operational cost (1) • Percentage of service contracted-out to the private sector (1)
Quality of service	5	• Service continuity (2) • Quality of water (2) • Total number of complaints (1)
Billing and collections	20	• Revenue (10) • Tariff structure (6) • Connection charges (2) • Collection period and efficiency (2)
Financial performance	2	• Operating cost coverage • Debt service ratio
Assets	1	• Fixed water assets per population served
Affordability/purchasing power parity	1	• This indicator includes the indicators of revenue, tariff and connection charges and is estimated by converting gross national income into US dollars for international comparison. Purchasing power parity takes account of what can be purchased locally and should be considered for indicators of what customers pay
Total	**80**	

*Only the types of indicators are described with number of indicators in parentheses.

The commission selected only 32 PIs grouped into four categories (i.e., characteristics, customer service level, environmental and water management, and financial) for comparative analysis of rural water utilities. For urban water utilities, the selected 116 PIs have been grouped into seven categories (i.e., water resources, asset data, costumers, environment, public health, finance, and pricing). The commission has been publishing annual reports on performance reporting indicators and definitions since 2005 (NWC 2012). Unlike in the IWA manual, all the indicators are not calculated as ratios, divisions, and percentages. The reason could be that this framework is used to compare the performance of utilities operating specifically in Australia under similar water resources and environmental conditions. A summary of the PIs is presented in Table 4.

The dry conditions resulting in water shortages have led Australia to partially rely on "rainfall independent supplies to enhance the water security in the country" such as desalination of sea water, recycled water, etc. (NWC 2012; Chartres and Williams 2006; Bari et al. 2005). Moreover, per capita water consumption in Australia is one of the highest in the world (Stoeckel and Abrahams 2007). Due to these issues, water resource indicators have been given primary importance in Table 4. Twenty-three PIs of water supply provide detailed insight to all possibilities of the water resources (e.g., ground water, surface water, desalinated marine water, desalinated ground water); the types of supplies (e.g., residential, commercial, industrial); and the water quality (potable and nonpotable). An example of the indicator "Total sourced water" is presented in Fig. 9. The indicators selected in this system are not defined as data elements or variables, subindicators or process indicators. For example, all the indicators given in Fig. 9 are essentially the data values (i.e., volume of water sourced) (see the comments in Table 4). These values cannot provide the basis of cross-comparison with other similar WSSs at an international level. In this connection, these PIs need to be calculated in terms of per thousand of population served or similar units. Indicators like percentage of recycled water can be compared with other WSSs practicing the same concept of reuse of supplied water (after applying desired level of wastewater treatment).

The way environmental indicators are addressed in the NWC (2012) framework, in terms of GHG emissions, is worth mentioning. Most of the development activities are generating various types of GHG such as CO_2, CH_4, and N_2O, which eventually lead to

Table 4. Performance indicators used by National Water Commission, Australia (NWC 2012).

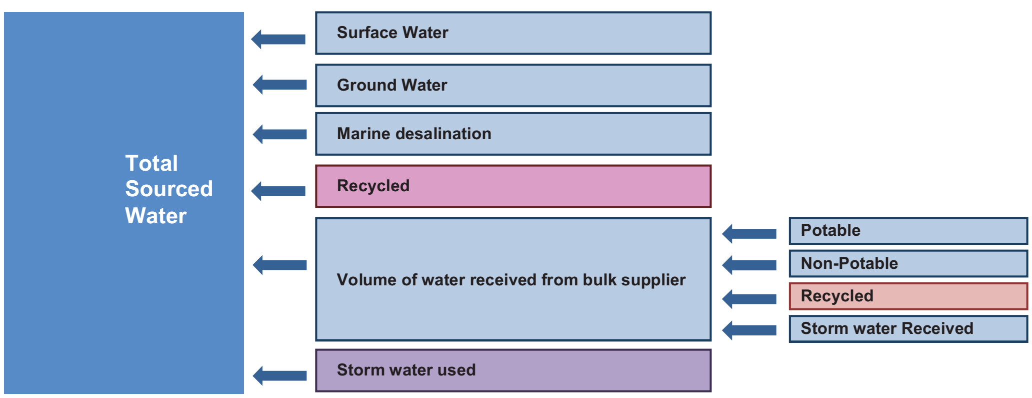
Indicator category	Total No. of indicators	Performance indicators*	Comments
Water resources	23 indicators and 23 subindicators	• Volume of water sources from surface water • Volume of water sourced from ground water • Volume of water sourced from desalination (3 subindicators) • Volume of water sourced from recycling • Volume of water received from bulk supplier (2 subindicators) • Volume of bulk recycled water purchased • Total sourced water	• 7 indicators of water sources with 3 subindicators (desalination of marine, ground, and surface waters) and 2 subindicators for potable and non-potable water received from bulk supplier.
		• Volume of water supplied – residential (2 subindicators) • Volume of water supplied commercial, municipal, and industrial (2 subindicators) • Volume of water supplied – other (4 subindicators) • Total urban water supplied (3 subindicators) • Average annual residential water supplied • Volume of water supplied – environmental • Volume of the bulk water exports (2 subindicators) • Volume of the bulk recycled water exports	• 6 indicators of water supplied with 9 subindicators classifying various types of supply and water quality (i.e., potable or non-potable).
		• Volume of the recycled water supplied – residential • Volume of the recycled water supplied – commercial • Volume of the recycled water supplied – agriculture • Volume of the recycled water supplied – environmental • Volume of the recycled water supplied – onsite • Total recycled water supplied (2 subindicators) • Recycled water (% of effluent recycled) • Total volume of urban stormwater discharges (4 subindicators)	• 8 indicators of recycled water. • Indicator of stormwater supply to different users has further subindicators for various users (i.e., infrastructure operators, aquifer recharge, urban stormwater and urban use).
Asset	7	• Number of water treatment plants • Length of water mains • Properties served per km of water main • Water main breaks per 100 km of water mains • Infrastructure leakage index • Real losses per service connection per day • Real losses per km of water main per day	• First three indicators represent the data of a utility and essentially are not the indicators of its performance.
Customer	12	• Population receiving water supply services • Connected residential properties • Connected non-residential properties • Total connected properties • Water quality complaints per 1000 properties • Water service complaints per 1000 properties • Billing and account complaints per 1000 properties • Percentage of calls answered by an operator within 30 s • Average duration (min) of an unplanned interruption • Average frequency of unplanned interruptions • Costumers with restrictions applied for non-payment of bill per 1000 properties • Costumers faced legal action on non-payment of bill per 1000 properties	• First four indicators provide the information about customer data of the water utility.
Environment	3	• Greenhouse gas emissions (tonnes CO_2-equivalents per 1000 properties)† • Greenhouse gas emissions (tonnes CO_2-equivalents per ML) • Net greenhouse gas emissions – other (tonnes CO_2-equivalents per ML)	• Relatively new indicator, importance to assess impacts of water utilities on global warming.
Pricing	3 indicators and 16 subindicators	• Tariff structure (13 subindicators) • Annual bill based on 200 kL per year (1 subindicator) • Typical residential bill (2 subindicators)	• All the indicators are developed for a specific situation and therefore have limited applicability.

Table 4 (*concluded*).

Indicator category	Total No. of indicators	Performance indicators*	Comments
Finance	18 indicators and 4 subindicators	• Total revenue from water utility • Percentage residential revenue from usage charges • Revenue per property for water supply services (1 subindicator) • Income per property for whole of utility (1 subindicator) • Revenue from CSO • Nominal written-down replacement cost of the fixed assets • Operating cost of water per property (1 subindicator) • Total capital expenditure • Total capital expenditure property (1 subindicator) • Economic real rate of return • 8 indicators covering dividend, debt, interest net profit, and capital grants	• Revenue from CSO is an indicator for utilities where water is supplied at lower rates than its cost. • Total revenue, replacement cost, CSO, total capital expenditure, dividend, community service obligations and grants are the data elements.
Public health	7	• Water quality guidelines • Number of zones where microbiological compliance was achieved • Percentage of population where microbiological compliance was achieved • Number of zones where chemical compliance was achieved • Risk-based drinking water management plan externally assessed? (YES/NO) • Name of the risk-based drinking water management plan used • Public disclosure of drinking water performance? (YES/NO)	• Water quality guidelines, risk based water management plan, and public disclosure are data elements or overall process indicator.
Total	**73**		

Note: CSO, community service obligations.
*Only the types of indicators are described with number of subindicators in parentheses.
†CO_2-equivalents are the amounts of carbon dioxide that would have the same relative warming effect as the greenhouse gases actually emitted.

Fig. 9. An example of interaction between various indicators and subindicators in the NWC (2012) performance assessment framework.



global warming. For example, use of vehicles for water quality monitoring, bills delivery and collection, transportation of construction materials and operational equipment, and operations of pumps and motors for distribution of water at desirable pressures produces significant GHG emissions. Moreover, most of the supplied water is converted into wastewater after use and thus requires a certain degree of wastewater treatment either for reuse (to meet desired irrigation of landscaping standards) or final disposal (depending on assimilative capacity of the receiving water body). In this regard, different wastewater treatment plant operations also utilize energy and thus produce GHG emissions. The Commonwealth of Australia (CWA) (2011) expresses different emission factors in terms of a quantity of a given GHG emitted per unit of energy (e.g., kg CO_2-e·(GJ)$^{-1}$ for energy (e, equivalent); tCH_4·(t coal)$^{-1}$ for fuel). These emission factors were used to calculate GHG emissions with activity data (e.g., kilolitres multiplied by energy density of petrol used). In the NWC (2012) framework, the overall GHG emissions from each activity of a WSS have been calculated as CO_2-equivalent. The CO_2-equivalents are the amounts of CO_2 that would have the same relative warming effect as the GHG actually emitted. It is desirable to consider indicators concerning global climate change for sustainable development in water sector.

The indicator system proposed by NWC (2012) could be very useful in areas facing water shortage or droughts. The framework shown in Fig. 9 is indeed very comprehensive and provides a deep insight to the interrelationships between different water resource indicators. Similar interactions have been developed between different indicators for other groups. Details can be seen in NWC (2012). However, certain very important indicators such as personnel and operational (pump, storage, network inspection, leakage inspection, etc.) have not been addressed. In case of a very detailed organizational and administrative structure of a WSS, like the one in Australia, indicators related to personnel and operational efficiency might not be significantly important for consideration. However, for SM-WSSs around the world where technical staff availability to solve day to day operational problems varies from system to system, these indicators are inevitable for the overall PA.

3.5. American Water Works Association

The American Water Works Association (AWWA), established in 1881, is the first scientific research organization of drinking water in North America. American Water Works Association started the performance evaluation of their water utilities in 1995 under the utility quality service program. In one of their early documents, titled "Distribution system performance evaluation" and published in 1995, criteria consisting of adequacy (quantity and quality), dependability (interruptions), and efficiency (utilization of resources) were used to evaluate the performance of a WDS. The main focus of discussion was related to distribution system components, and no detailed discussion was provided on environmental and water resource PIs.

Later in 2004, the AWWA launched the QualServe Benchmarking Program (originally named as a utility quality service program) and proposed a set of high level (most important) PIs with a goal to facilitate interutility comparisons for utility managers (i.e., in case a utility consists of more than one WSS) and intrautility trend analysis. Later, with experience, lower level indicators can be added to measure the performance of each operational process of a water utility. In this benchmarking program 22 combined PIs were suggested for various operations of water and wastewater utilities. Amongst these 22 indicators, 17 indicators are applicable to water supply. Some of these indicators comprised a set of indicators (or subindicators), which makes a total count of 35 indicators (Lafferty and Lauer 2005).

The PIs in the AWWA (2004) framework have been divided into four groups including organizational development, customer relations, business operations, and water operations. The indicator system showing groups of PIs along with individual indicators is presented in Table 5. Using the PIs given in Table 5, the AWWA published a survey data and analysis report in 2005 for benchmarking PIs of 202 water utilities across North America. Among the participating utilities in the survey, only 21% were SM-WSSs with a population <100 000. These results also show the lower participation tendency of such WSSs in the benchmarking process. It is also reported that SM-WSSs were operated at more residential cost (customer relation indicator) than the L-WSSs. However, water distribution pipelines renewal and replacement rates (business operations indicator) were much lower in SM-WSSs than L-WSSs.

It is found that some of the small utilities (population <10 000) were not considered in the analysis due to insufficient sample size. It can also be observed in Table 5 that the PIs seem to be highly suitable for the benchmarking process in North American water utilities but might not be directly applicable for detailed PA with respect to specific requirements (e.g., water source and watershed characteristics) of any SM-WSSs. Environmental and water resources indicators have also not been addressed.

3.6. Office of the Water Services, United Kingdom and Wales

The technical evolution of the water industry gives an insight into the history of privatization of water utilities in United Kingdom (UK). In 1970, the British government decided to merge hundreds of medium- and (or) small-sized water companies into 10 water authorities to solve the problems associated with lack of human resources and equipment due to size. Later, the water authorities found that the existing systems had become very old and required massive investments for improvements; therefore, it was decided in 1990 to privatize all water and wastewater services in England and Wales. The consumers in England and Wales cannot choose their water supply providers, and thus the Office of the Water Services (OFWAT) monitors and compares the performance of these water companies to ensure that consumers are getting what they pay for and also check the compliance of the companies with their legal obligations (OFWAT 2010*a*).

Recently, OFWAT has reported a minimum set of 14 PIs (grouped into four categories) to review the prices and check the regulatory compliance of water companies in UK and Wales (OFWAT 2012, 2010*a*, and 2010*b*). The information regarding these selected indicators is given in Table 6 along with description of some specific indicators such as service intensive mechanism (SIM) and Security of Water Supply Index (SoSI). Service intensive mechanism is used to control the water rates, whereas SoSI indicates the guarantee a supplier can give to ensure the level of service. Moreover, sufficient importance has been given to environmental indicators.

This indicator system provides two important findings. Firstly, the system could be suitable for a regulatory authority dealing with a number of utilities, irrespective of their size. Secondly, a regulatory authority like OFWAT should have selected the most important and commonly used set of minimum indicators. At an individual level, companies have been using a much wider set of indicators (e.g., indicators covering the quality of supplied drinking water). The reason for considering such a small number of indicators could probably be the overall performance monitoring of different companies, for which financial and customer service indicators are more important to ensure customer satisfaction.

Some of these indicators are related to more than one variable and provide information regarding performance of more than one indicator with one qualitative or quantitative value. For instance, SIM is a financial mechanism to incentivize optimum levels of customer service through the price control process. It is composed of a quantitative indicator that measures complaints and unwanted contacts and a qualitative indicator that measures how satisfied customers are with the quality of service they receive, based on a survey of consumers who have had direct contact with their water company.

Service intensive mechanism can be calculated to assess the performance of the company for customer satisfaction using the following formula (OFWAT 2012, 2010*a*):

$$\text{SIM} = \underbrace{\{[(S-\text{LS})/(\text{HS}-\text{LS})] \times \text{WS}\}}_{\text{Quantitative indicator}} + \underbrace{(\{1-[(C-\text{CL})/(\text{CH}-\text{CL})]\} \times \text{WC})}_{\text{Qualitative indicator}} \tag{1}$$

where S is the satisfaction score achieved (qualitative survey); LS is the satisfaction minimum (1); HS is the satisfaction maximum (5); WS is survey weighting (50); CL is composite measure minimum (0); CH is composite measure maximum (600); WC is the quantitative composite measure weighting (50); and C is the quantitative composite measure, which can be calculated by using the following equation:

$$\begin{aligned} C = {} & [\text{all lines busy} + \text{calls abandoned} + \text{unwanted telephone contacts} + (\text{written complaints} \times 5) \\ & + (\text{escalated written complaints} \times 100) + (\text{Consumer Council of Water (CCW) investigated complaints} \times 1000)] \\ & /(\text{connected properties}/1000) \end{aligned} \tag{2}$$

Each of the elements in eqs. (1) and (2) has been given weights (i.e., the values being multiplied with the elements; for example all lines busy weighs "1" and CCW investigated weighs "1000") to reflect the increasing impact on consumers and the resulting cost to the water supply company. The overall value of SIM is calculated annually by combining the two indicators (quantitative and qualitative) with equal weightings (i.e., 50). The value of SIM is assessed as "tolerance" designated with different colours, such as green (SIM > 50), amber (SIM = 40–50), and red (SIM < 40). A higher value of SIM indicates better performance (OFWAT 2012, 2010*a*).

According to OFWAT (2012), new small-size companies are entering into the OFWT system and the set of indicator system pro-

Table 5. American Water Works Association system of performance indicators (AWWA 2008).

Indicator group	Total No. of indicators	Performance indicators*	Description
Organizational development	11	• Organizational Best Practices Index (7) • Employee Health and Safety Severity Rate • Training Hours Per Employee • Customer Accounts Per Employee (2)	• Organizational Best Practices Index is a self-assessment of the degree to which different management practices, including strategic planning, long-term financial planning, and risk management planning are implemented by a utility. • Employee Health and Safety Severity Rate is a measure of lost workdays per employee per year. • Customer Accounts per Employee, MGD Water Delivered per Employee is a measure of employee efficiency and accounts for contributions completed through contracts.
Customer relations	8	• Customer Service Complaints and Technical Quality Complaints per 1000 customers. (2 practically) • Disruptions of Water Service per 1000 active customer accounts (2) • Residential Cost of Water Service (2) • Customer Service Cost Per Account • Billing Accuracy	• Customer Service Complaints and Technical Quality Complaints per 1000 customer accounts. Practically two indicators; the first is associated to service; and the second quantifies complaints related to technical quality. • Disruptions of Water Service are measured for both planned and unplanned interruptions with respect to time (<4 h, 4 – 12 h, >12 h). • Residential Cost of Water is a suite of six indicators, following two of which are specific to water utility; – Bill amount for monthly residential water service for a customer using 7500 gallons per month. – Average residential water bill amount for one month of service. • Customer Service Cost per Account is a measure of the cost a utility bears to manage a single customer account in a year. • Billing Accuracy is a measure of the number of error-driven bill adjustments per 10 000 issued bills per year.
Business operations	4	• Debt Ratio • System Renewal or Replacement Rate (2) • Return on Assets	• Debt Ratio is a measure of utility indebtedness. • System Renewal or Replacement Rate is a measure of the degree to which a utility is renewing or replacing its infrastructure. Rates are provided for water distribution and treatment. • Return on Assets indicates the financial effectiveness of the utility.
Water operations	8	• Drinking Water Compliance • Distribution System Water Loss • Water Distribution System Integrity • Operations and Maintenance Cost Ratio (3 indicators) • Planned Maintenance Ratio (2 indicators)	• Water loss is essentially unaccounted for water. • Water Distribution System Integrity is an assessment measure of the condition of the water distribution system in terms of number of repairable breaks and leaks per 100 miles of distribution mains. • Operations and Maintenance Cost Ratio is the ratio between the cost of operations and maintenance and number of accounts per millions of gallons of produced water. • Planned Maintenance Ratio measures how effectively utilities are investing in planned maintenance. Two separate indicators in terms of cost and hours invested in maintenance activities.
Total	**31**		

*Only the types of indicators are described with number of indicators in parentheses.

posed in Table 7 has been established, keeping in view the limitations of reporting of small utilities.

3.7. The National Research Council of Canada

The National Research Council of Canada (NRC) (2010) proposed a model framework composed of three building blocks: objectives, assessment criteria, and the PIs. The National Research Council of Canada suggested six key objectives (public safety, public health, economy, environmental quality, social equity, and public security), which can only be satisfied through a feasible and durable initial design, an efficient and continuous maintenance system, the preservation activities to ensure acceptable physical condition, and acceptable levels of functionality during the entire life cycle of these important public assets (NRC 2010).

Furthermore, in the framework proposed by NRC, the PIs are evaluated for 11 assessment criteria to provide the linkage between the PIs and the objectives of the WSS. These assessment criteria are also known as “indices” or “indicator domains”. These are the statements or principles used to determine whether the specified, above-stated objectives have been met or not (either qualitatively or quantitatively). Under these objectives, 31 PIs along with their associated groups are presented in Table 7. The associated assessment criteria for each group of indicators listed in Table 7 are defined in the following (NRC 2010):

- **Safety impacts.** How water supply services support the reduction of incidents or accidents that result in death and (or) injury and (or) property loss.
- **Health impacts.** The health impacts (both direct and indirect) which are beneficial or detrimental to consumers as well as to the general public.
- **Security impacts.** The performance of the water supply service in terms of protecting the security of the users, operators, and public at large.
- **Economic Impacts.** The direct and indirect impacts (beneficial or detrimental) of WSS on local, regional, and national economies.

Table 6. Office of the Water Services system of performance indicators (OFWAT 2012).

Indicator group	Total No. of indicators	Performance indicators	Description
Customer experience	3	• Properties at risk of low pressure • SIM • Water supply interruptions of ⩾12 h	• SIM is a financial mechanism to incentivize optimum levels of customer service through the price control process.
Reliability, availability, and security	5	• Service water non-infrastructure • Service water infrastructure • Leakage • SoSI • Population with hosepipe restriction	• Service water non-infrastructure and infrastructure cover a wide range of indicators relating to customer service, public health, the environment and asset performance. • Total leakage measures the sum of distribution and mains losses in megalitres per day (ML/day). • SoSI indicates the extent to which a company is able to guarantee provision of its levels of service for restrictions of supply.
Environmental impact	2	• GHG Emissions • Pollution Incidents	• Measurement of the annual operational GHG emissions of the regulated business. • The total number of pollution incidents in a calendar year emanating from a discharge or escape of a contaminant from a water company asset related to a water-related premise (also known as assets under the 'water service').
Financial	4	• Post-tax return on capital • Credit rating • Gearing • Interest cover	• Post-tax return is the current cost operating profit less tax as a return on regulatory capital value (e.g., 4.4%). • Credit rating is the current cost operating profit less tax as a return on regulatory capital value (e.g., AAA). It is the assessment from the rating agencies. The company gets a certificate showing its rating with all the customer agencies. • Gearing is the net debt as a percentage of the total regulatory capital value at the financial year.
Total	**14**		

Note: GHG, greenhouse gas; SIM, service incentive mechanism; SoSI, security of supply index.

- **Environmental impacts.** The direct and indirect impacts of water supply service on the natural environment (air, water, soil, fauna, and flora) and climate change.
- **Quality of Service.** An assessment of how well the service meets established levels of service, regulatory requirements, industry standards, and customer satisfaction.
- **Access to service.** The geographical coverage and affordability of infrastructure services and provision of access to people with disabilities.
- **Adaptability.** The capacity of the service to adapt to short- and long-term changes and pressures.
- **Asset preservation, renewal, and decommissioning (Asset P/R/D).** The management of water supply assets to keep the service operational at its intended level of service through inspection, routine maintenance, repair, rehabilitation, renewal, and ultimately decommissioning.
- **Reliability of service.** Ability of WSS to perform its required function under stated conditions for specified periods of time.
- **Capacity to meet demand.** The capacity of the service to meet demand under current and future conditions, extreme events, and in emergency situations.

The indicators proposed by NRC (2010) for a WSS in Table 7 provide detailed information regarding environmental, public health, social, security, and economic performance. On the other hand, indicators related to personnel, physical, and operational aspects of a water utility have not been given required importance. Out of the 37 PIs given in Table 7, 18 indicators are essentially the service indicators; the remainders are related to both the service and asset. For example, protection against climate change impact can be reduced by maintaining and improving the conditions of the pumps and vehicles (i.e., lowering the emissions from fuel burning and use of electricity), which will also improve the service of the WSS. Overall, the PIs seem to be more suitable (directly) in the context of asset management at a strategic level and need to be supported with more PIs for practical PA of SM-WSSs. However, this indicator system also provides useful information to identify the most important and common indicators.

3.8. The Asian Development Bank

The Asian Development Bank (ADB) has developed the project performance management system (PPMS), having a result-based management approach focusing on service targets and outcomes. The concept emerged during the 1980s, when result-based management was gradually applied to public sector management in the course of public sector reforms. The result-based management needs a series of tools to carry out strategic planning, performance monitoring and assessment, and reporting. However, this management system needs three prerequisites — support from the leadership, result-based organizational culture, and improved support systems. Moreover, the result-based management approach combines the whole project life cycle including project identification, preparation, appraisal, loan negotiations and approval, implementation, and project evaluation (ADB 2012).

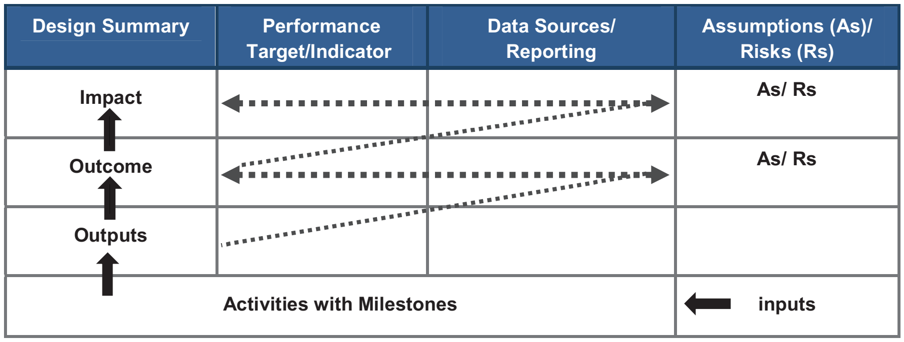
As ADB is a funding agency, it is primarily concerned with the allocation and utilization of resources in a water supply project. After the completion of the project, ADB's independent evaluation department evaluates the project performance and also shares the experiences and lessons learned for the planning and design of new projects. The PPMS developed by ADB is based on a comprehensive project design and monitoring framework (DMF) shown in Fig. 10. In DMF the cause–effect relationship between inputs, activity, outputs, outcome, and impacts has been established to determine the targets at the result level and select the indicators for gauging these selected targets. The selection of the relevant indicators is carried out with the participation of all the stakeholders in the process of problem identification, targets

Table 7. Indicator system used by the National Research Council (2010).

Objective/ indicator group	Total No. of indicators	Performance indicators*	Assessment criteria
Public safety	7	• Percentage of affected population days/year for which service pressures do not meet standards (A/S) • Percentage of critical service areas with more than one distribution system connection (S) • Percentage of average water delivery maintained during power failure (S) • Percentage of total population served capable of receiving emergency water supplies to meet minimum sanitation needs (S) • Condition rating of assets (A/S) • Remaining service life (A/S) • Protection against deliberate/vandalism acts (A/S)	• Health impacts • Safety impacts • Security impacts • Environmental • Economic • Quality of service • Access to service • Adaptability • Asset P/R/D • Reliability of service • Capacity to meet demand
Public health	11	• Percentage of population days/total population days with Boil Water Advisories (S) • Percentage of design capacity remaining on maximum demand days (A/S) • Storage capacity as a percentage of average daily demand (A/S) • Number of breaks/year/km pipe (A/S) • Condition rating of assets (A/S) • Remaining service life (A/S) • Number of planned service interruptions as a percentage of total service interruptions(S) • Rated capacity versus actual average service load (A/S) • Rated capacity versus actual daily maximum service load (A/S) • Reduction in number of illnesses, injuries, and deaths/population served (S) • Protection against climate change impacts (A/S)	• Health impacts • Safety impacts • Environmental • Economic • Quality of service • Reliability of service • Capacity to meet demand
Environmental quality	4	• Percentage of water treatment water that is recycled (S) • Percentage of back flush water that meets environmental discharge standards (S) • Percentage of current water allocation used to meet current demand (S) • Reduction in total greenhouse gas emissions/population served (A/S)	• Health impacts • Environmental • Economic • Adaptability • Reliability of service • Capacity to meet demand
Social equity	4	• Monthly average cost of service/median income (S) • Fee structure (cost /consumption structure) (S) • Benefit/cost ratio of service and assets (A/S) • Percentage of total population in jurisdiction connected to central water services (S)	• Health impacts • Safety impacts • Economic • Quality of service • Access to service • Capacity to meet demand
Economy	8	• Reserve funds as a percentage of total present value of infrastructure (S) • Total cost (capitals, operations, maintenance, labour, materials, etc.) of service population in service area (S) • Reduction in total energy used/population in service area (A/S) • Remaining service life (A/S) • Percentage change in number of assets versus percentage change in operational funding (S) • Agency costs/agency revenues (A/S) • Value of assets (S) • Percentage of underground infrastructure renewed or rehabilitated annually (S)	• Environmental • Economic • Quality of service • Access to service • Adaptability • Asset P/R/D • Reliability of service • Capacity to meet demand
Public security	3	• Number of acts of vandalism against agency assets/population served (A/S) • Security measures costs/number of security breaches/population served (S) • Protection against deliberate vandalism acts (A/S)	• Safety impacts • Security impacts • Environmental • Economic • Quality of service • Reliability of service
Total	**37**		

Note: P/R/D, preservation, renewal, and decommissioning.
*A/S, related to asset and service; S, related to service only.

Fig. 10. ADB (2012) Project Design and Monitoring framework (DMF).



analysis, solution selection, formation of assumption, and risk analysis. The first column in Fig. 10 is a design summary, which outlines the elements of the project (i.e., inputs, output, outcome, and impact). The other three columns provide a framework for project performance and monitoring. Details can be seen in ADB 2012).

To understand the PA mechanism proposed by ADB (2012), the core components of the framework are impacts, outcomes, outputs, activities, and inputs. Impacts are the goals or longer term targets referred to as the sectorial, subsectorial or in some cases national targets; or the social, economic, environmental, and policy changes brought about by the project. Outcomes are expected targets for realization upon project completion and they should explicitly describe the specific development issues to be addressed by the project. Outputs are the physical assets, tangible goods, and (or) services delivered from the project, as well as the descriptions of the project scope. Activities consist of a series of tasks conducted for the realization of outputs from production. Inputs are the main resources necessary for engaging in activities and generating outputs, including staff, equipment, materials, consulting services, and operating funds.

In the DMF system, targets (outcomes) can be gauged both quantitatively and qualitatively. It has always been better to measure any indicator quantitatively but sometimes it is not possible. In such situations qualitative indicators are determined and then converted to quantifiable data using methods to realize their gauging functionalities. According to this system, a PI should be clear, relevant, economical, adequate, and monitorable; where "Clear" means precise and unambiguous, "Relevant" means appropriate and timely, "Economical" means available at reasonable costs, "Adequate" means sufficient to assess performance, and "Monitorable" means the indicator can be independently verified.

Overall, 15 PIs at impact level and 39 at outcome level for urban water supply systems are presented in Table 8. Details can be seen in ADB (2012). Indicators given in Table 8 are grouped based on specific targets established by the ADB. On the other hand, all these indicators also belong to various groups of indicators as described by other organizations (refer to comments column of Table 8) (IWA 2006; AWWA 2004; NWC 2012). The framework proposed by ADB seems to be relatively complex for practical application for SM-WSSs. However, its contribution could be useful to identify the commonly used important PIs.

3.9. The Canadian Standards Association

The Canadian Standards Association (CSA) is a nonprofit organization chartered in 1919. It was accredited by the Standards Council of Canada in 1973. The CSA Technical Committee reviewed and recommended the International Organization for Standardization (ISO) Standards guidelines (i.e., CAN/CSA-Z24510, CAN/CSA-Z24511, CAN/CSA-Z24512) for the improvement of service to users for Canadian water utilities in 2007. Among these standards, CAN/CSA-Z24510 is service-oriented whereas both CAN/CSA-Z24511 and CAN/CSA-Z24512 are management-oriented. These guidelines are applicable to both publicly operated and privately owned water utilities. All these standards propose a step-by-step, loop-back approach to establish PIs (CSA 2010).

According to CSA (2010), the main objective of its approach is to provide guidelines (consistent with the goals defined by the relevant authorities) to stakeholders for the management, assessment, and improvement of water utilities to ensure desirable service to the users. The contents of the international standards given in ISO 24512: 2007 (CAN/CSA-Z24512-10) are shown in Fig. 11. The management components of a utility defined by CSA (2010) in CAN/CSA-Z24512 are activities and processes to achieve the principal objectives including protection of public health, meeting user needs and expectations, provision of services under normal and emergency situations, sustainability, promotion of sustainable development of the community, and protection of the environment. To meet these objectives, the CSA (2010) framework provides guidelines at the organization, planning and construction, and O&M levels for the efficient performance of all the management components. It is obvious that each management component has its own hierarchal structure and specific requirements at all levels. For example, the objective with storage structures is provision of emergency services; therefore, the guidelines applicable to this asset would be related to watershed characteristics. On the other hand, a water treatment plant will be constructed and operated to meet the objective of protection of public health and thus requires different management guidelines. The next step in the CSA (2010) framework is defining the assessment criteria. One service criterion can be related to more than one objective. For example, the assessment criteria of source protection is associated with protection of public health, provision of services under normal and emergency situations, sustainability, and protection of the environment at the same time. The calculations of PIs proposed in this framework are similar to IWA (2006) based on context information and variables. Details of each component of the framework can be seen in CSA 2010.

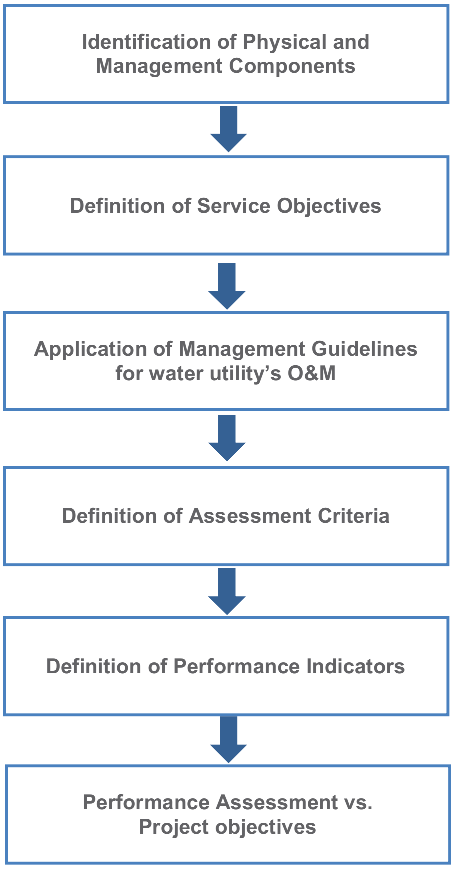
An appropriate application of the CSA (2010) system is the Canadian National Water & Wastewater Benchmarking Initiative (NWWBI). The 2012 public report prepared by AECOM (2012) summarizes the performance evaluation results of 41 water utilities from the year 2010. In this report, the performance of a WSS is addressed for its three major physical components (i.e., utility, water distribution, and water treatment). For each component, a total of 62 PIs are reported against all the objectives and (or) goals. The summary of PIs used is presented in Table 9. No discussion has been presented on size of the utility. In CSA 2010 no specific discussion is provided on the PA of SM-WSSs. Although the framework seems to be well structured and comprehensive, its direct application for SM-WSSs can be further investigated by involving large numbers of stakeholders in the continuous benchmarking process (CSA 2010).

Table 8. Indicator system proposed by the Asian Development Bank (2012).

Target	Total No. of indicators	Performance indicators*	Comments
Impact level			
Meeting the needs for urban development to ensure water supply for living, production and other construction in urban areas	8	• Newly increased no. of household and people (10 000 persons) • Total volume of water supplied, produced, and used (6) • Per capita ownership of urban maintenance and construction fund (RMB)	Indicators related to water resources and economic
Improving the life quality of residents to reduce the occurrence of waterborne diseases	7	• Water outage - persons affected and time of outage (3) • Waterborne diseases–persons affected and time lost (2) • Economic loss from sudden events of drinking waterborne diseases (measured at RMB10 000) • Per capita volume of water for daily living (L)	Operational indicators related to interruptions, water quality, and economics
Outcome level			
Improving water supply capacity through developing and improving water sources and building and rebuilding water plants and water supply pipeline networks	8	• Water demand and production capacity (2) • Length of newly built and rebuilt water supply pipelines (km) • Coverage rate (%) • Proportions of water for household, usage in production, public, and others (4)	Water resources, physical, quality of service indicators
Improving the quality of drinking water through improving and protecting water source, building new water treatment facilities and updating pipelines.	8	• Water source biochemical water quality (4) • Biochemical water quality in the network (4)	Water quality
Improving the efficiency in water supply through building and rebuilding water plants and water supply pipelines	7	• Rate of water consumed and recycled (2) • Volume of water sold (%) • Volume of water loss (%) • Power consumption by water plant due to water supply (kWh) • Comprehensive quality rate of water quality in plant and water (%) • Comprehensive quality rate of water quality in network and water (%)	Water resources, operational and customer service indicators
Improving the efficiency in management and operation of the water supplying organization	7	• Total industrial output value and growth (%) • Total profit and growth rate (%) • Fiscal subsidies and growth rate (%) • Employed people in organizations (10 000 persons) • Attainment rate of living drinking water (%) • Construction and operation of the water supply dispatch and monitoring system • Construction and operation of early warning, emergency response and handling information systems	Financial, personnel, quality of service, and physical indicators
Improving the water supplying conditions for poverty stricken population in urban areas	4	• No. of water householder users with the lowest income (households) • Average drinking water volume of households with the lowest income (ton) • Average drinking water expense of households with the lowest income (RMB) • Preferential policy on water charge subsidies for poverty-stricken households	Indicators related to poverty alleviation
Promoting private sector participation in the construction and operation of urban water supply	5	• Water pricing (2) • Total annual water supply of non-state tap water companies (10 000 tons) • Length of water supplying pipelines of non-state tap water companies (km) • Non-state investment and its proportion (%)	Pricing and economic indicators
Total	**54**		

Note: RMB, official currency of the People's Republic of China.
*Only the types of indicators are described with number of indicators in parentheses.

Fig. 11. Content and application of the ISO (2007) (CSA 2010). O&M, operation and management.



3.10. Evaluation of performance indicator systems

3.10.1. Summary of performance indicator systems

The PIs are grouped in different categories by various agencies (CSA 2010; NWC 2012; ADB 2012; OFWAT 2012; WB 2011; NRC 2010; IWA 2006; AWWA 2008) as stated earlier in paper. Different agencies have used different terminologies as per their specific organizational setups and operational requirements. For example, Alegre et al. (2006) included a water interruption indicator in the operational category, whereas the same indicator was grouped into the customer relations category by AWWA (2008). Moreover, various indicators are associated with economic performance of a WSS and are interrelated (e.g., finance, economic, and pricing). Some of the agencies like NWC (2012) have included indictors of pricing and finance in separate categories, whereas others have grouped them into the same category of economic and finance (AWWA 2004; ADB 2012). Generally in the case of SM-WSSs, because of relatively smaller financial expenditures than for L-WSSs (for which various categories have been developed), the most relevant financial PIs can be collected into one category.

A comparison of different categories has been made in Table 10 to study the number of indicators grouped in each category by different agencies. It can be seen in Table 10 that most PIs are related to finance, customer service, and operation of a WSS. Importance given to these PIs indicates that these are the most important categories and also have strong interaction between each other. For example, efficient operations with skilled personnel require more financial investment but ultimately ensure customer satisfaction. As describe earlier in the paper, the PIs are typically expressed as ratios between variables. These ratios may be commensurate, such as percentages or noncommensurate (e.g., $\$\cdot m^{-3}$) (IWA 2006). Other indicators are expressed in units such as volume of sourced or supplied water in the literature (NWC 2012). Such units may provide insight into the performance of the system to the utility management but might not be suitable for cross-comparison. Moreover, the data availability may vary from utility to utility even within the same geographical region. For example, sometimes sufficient data for performance evaluation are available (e.g., a small- or medium-sized WSS operating in the near vicinity of a large urban center), and, on the other hand, within the same country a similar sized WSS working under the same or different operating conditions (working standalone away from large cities) might not be having the similar type of the data. Therefore, a minimum set of PIs should be established for cross-comparison by country or region, and then each utility can include additional PIs according to availability of data, water source, and administrative setup.

Environmental indicators have been highlighted in the recent years because of regulations associated with GHG emissions. Conservation of water resources has also been given specific importance in water scarce areas. The WSSs should control and manage the discharge of backwash water; and the amount of sourced water in such a way that downstream use, even during drought (based on the calculations related to water balance and assimilative capacity of the source water), is not disturbed. However, relevant water resource indicators depending on the source of water supply and quantity of available water need to be carefully selected. The agencies that consider environment as a separate category are mostly the ones responsible for combined PA of water supply and wastewater systems because most of the indicators are related to discharge of wastewater and sludge disposal issues (NWC 2012; AWWA 2004). Furthermore, most of the agencies included impacts on water resources in the category of water resources rather than environment so that only one parameter is left (i.e., GHG emissions) in the environment category, which is relatively new as well (CSA 2010). Therefore, it is recommended that water resources be included in the category and the category be renamed "Water resources and environment". In addition, indicators related to impact of residual chlorine (not addressed so far) on aquatic life should be included in this category.

The indicators related to water quality and public health are considered either under the category of customer services or operational. For example, IWA (2006) considered water quality in the operational category, whereas the WB (2011) considered residual chlorine as the only water quality indicator under the category of service. These are the most important parameters to ensure supply of safe drinking water to the consumers. It is well established that water quality regulation compliance decreases as the size of the utility decreases (USEPA 2006*b*), meaning more water quality problems and resulting public health issues in SM-WSSs as compared with L-WSSs. Therefore, water quality and public health indicators are grouped into a separate category in Table 10 to give them appropriate importance.

Only the IWA (2006) has given desirable importance to the numbers, skills, training, and qualification of personnel (staff) by developing 26 PIs under a specific category allocated to personnel. Some of these indicators could be very important for the performance evaluation of different components of a SM-WSS. For example, consider a S-WSS having saline ground water and no surface water source. The only possible option would be a tertiary-level, highly technical water treatment facility, such as reverse osmosis; therefore, the PIs related to staff training and their monthly salaries will be extremely important in this case. Overall, the IWA (2006) system seems to be more balanced with a maximum number (170) of total PIs, followed by WB (2011) with 81 indicators relatively well distributed amongst all categories as compared with the rest of the PI systems. Performance indicators have also been distributed rationally to cover all physical and

Table 9. Indicator system proposed by ISO (2007) (CSA 2010).

Objective/goal	Total No. of indicators	Performance indicators	Comments/possible classification*
Utility			
Sufficient capacity	1	• Treated water storage capacity at average day demand (h)	• Physical (1)
Minimum sustainable cost	4	• Cost of water quality monitoring/population served • Cost of customer billing/service connection • (Total water operating cost + cost of bulk water purchased)/population served • Rate of water for a typical size residential connection using 250 m^3/year	• Financial (4)
Protection of environment	3	• Cost of water conservation program/population served • No. of days of water restrictions • Per capita average day consumption for residential customers	• Financial (1) • Water resources (2)
Customer satisfaction	2	• Cost of customer communication/population served • No. of water quality customer complaints/1000 people served	• Customer satisfaction (2)
Public health	1	• No. of boil-water advisory days × capita affected/population served	• Water quality (1)
Water Distribution System			
Provide reliable service and infrastructure	9	• No. of main breaks per 100 km length • % of valves cycled • % of inoperable or leaking valves • Non-revenue water (L/connection/day) • % of hydrants checked and inspected 2010 • % of inoperable or leaking hydrants • No. of emergency service connection repairs and replacements/total number of service connections • No. of unplanned system interruptions per 100 km length • 5 year running average capital reinvestment/replacement value	• Physical (4) • Operational (3) • Customer satisfaction (1) • Financial (1)
Meet service requirements with economic efficiency	11	• No. of field FTEs per 100 km length • No. of O&M FTEs per 100 km length • No. of in-house metering field FTEs per km length • 25 total operating cost with actual indirect charge-back ('000) per km length • O&M cost ('000) per km length • Pump station O&M cost ('000)/Total pump station horsepower • Pipes O&M cost ('000) per km pipe length • Metering O&M cost/number of total metres • Pump station energy consumed kWh/total pump station horsepower • Cost of fire hydrant O&M/No. of fire hydrants • Unplanned maintenance hours/total maintenance hours	• Operational (1) • Financial (6) • Environment (1) • Personnel (3)
Provide a safe and productive workplace	6	• No. of field accidents with lost time per 1000 field labour hours • No. of lost hours due to field accidents per 1000 field labour hours • No. of sick days taken per field employee • Total available field hours/total paid field hours • Total overtime field hours/total paid field hours • % of field employees eligible for retirement per year category 2010	• Personnel (6)
Have satisfied and informed customers	1	• No. of water pressure complaints by customers per 1000 people served	• Customer satisfaction (1)
Protect public health and safety	4	• % of main length cleaned • Average turbidity (NTU) • No. of total coliform occurrences • Average THMs (mg/L)	• Water quality (3) • Operational (1)

Table 9 (*concluded*).

Objective/goal	Total No. of indicators	Performance indicators	Comments/possible classification*
Water Treatment			
System reliability	1	• 5-year running average capital reinvestment/replacement value	• Financial (1)
Sufficient capacity	2	• Average day demand/existing water license capacity • No. of days the plant operated at >90% capacity	• Physical (2)
Minimum sustainable cost	7	• No. of field FTEs/1000 ML treated • No. of O&M FTEs/1000 ML treated • O&M cost/ML treated • Total operating cost with actual indirect charge-back/ML treated • Energy consumed (kWh)/ML treated • Chemical cost/ML treated • Unplanned maintenance hours/total maintenance hours	• Financial (3) • Environment (1) • Personnel (2) • Operational (1)
Public health	3	• Median turbidity (NTU) • No. of occurrences of TC • Median value of nitrates (mg/L)	• Water quality (3)
Safe and productive workplace	6	• No. of field accidents with lost time per 1000 field labour hours • No. of lost hours due to field accidents per 1000 field labour hours • No. of sick days taken per field employee • No. total available field hours/total paid field hours • No. total overtime field hours/total paid field hours • % of field employees eligible for retirement per year category 2010	• Personnel (6)
Protect the environment	1	• % residuals	• Environment (1)
Total	**62**		

Note: FTE, full time employee; O&M, operation and management; TC, total coliform; THM, trihalomethanes.
*Number of PIs in possible conventional classification of PIs in parentheses.

Table 10. Number of water supply performance indicators under different categories by various agencies.

PI category	WB (2011)	OFWAT (2012)	ADB (2012)	NWC (2012)	NRC (2010)	IWA (2006)	AWWA (2008)	CSA (2010)
Water resources/Environmental	11[a]	2	15	23+3[b]	3[c]+2	4	—	5
Physical/Asset	1[d]	—	2	2[e]	—	15	—	7
Personnel/Staff	(6+5)[f]	—	1	—	—	26	11[g]	17
Water quality/Public health	2[h]	—	13	7	3	5	1[i]	7
Operational	(3+1)[j]	4[k]	10	5	7+3[l]	39[m]	8[n]	6
Quality of service/Customer service	(9+3+5)[o]	3+1[p]	2	12	(4+1+3)[q]	34	2	4
Economic/Financial/Pricing	35[r]	4[s]	11	3[t]+18	7[u]	47	9[v]	16
Total	**81**	**14**	**54**[w]	**73**	**33**	**170**	**31**	**62**

Note: ADB, Asian Development Bank; AWWA, American Water Works Association; CSA, Canadian Standards Association; IWA, International Water Association; NRC, National Research Council; NWC, National Water Commission; OFWAT, Office of the Water Services; WB, World Bank.
[a]IBNET includes these indicators under water consumption category (see Table 4 for details).
[b]Environmental indicators were considered separately by NWC (2012).
[c]These water resources indicators were considered under environmental quality by NRC.
[d]IBNET considers only metering level (see Table 4 for details).
[e]Indicators of water loss and pipe breaks (5 indicators) were included under asset category (see Table 5 for details), now added to operational.
[f]6 under process category and 5 under operating cost and staff category (see Table 4 for details).
[g]AWWA (2008) used the term organizational development (see Table 6 for details).
[h]These indicators are considered under quality of service (see Table 4 for details).
[i]Drinking water compliance under water operations category by AWWA (2008).
[j]3 Non-revenue water, and 1 of pipe breaks (see Table 4 for details).
[k]OFWAT used the term reliability, availability and security for this category (see Table 7 for details).
[l]6 indicators considered in public health and 3 under economy (see Table 8 for details).
[m]Water quality monitoring was considered under operational category by IWA (2006) (see Table 3 for details).
[n]Water disruptions under customer relations; system renewal rate under business operations; water loss and structural integrity under water operations.
[o]9 indicators from process category, 3 from service coverage and 5 from quality of service (see Table 4 for details).
[p]Service Intensive Mechanism includes additional indicators related to customers complaints and 1 hosepipe restrictions from reliability category (see Table 7 for details).
[q]4 public safety, 1 social equity and 3 public security (see Table 8 for details).
[r]4 under process indicators, 6 operating costs and staff, 20 billing, 2 financial, 2 assets and one affordability category (see Table 4 for details).
[s]OFWAT indicators are based on financial performance of companies through more indicators (see Table 7 for details).
[t]3 pricing indicators and 18 finance (see Table 5 for details).
[u]3 under social equity and 4 under economy category by NRC (2010).
[v]Indicators were distributed amongst customer relations, business operations and water operations categories by AWWA (2008) (see Table 6 for details).
[w]Personnel and customer complaints have not been addressed in detail because of different organizational structure (see Table 9 for details).

Table 11. Evaluation of different performance assessment systems for small- and medium-sized water supply systems.

Performance assessment system	Performance indicators			Performance assessment framework		
	Understandability	Measurability	Comparability	Simplicity	Comprehensiveness	Overall applicability to SM-WSS utilities
WB (2011)	Medium	Medium	Low	Medium	Medium	Medium
OFWAT (2012)	Low	Medium	Low	Low	Medium	Low
ADB (2012)	Low	Medium	Medium	Low	Medium	Medium
NWC (2012)	High	Low	Low	Medium	Medium	Medium
NRC (2010)	Low	Medium	Low	Medium	Low	Low
IWA (2006)	Medium	Medium	High	Medium	High	High
AWWA (2008)	Low	Medium	Low	Low	Medium	Low
CSA (2010)	Medium	Medium	Medium	Low	Medium	Medium

Note: ADB, Asian Development Bank; AWWA, American Water Works Association; CSA, Canadian Standards Association; IWA, International Water Association; NRC, National Research Council; NWC, National Water Commission; OFWAT, Office of the Water Services; WB, World Bank.

management components of a WSS with a total number of 62 PIs by CSA (2010).

3.10.2. Evaluation of different performance indicator systems

It is well recognized that PIs should be clearly defined, easy and economical to measure and verify, easily understandable, and relevant to a specific WSS. Moreover, the overall framework of the PA should be simple, well defined, comprehensive (i.e., covering all components of a WSS), and comparable with similar utilities at regional, national, and international levels. Various PA systems and indicators are reviewed in the previous sections along with their strengths and limitations. Here an effort is made to evaluate the performance evaluation systems for their general application (not limited to a specific region) to SM-WSSs. The findings of the literature review conducted earlier in the paper are summarized in Table 11. The PIs defined by each PA system are evaluated in the context of SM-WSSs on the basis of the following criteria:

- **Understandability.** The indicator should be easily understandable to both the utility operators and the public.
- **Measurability.** The data required to calculate an indicator should be easy to measure and the indicator's calculation should also be as simple as possible.
- **Comparability.** The indicator should be comparable across similar utilities in the same region as well as for international comparisons.

The following criterions have been used for the evaluation of the PI frameworks proposed by these agencies, as mentioned in Table 11:

- **Simplicity.** How simple (i.e., interrelationships between data variables, indicator groups, and PIs) is the framework to be implemented for SM-WSS utilities?
- **Comprehensiveness.** How and up to what level of detail does the framework consider the most important aspects (i.e., personnel, customer service, financial, and environmental) of the WSS?
- **Overall applicability.** Is the framework applicable to SM-WSS in its original form with minimum modifications (i.e., by just selecting the relevant suitable PIs with regard to a specific WSS)?

The IWA (2006) seems to be the most suitable system for SM-WSS in Table 12. This system provides a wide range of PIs with a comprehensive classification system. Moreover, categorization of indicators into different levels may also facilitate the managers of SM-WSSs starting with Level 1 indicators and then including higher levels depending on data availability. The way the data variables (as m^3, numbers and cost) and the PIs (in terms of percentages and ratios) are distinguished from each other also provides an opportunity for the regulatory agencies and utility managers to perform cross-comparison with similar sizes and types of utilities. The PI systems developed by ADB (2012), NWC (2012), and CSA (2010) can also be implemented in SM-WSSs with appropriate modifications.

It is very important to mention here that the rationale developed to review the distribution of PIs by various agencies in the previous sections is done to evaluate that how the important PIs have been grouped in each category associated with various components of the overall PA framework of SM-WSSs. The purpose of comparison between different PI systems is primarily to meet this objective rather than identifying the strengths and (or) the limitations of these PI systems. The authors clearly understand that each system of PIs has been developed to meet the specific objectives of a certain project within its defined geographical boundaries.

4. Performance assessment of water utilities with limited data and resources — a brief summary of some reported case studies

Small- and medium-sized water supply systems often face problems with availability of the data required to calculate the PIs. Mostly, WSSs in developing countries face similar problems irrespective of the size of WSS. In the following sections, some case studies of PA of WSSs in developing countries are described to identify the basic PIs used by the water regulatory agencies with very limited data. Outcomes of the application of these selected indicators are described briefly as well.

4.1. South Asia – Bangladesh, India, and Pakistan

Bangladesh is one of the most densely populated countries in the world with over 146 million residents (WSP 2009). According to the Government of Bangladesh, the urban utilities in Bangladesh are not performing well owing to lack of effective management. Under the Bangladesh benchmarking and performance improvement for water utilities project facilitated by Water and Sanitation Program - South Asia (WSP-SA), the concept of performance benchmarking was introduced in June 2005 for 11 utilities of all sizes (i.e., serving a population ranging from 21 000 to 10 000 000). The Government of Bangladesh took the initiative to introduce benchmarking and performance improvement programing (BM&PIP) tools (i.e., IB-Net) along with other stakeholders.

In a similar study conducted by WB, the performance of over 30 urban water utilities across Bangladesh, India, and Pakistan under WSP-SA was compared to evaluate the effectiveness of the program (WB 2010). Almost all of the utilities in these countries are providing intermittent supply with an average duration of 5 h per day. The selected PIs used in this study are given in Table 12. As a result of the benchmarking process in Rajkot, India, a 48% in-

Table 12. Checklist of key performance indicators used in developing countries.

Indicator category	Performance indicator	Arab countries (ACWUA 2010*a*, 2010*b*)	Africa (WOP-Africa 2009)	South Asia (WSP 2009)	Armenia (Mkhitaryan 2009)	Scoreboard (WB 2002)
Water resources/environmental	Water sourced*	✓	✓			
	Water supplied*	✓	✓	✓		
	Water balance*	✓	✓			
	Water consumption*			✓	✓	
Personnel	Number of staff per 1000 connections	✓	✓	✓		✓
	Personnel training*	✓	✓			
	Health and safety*				✓	
Quality of service/customer service	Supply coverage			✓	✓	✓
	Customer complaints	✓	✓		✓	
	Response to complaints				✓	
	Water availability/supply duration			✓	✓	✓
Operational	Non revenue water/unaccounted-for water		✓	✓	✓	✓
	Metering (new connections and maintenance)				✓	
	Water treatment plant operation				✓	
	Water main breaks	✓			✓	
Water quality/public health	Water quality compliance	✓			✓	
Financial/economic	Revenue/financial inputs (bills)	✓		✓	✓	
	Operation and management cost*		✓	✓		✓
	Energy cost*	✓			✓	
	Water charges*		✓	✓		✓
	Billing efficiency				✓	✓
	Collection period		✓			✓
	Working ratio			✓		✓
	Tariff structure					✓
	Connection charges*			✓		✓

*Essentially data variables.

crease in billing and 31% increase in collection were achieved in a 3-year period between 2006 and 2009. Moreover, 20 000 unauthorized connections have also been regularized in the same time frame (WB 2010). It can be observed in Table 12 that the benchmarking process is currently focusing on meeting water demands and revenue collection to meet the financial and operational requirements in these South Asian countries. It is expected that with time, water quality, personnel, environmental, and water resource indicators will also be included in the benchmarking process.

4.2. Eastern Europe, Caucasus, and Central Asian countries – Armenia

In the past, under the administration of the former Soviet Union (FSU), water was supplied to consumers by the public sector suppliers at very low prices. The gap between service revenues and cost of provision used to be filled by the government budget (Mitrich 1999). Armenia is one of the 12 countries in Eastern Europe, Caucasus, and Central Asia (EECCA). After the collapse of the old administrative system and subsequent financial crises in the FSU, the WSSs completely deteriorated and were unable to meet the demand of residential, commercial, industrial, and institutional consumers in Armenia (Mkhitaryan 2009).

In 2001, the water sector was decentralized and privatized to improve the situation, as part of institutional, legislative, and regulatory reforms in the country. In this system, priority was given to the customer satisfaction due to higher water rates. Therefore, it was decided that performance of the water suppliers would be assessed and customer feedback would be incorporated to achieve customer satisfaction. After reviewing the previous studies and the data availability, the PIs were finalized by the Public Service Regulatory Commission (PSRC) for Armenia in 2005 and 2008 (PAGS 2008). These selected PIs are listed in Table 12. After implementing these PIs, substantial improvements were observed: an almost 50% reduction in energy; a massive drop in per capita consumption from 250 to 87 L per day due to improved metering system; and significant improvements in user fee collection efficiency, from 21% to 90% before and after the privatization, respectively (Mkhitaryan 2009).

4.3. Arab countries

Recently in July 2010, the first training course to establish key performance indicators (KPIs) and benchmarks for water utilities in the Middle East and North Africa (MENA)/Arab region was held in Alexandria, Egypt. The course was organized by Arab countries water utilities association (ACWUA), InWEnt Capacity Building International, Cairo and Germany, and Alexandria Water Company, Egypt. A number of representatives from six Arab countries including Egypt, Jordan, Syria, Yemen, Palestine, and Morocco participated in the course. One of the main objectives was to promote the use of common indicators within the MENA/Arab region. The four categories of PIs including personnel, quality of service, O&M, and finance and economics were proposed (ACWUA 2010*a*). These proposed indicators were further discussed in the 1st Arab Water week held in Amman, Jordan, during December 2010. This time 65 participants from 13 countries (in addition to previously stated countries, Algeria, Tunis, Lebanon, Bahrain, UAE, Kenya, and Albania) participated in the course and proposed a set of PIs, given in Table 12, to start the benchmarking process in the region (ACWUA 2010*b*).

4.4. Africa – Malawi and 134 water utilities

Kalulu and Hoko (2010) carried out the PA of a public water utility in the city of Blantyre, Malawi. It is a commercial and industrial city with a population of 661 000 as per 2008 estimates.

The baseline data (variables) were collected from national legal and policy documents and Blantyre Water Board. The PIs used in their study are given in Table 12. For calculation of water loss, an unaccounted-for-water (UFW) indicator was used instead of the nonrevenue water (NRW) that was used in other case studies of developing countries, as the major water losses were apparent and real. The indicators were then compared with the best practice targets proposed by the WB in 2002 (Tynan and Kingdome 2002). This document is a WB note in which Tynan and Kingdome (2002) used the data from 246 water utilities in 51 developed countries and proposed the KPIs to establish best practice targets for developing countries (Table 13).

Water Operators Partnership Program for Africa (WOP-Africa) was initiated in December 2006 with the Nairobi Workshop by the WB Water and Sanitation Program (WSP) to endorse the idea of involving a number of African utilities (WOP-Africa 2009). Under this program, the self-assessment process of 134 African utilities from 35 countries was started with a comprehensive utility self-assessment questionnaire (USAQ) adopted from the IB-NET assessment tool. The PIs selected from the standard IB-NET assessment tool are listed in Table 12. It can be observed from Table 12 that indicators related to water supplied, water sourced, and the overall water balance are the most commonly used PIs in the water resources category. Number of personnel per 1000 connections is also a very common indicator; however, in some S-WSSs the number of connections could be <1000. For these systems, this indicator cannot be used with its original formulation. Customer complaints were recorded in almost all the cases in Table 12. The NRW is the most commonly used indicator in the operational category. Overall costs of O&M, energy, and water charges are the only financial indicators. The results of these case studies suggest that even in developing countries a set of easily measurable PIs can improve the performance of a WSS. These PIs also provide a guideline for SM-WSS with limited available data.

5. Proposed performance indicators for SM-WSSs

This section includes a system of PIs to start, implement, and improve the performance evaluation process for SM-WSSs. The proposed system mainly consists of a list of most simple and relevant PIs based on this review. The main purpose of this review is to provide a guideline towards effective performance evaluation of SM-WSSs, and not the development of an operational manual.

5.1. Proposed system of performance indicators for SM-WSSs

The proposed system of PIs shown in Fig. 12 provides a stepwise approach based on three levels of indictors, including start-up, additional, and advanced PIs depending on the availability of resources and site-specific requirements. Required data variables are presented for the calculation of startup PIs, here as, additional and advanced PIs are only listed because the detailed data requirement of these PIs cannot be covered in this paper. In this regard, enough data sources have been provided for consultation to use the advanced PIs.

The utility can evaluate its existing data availability and then can select the level from which it can start its PA process. A S-WSS facing issues related to lack of funding and availability of trained staff in a developing country may start the performance evaluation process with a few of the most relevant startup indicators. The startup indicators might be different in the case of a small utility located near a larger city in a developed country. In this situation, it is easier for the municipality to hire and retain trained personnel. The number and types of indicators in the latter case would be much higher than the former. Moreover, special care is required in the case of such a M-WSS, which comes under the category of M-WSSs but where population is slightly more than that of a S-WSS. For example, if the maximum population limit for a small-sized utility is 3300 persons, the medium-sized utility with 8000 persons might be facing all the difficulties as a S-WSS.

5.2. Categorization of performance indicators for SM-WSS

In the following subsections, the proposed PIs along with their units and required data variables are listed under each category. The selected PIs categories include water resources and environmental, personnel and staff, physical and asset, operational, water quality and public health, quality of service, and financial and economic indicators. The users of these selected PIs under each category are also mentioned in respective tables. The users are classified as technical personnel (T), managers (M), and policy and (or) decision makers (P). It is possible that more than one user are associated with one PI, depending on the nature and significance of the indicator.

5.2.1. Water resources and environmental indicators

Proposed water resources and environmental indicators for small- and medium-sized utilities are presented in Table 13. Some of the water resource indicators are strongly associated with environmental indicators. For the sustainable utilization of natural water resources, amount of water sourced should not affect the existing designated use of the source (i.e., downstream use in case of surface waters, and lowering of groundwater table). In case of ground water, source yield of a pump is usually given with pump design, and (or) in the findings of the hydrogeological investigations carried out during selection of the source. On the other hand, hydrological analysis of low drought conditions in the case of a surface water source can give the information about maximum allowable draw during low flow periods. It is better to have assessments on the basis of yearly average, but assessment periods of less than 1 year can also be adopted by using the proportionate time periods (i.e., 365/assessment period) (IWA 2006). Availability of water resources in a sustainable way is an important water resource indicator.

Every water source needs to be sustainably utilized by ensuring the continuity of its intended water uses. Integrated water (quality and quantity) management plans requires estimation of optimum degree of treatment of receiving wastewater (also known as total maximum daily loads) based on the allowable threshold concentrations of the aquatic ecosystem to avoid water quality problems. In this connection, a minimum amount of water in the water body is always required to provide a certain dilution. Environmental protection agencies in collaboration with water supply agencies issue water licenses to the water utilities based on their management plans. The utility is supposed to draw water within the allocated license capacity. To achieve this objective "water license capacity" should be compared with the amount to water supplied as an indicator. This indicator also predicts the needs for water conservation, water reuse, and investigation of a new water source in future.

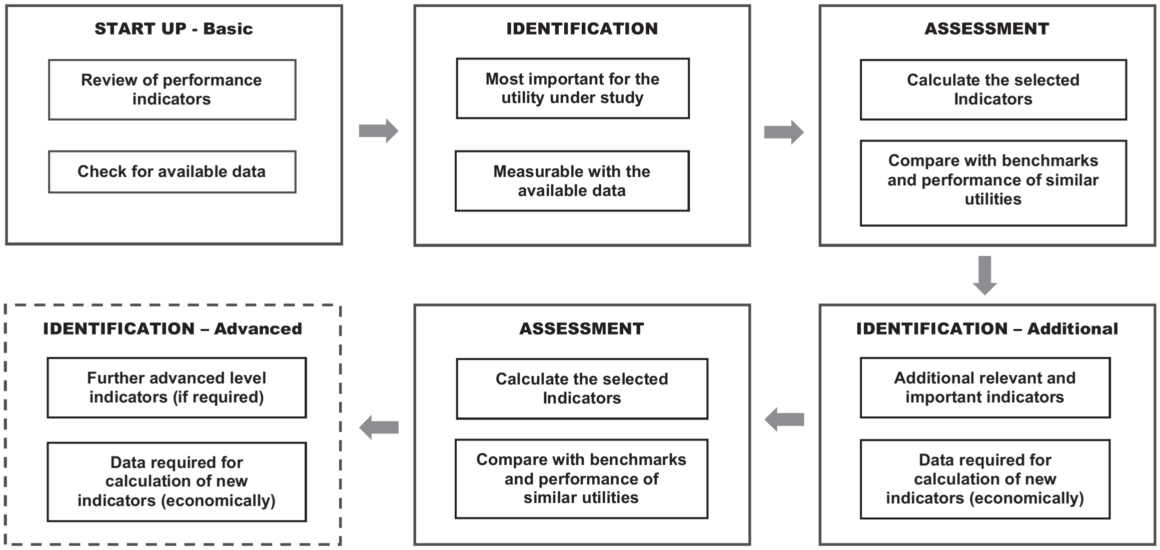
In water scarce areas, reuse of wastewater is commonly practiced even in developing countries (e.g., for agriculture with treatment through waste stabilization ponds). If the amount of water reused (after wastewater treatment) cannot be calculated at the starting time, these estimates can be done in the following year. The data can be collected from the wastewater treatment plant operating in that area. The concept of water reuse can also be useful in situations where the main water supply use is agriculture. In this regard, there is a need for careful assessment with the help of a conventional water balance approach based on the amount of available reuse water, precipitation, and crop water requirements. Experience shows that in some cases much more water is supplied that the actual agricultural water requirements. This approach is environmentally sustainable with additional so-

Table 13. Proposed water resources and environmental indicators.

	Basic (start-up) indicators				
Use of the PI*	Indicators	Calculation	Data variable	Additional indicators†	Advanced (long-term)‡
T/M/P	Availability of water resources (%)	[(Volume of supplied water in a year)/(annual yield of water resources)] × 100	• Water supplied metered volume • Assessment of possible annual yield of source (from surface or ground or both) as per regulations	• Efficiency of reused water supply • Water license capacity	• Sector vise availability of water resources (i.e., domestic, industrial, commercial) • Sector vise availability of water resources for both potable and non-potable water (if applicable)
T/P	GHG emissions§ (tonnes CO_2-equivalents per 1000 connected water properties)	GHG emissions = [quantity of electricity purchased (kWh) × (emission factor/1000 connections)]	• Number of connections • Electricity consumption records • Emission factors established at state level	• GHG emissions from routine transport fuel emissions • Disposal of backwash water (aquatic life should not be affected)	• GHG emissions from fuel consumption by stand-by pumps, construction equipment working during maintenance works, etc.
T/M				• Impact of residual chlorine on aquatic life due to leakage in mains passing nearby the natural water bodies	
T/M				• Impact of residual chlorine on aquatic life due to flushing of mains	

Note: GHG, greenhouse gases.
*T, technical personnel; M, management personnel; P, policy/decision makers.
†Need to be added within a year.
‡Might be suitable for medium-sized utilities in developed countries.
§Might be applicable to medium-sized utilities only in countries where emission factors for consumption of purchased electricity from the grid have been established (CWA 2011).

Fig. 12. Proposed system of PIs to start, proceed, and improve the performance evaluation mechanism in SM-WSS.



cioeconomic benefits. Further detailed PIs can be added in later years for type of water (potable, nonpotable) and type of service area (domestic, industrial, commercial, etc.) as mentioned in NWC (2012). However, these are proposed as additional PIs that can be considered at later stages of PA based on their relevance.

Green house gases emissions, which are responsible for climate change, can lead to drought conditions in the future. These emissions can be considered at the start, since it is not difficult to collect data regarding electricity bills and the number of connections. However, all countries might not have established emission factors for consumption of purchased electricity for CO_2, CH_4, and N_2O emissions as CO_2-equivalent. The values of combined emission factors range between 0.3 and 1.21 in Australia for various states and territories. However, a value of 0.67 was recommended for other territories in Australia in which these emission factors have not been established (CWA 2011).

It is also recommended to develop strategies to reduce water consumption even in areas where abundant water resources are available. Acceptance to higher water losses on the basis of financial analysis (i.e., lower cost of water in the case of plentiful ground or surface waters as compared with the repair cost of a pipe break) could be highly misleading in terms of long-term environmental and socioeconomic sustainability. Consider a WSS with very high water consumption, more than 80% of the water is being converted into wastewater, which will not only lead to higher wastewater cost but will also negatively impact the receiving water body (e.g., low dissolved oxygen, eutrophication, etc). Moreover, wastewater treatment uses significant energy, thereby producing extra GHG emissions in addition to those initially generated during the pumping of large amounts of water. Therefore, sufficient attention should be given to the PIs associated with water resources and environment.

Impact of residual chlorine on aquatic life has not been addressed in literature so far. In this regard, the following two indicators are proposed (PI Nos. 3 and 4, Table 13):

- **WE 3.** Impact of residual chlorine on aquatic life due to mains leakage and breaks = (Volume of water in receiving water body)/(Volume of water due to leakage or break of main); and
- **WE 4.** Impact of residual chlorine on aquatic life due to flushing of water mains = (Volume of water in receiving water body)/(Volume of water drained from flushing of main).

In both indicators, the impact can be considered negligible if 1:10 dilution is available in the receiving water body.

5.2.2. *Personnel and staffing indicators*

Personnel and staffing indicators are very important, as they are strongly aligned with the performance of the other categories. However, it is observed in review stated earlier the paper that most agencies either have not given relative importance to this category or have ignored completely. Like the other organizations, human resources is also an important department in a water utility; therefore, the skills, qualifications, experience, training, overtime, and sick leaves should be included in the performance evaluation process, irrespective of the size of WSS. The personnel indicators recommended by IWA (2006) arranged within the proposed, staged framework for SM-WSS are presented in Table 14. Most of these indicators are simple to calculate with the help of data obtained from the human resource division of the utility under study.

The number of O&M staff may increase as the WSS becomes older. If the hiring of additional staff is planned accordingly, the utility performance will be improved due to prompt response to customer complaints. On the other hand, in case of new schemes where customer complaints are low, a higher number of O&M staff indicates over-hiring in the water supply utility. Additional PIs related to water resources, catchment, treatment, transmission, and distribution can also be calculated for M-WSSs with more connections and long water mains, as shown in Table 14. The PIs related to personnel training, including operation of latest equipment, methods, techniques, and software regarding water quality improvements and water main repairs, are also important. According to Brown (2004), one of the most important indicators of successful small-sized water utilities in the United States is training of operators and decision makers. Major accidents during operations in which workers have been hospitalized should always be recorded to measure the effectiveness of the health and safety procedures adopted by the utility. Depending on the source water, the importance of technical personnel varies; for example, there is less need for technical personnel in the case of sweet ground water, on the other hand there is a much higher requirement for technical staff in the case of saline ground water to operate the reverse osmosis plant. Therefore, it is important to distinguish between the types of technical staff in terms of their skills, experience, and qualifications for cross-comparison with similar sized utilities having different types of water sources. Water quality monitoring personnel is also an important indicator in a WSS. In case of S-WSSs, this activity is sometimes outsourced owing to the absence of a laboratory setup to perform bacterio-

Table 14. Proposed personnel and staffing indicators.

	Basic (start-up) indicators				
Use of the PI	Indicators	Calculation	Data variable	Additional indicators[*]	Advanced (long-term)[†]
T/M	Employees per connection (No./1000 connections)[‡]	[(No. of full time employees)/(No. of service connections/1000)]	• Total personnel • Total No. of service connections	• Employees per volume of water supplied	—
M	• Management personnel (%) • Technical personnel (%)	[(No. of full time management (i.e., finance, human resources, marketing, customer services) employees)/(total No. of full time employees)] × 100 [(No. of full time technical (i.e., planning and construction, operation and maintenance) employees)/(total No. of full time employees)] × 100	• No. of connections • No. of total management personnel • No. of total technical personnel	• Water resources and catchment management employee • Abstraction and treatment employee • Transmission, storage, and distribution employee	• General management personnel • Human resources management personnel • Financial and commercial personnel • Customer services personnel • Planning and construction personnel • Operation and maintenance personnel
M/P	Qualified personnel (%)	[(No. of full time employees with university degree and basic education)/(total No. of full time employees)] × 100	• No. of personnel with university degree and high school education • Total No. of employees	• University degree personnel • Basic education personnel • Other qualification	—
M/P	Personnel training (h/employee/year)	[(No. of training hours during a year)/(total No. of employees)]	• Total No. of training hours • Total No. of employees	• Internal trainings • External trainings	—
T/M	Working accidents (No./100 employee/year)[§]	[(Number of major working accidents in a year)/(total No. of employees/100)]	• No. of major accidents in a year • Total No. of employees		• Absenteeism • Overtime
	—	—	—	Water quality monitoring personnel (No./100 tests/year)	—
	—	—	—	Metering management personnel (No./100 m)	—

[*]Could be added during next year.
[†]Might be suitable for medium-sized utilities in developed countries.
[‡]For smaller utilities, units of employees/100 connections can be used.
[§]For smaller utilities, units of No./10 employees/year can be used.

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logical and chemical analyses. This indicator can be included at later stages in the PA process of such S-WSSs (Table 14).

5.2.3. Physical and asset indicators

Physical indicators are related to performance and efficiency of various components (assets) of a WSS, such as storage, pumping, treatment, transmission, and distribution mains. Most of these components are designed to meet the demand until the end of their design period (i.e., optimally equal to their structural life). Considering both the remaining capacity and the total structural life together, technically feasible and economically viable future planning can be done. For example, treatment facilities are easily extendable and have relatively less service life than the mechanical equipment installed with them, whereas buried pipelines are difficult to replace and possess much longer structural life. The outcome of these PIs is useful for asset management, if properly utilized. Proposed indicators in this category for SM-WSSs are listed in Table 15.

It can be seen in Table 15 that treatment plant utilization and level of metering are the most important PIs in this category. Treatment plant capacity utilization indicates the need for additional treatment units in future, and the metering level is important for estimating water losses. It is very common in SM-WSSs to provide water at flat rates, particularly when the source water is ample. Such WSSs face several operational complications, including wastage of large volumes of water and difficulties in estimation of nonrevenue water. The estimates of water loss would be more accurate if based on the data from bills of metered connections. It is also reported that the reason for higher water loss in Central America than the Latin American countries is possibly the poor metering system (Corton and Berg 2009). Indicators related to valves, hydrants, and automation and control could be important for M-WSSs in developed countries. Some of the source water bodies, particularly rivers and streams, are influenced by large flow variations. Under extreme low flow condition in hilly areas, there is sometimes no water available for water supply. Storage of water during high flows is necessary with application of rain water harvesting methods or diversion structures. Estimation of the capacity of storage reservoirs should be carefully carried out based on the flow variations in source water (sufficient storage during period of low flows). Therefore, the indicator of raw water storage capacity is included for SM-WSSs in Table 15.

5.2.4. Operational indicators

Operational indicators are essentially related to inspection and maintenance of the physical assets discussed earlier in the paper. IWA (2006) and others have included water quality monitoring indicators in the same category, but here water quality indicators are proposed under a separate category. The operational indicators recommended in this work are listed in Table 16. Periodic cleaning of storage tanks is mandatory to reduce water quality issues resulting from formation of algae, particularly in S-WSSs relying on a surface water source. Percentage of mains subjected to leakage during the year can be identified from the location of the breaks. This indicator is important for assessing the structural integrity of the WDS, and also to find out the main problematic areas with repeated complaints about leakage.

Lengths of rehabilitated mains also provide information regarding the operational efficiency of the O&M staff, as well as the conditions of the mains. The main failures indicator is important because this failure could be due to the failure of any of the components, including valves, fittings, etc. Meters are one of the most important components of the WDS for measuring water losses, so meter operation should also be recorded in terms of working conditions.

The "best practice" proposed by the IWA Task Force, a water balance to determine losses in a water distribution network, is shown in Fig. 13 (Alegre et al 2000; Hirner and Lambert 2000). This is the only comprehensive water loss calculation framework that can be efficiently used for cross-utilities comparisons at an international level (Lambert 2003).

All the components of the water balance given in Fig. 13 need to be determined in terms of volume of water (preferably for 1 year). The main component of apparent losses are illegal use (theft) and the errors associated with billing, data handling, and metering as shown in Fig. 13. Experience shows that apparent losses may range between 1% and 9% of the total system input volume (Lambert 2002). It has also been reported that the main component of apparent losses is inaccuracies in metres (Mutikanga et al. 2009; Criminisi et al. 2009). The other component of water losses is the real losses (also known as physical losses) due to leakage from different components of a WSS. Recent studies have found that one third of the total water lost in urban water distribution systems is due to the leaks and breaks of water mains (Kanakoudis and Tsitsifli 2010). The following seven real loss indicators have been reported in the literature (Sharma 2008; Radivojević et al. 2008; Hamilton et al. 2006):

- Percentage of system input volume;
- Per property per day;
- Per length (km) of mains per day;
- Per service connection per day;
- Per service connection per day per metre pressure;
- Per length (km) per day per metre pressure; and
- Per length (length of main + length of service connections up to meter locations) of system per day.

Hamilton et al. (2006) developed a matrix based on results of several studies over years, identifying limitations of the above-mentioned real loss indicators in consideration of key factors that affect real losses. According to them, none of the indicators takes all the key factors affecting real loss into account. Detailed discussions on the application of the different above stated indicators of real losses can be found in the literature (Kanakoudis and Tsitsifli 2010; Radivojević et al. 2008; Hamilton et al. 2006; Lambert and Hirner 2000; Lambert and Morrison 1996; Arscott and Grimshaw 1996; Butler and West 1987).

It is well recognized that real losses cannot be completely avoided economically because of continuous, unavoidable deterioration of the WDS (Radivojević et al. 2008). The IWA Task Force recommended a comparison between the current annual real losses (CARL) and unavoidable annual real losses (UARL) (Hamilton et al. 2006). Lambert et al. (1999) developed the following equation empirical relationship to calculate UARL

$$\text{(3)} \qquad \text{UARL (L/day)} = (18 \times \text{Lm} + 0.8 \times \text{Nc} + 25 \times \text{Lp}) \times P$$

where Lm is the length of mains (km); Nc is the number of service connections; Lp is the length of private service pipes from property boundary to the meter (km); and P is the average pressure. A value of 0 for Lp can be used when a meter is installed at the boundary line.

ILI, previously known as the International Leakage Index, has been well recognized as the most appropriate indicator for the calculation of real losses (physical losses). It frequently investigates the management efficiency at a certain operating pressure. Liemberger (2002) proposed the following formula to calculate ILI as the ratio CARL and UARL:

$$\text{(4)} \qquad \text{ILI} = \frac{\text{CARL}}{\text{UARL}}$$

The ILI calculated from eq. (4) is unitless, therefore providing a better opportunity for international cross-utility comparison. The

Table 15. Proposed physical and asset indicators.

Use of the PI	Basic (start-up) indicators			Additional indicators*	Advanced (long-term)†
	Indicators	Calculation	Data variable		
M/P	Treatment plant capacity (%)‡	[(Maximum volume of water treated per day)/(maximum daily designed capacity)] × 100	• Treated water supplied from water treatment plant • Design capacity of treatment plant	—	• Remaining capacity of treatment plant
M/P	Raw water storage capacity (days)	[(Net capacity of raw water reservoir)/(volume of supplied water during the period of assessment)]	• Volume of the reservoir (can be monitored by keeping the record of reservoir level) • Volume of supplied water (metered volume supplied) • Assessment period of one year will give reliable estimate	• Treated water storage (days)	• Remaining capacity of storage
T/M	Metering level (%)	[(Number of connection with meters installed)/(total No. of connections)] × 100	• Number of metered connections • Total number of connections	—	• Metering density (No./1000 service connections)
	—	—	—	• Pumping utilization (%)	• Energy recovery (%) • Standardized energy consumption§ • Reactive energy standardized energy consumption§
	—	—	—	—	• Valves density (No./km of main) • Hydrant density (No./km of main)
	—	—	—	—	• Degree of automation and remote control units

*Can be added during next year.
†Might be suitable for medium-sized utilities in developed countries.
‡Applicable to the utilities relying on surface water sources or saline ground water, treatment is done with reverse osmosis or marine water treatment with thermal desalination.
§See International Water Association 2006 manual for details.

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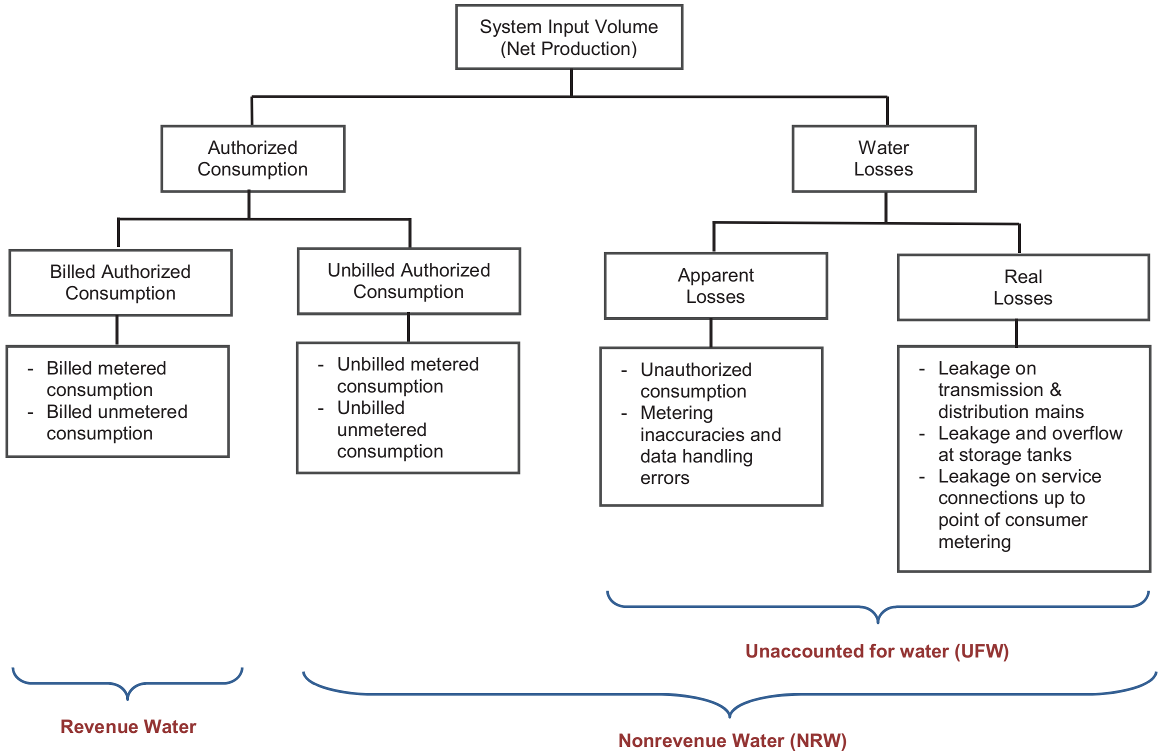
Table 16. Proposed operational indicators.

	Basic (start-up) indicators				
Use of the PI	Indicators	Calculation	Data variable	Additional indicators*	Advanced (long-term)†
T	Cleaning of storage tanks per year	[(Total volume of storage tanks cleaned during the assessment period)/(total volume of all storage tanks)]	• Sum of volume of storage tanks cleaned • Total storage volume of tanks	—	—
T/M	Leakage (%/year)	[(Length of mains detected to leakage in a year)/(total mains length)] × 100	• No. of breaks in a pipe (total length of that pipe is known from design) • Pipe lengths	• Leakage detection and repairs	—
M/P	Rehabilitation, renewal or replacement of mains (%/year)	[(Length of mains rehabilitated, renewed or replaced during a year)/(total mains length)] × 100	• No. of repairs • Pipe lengths	• Rehabilitated, renewed and replaced mains individually	—
T/M	Unaccounted for water	[(System input volume) – (billed and unbilled authorized consumption)]	• System input volume • Data of billed consumption • Data of unbilled authorized consumption	• Apparent losses • Real losses	• Infrastructure leakage index (ILI)
T/M	Main failure (No./100 km/year)	[(Number of main failures during the year including valves and fitting)/(total main length × 100)]	• Data of main failure irrespective of type • Total main length of the distribution system	• Pump failure • Hydrant failures	• Power failures
T/M	Operational meters (%)	[(Number of direct customer meters installed that are operational)/(total number of meters installed)] × 100	• Total number of installed meters • Complaints received for out-of-service meters or meters found out-of-service during the meter reading	• Customer meter reading efficiency	—
	—	—	—	• Refurbishment or replacement of pumps (%/year) • Frequency of inspection of pumps	—
		—	—	• Inspection of mains (valves, fittings and hydrants)	• Valves replaced • Service connections replaced
	—	—	—	—	• Inspection and calibration of instruments‡
	—	—	—	—	• Degree of automation and remote control units

*Can be added within a year.
†Might be suitable for medium-sized utilities in developed countries.
‡See International Water Association 2006 manual for details.

Fig. 13. Components of water balance for calculation of water losses in water distribution defined by Farley and Trow (2003).



relationship among ILI, CARL, and UARL has been best presented in Fig. 14. The outer rectangle shows that CARL increases with aging of the WDS, and hence the ILI value. To reduce the volume of CARL, management methods (shown as arrows in the Fig. 14) to control the real losses need to be applied. Asset management pushing the CARL rectangle from the bottom includes selection, installation, maintenance, renewal, and replacement of deteriorating assets of a WSS (Lambert and McKenzie 2002).

Liemberger (2002) presented a graphical visualization of ILI from 1 to 100, where a value of 1 is ideal but not necessary to be set as the target value. Liemberger and McKenzie (2005) found that the ILI formula had limited applicability in developing countries where data are often unavailable and (or) inaccurate due to limited resources. According to them, the efficiency of the ILI depends on the accuracy of the UARL formula to some extent but mainly on the annual volume of real losses (i.e., CARL), average pressure, and the data related to the distribution network.

It is uneconomical to completely control the leakage from all the reservoirs and pipe mains; NWC Department of the Environment (1980) stated that there is always an economic level of leakage (ELL). According to OFWAT (2003), the ELL is the level at which further reduction in leakage becomes more expensive than producing water from another source. The optimum or economic level can be determined by adding the cost of distributing treated water and the cost of reducing leakage. The water production cost will vary with the type of network and level of treatment (e.g., direct pumping or gravity systems). However, there were questions raised about the application of UARL formula and using the ILI approach for systems operating with <3000 service connections, service connection density of <20 per km of main length, and an average pressure <25 m, which could be the case of SM-WSSs. Due to the immense amount of unauthorized consumption from illegal connections, the concept of nonrevenue water (NRW) is not a reliable estimate of real losses. However, NRW is still most commonly used in developing countries and SM-WSSs, as it is easy to calculate and can be useful as a financial indicator (Kanakoudis and Tsitsifli 2010; Lambert 2003; IWA 2006). It is recommended here as well for use as a financial indicator for SM-WSSs. The UFW is proposed as a startup indicator in Table 16 for SM-WSSs because of its simple calculation. It can be easily calculated by deducting the authorized consumption (both billed and unbilled) from the net production.

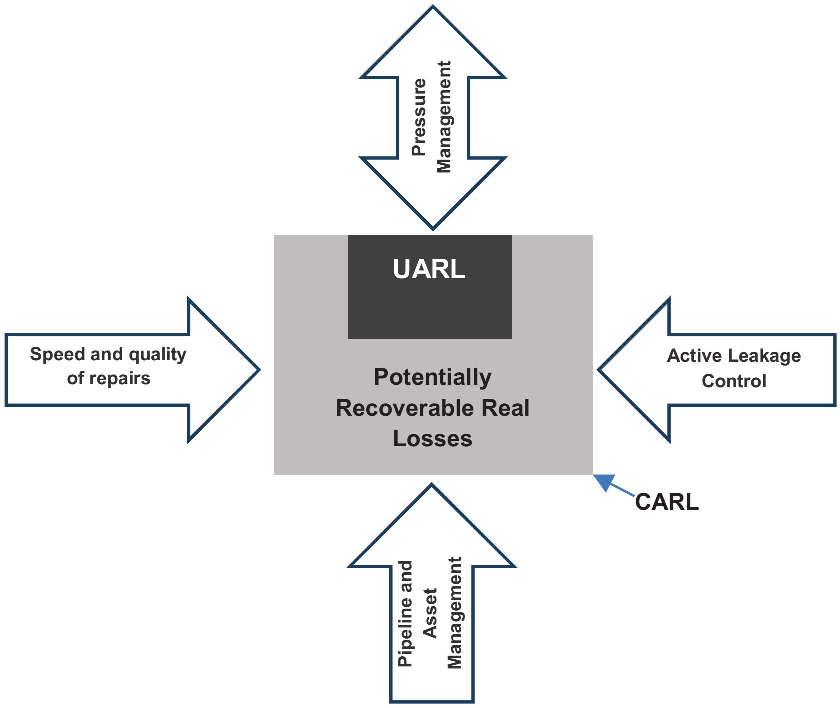
5.2.5. *Water quality and public health indicators*

Most of the health problems in S-WSSs are caused by pathogenic microorganisms (MO), which can be removed by disinfection. All types of MO are important regardless of the size of the system. The most common MO in small systems are *Escherichia coli* (*E. coli*) and *Campylobacter species* (Ford et al. 2005). However, the type of pathogen depends on the water source and the geographical location of the area. The main reasons of their presence might be incomplete disinfection or inefficient working of the treatment plant. However, it is always easy to identify and rectify water quality outbreaks in small systems because of their relatively smaller network size. A well-known example, Washington County Fair, New York, USA in 1999, describes the potential risk of public health associated with a contaminated shallow well in small counties; 921 diarrhea cases were reported as a result of drinking nonchlorinated water (MMWR 1999).

Chronic and acute chemical risks include arsenic, nitrates, pesticides, disinfection by-products (DBPs), iron, lead, pH, etc. Trihalomethanes (THMs) and haloacetic acids (HAAs) are the main DBPs if the source water contains sufficient OM and the disinfection method is chlorination. The most common aesthetic water quality aspects are taste, odour, and colour (WHO 2011). Detailed reviews on the fate and transport of various chemical constituents (fluoride, iron, nitrification, chlorine residual) in WSSs and their impacts on both human health and system integrity have been frequently reported in the literature (Benson et al. 2011; Fisher et al. 2011; Zhang et al. 2009; Ayoob and Gupta 2007).

Natural waters may contain some chemical elements that are naturally radioactive. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2008),

Fig. 14. The four basic methods of managing real losses (source: Lambert et al. 1999). CARL, current annual real losses; UARL, unavoidable annual real losses.



the global average yearly dose from all environmental sources of radioactive radiation is about 3.0 mSv per year per person. However, the possibility of cancer risk through ingestion of drinking water has been reported for doses of 100mSv for extended time exposures. It is not economically viable to identify individual radionuclides in the WSS, but a screening process is practical for identifying the total radioactivity without regard to specific types of radionuclides. Details can be seen in WHO (2011). Therefore, it is important to conduct overall radioactivity tests in SM-WSSs. Proposed water quality and public health indicators are presented in Table 17 (IWA 2006; NWC 2012; NRC 2010).

In Table 17, the PIs proposed for SM-WSSs are dealing with classification of water quality parameters (e.g., aesthetic, chemical), instead of the parameter itself (e.g., pH, chlorine residual) due to the fact that the selection and importance of detailed water quality indicators depends on the source of the water supply. Sources of chemical constituents in surface waters are natural rocks, industrial and domestic activities, fertilizers and pesticides used in agricultural activities, and the use of specific chemicals (e.g., coagulants, polymers, and chloramines) in the treatment processes. Therefore, special considerations for detailed parameter wise analysis are recommended at the time of source selection to select the most suitable water quality parameters and their sampling frequency. Moreover, extra care and frequent monitoring (with strict quality control and quality assurance practices) of various types of aesthetic, chemical, and microbiological water quality aspects would be required particularly in the case of a fresh surface water source.

For fresh ground water sources, residual chlorine and microbiological water quality aspects are more important because the source is free from suspended and dissolved organic and inorganic elements and the only possibility of microbiological contamination is from cross-connections in cracked pipelines. Turbidity and pathogens are the main problems of surface water sources, which are conventionally controlled through water treatment facilities (e.g., coagulation, sedimentation, filtration, disinfection). Sometimes higher dissolved oxygen (DO) concentrations from saturated water sources (rivers and lakes) may also exacerbate corrosion of metal pipes (WHO 2011).

If the source is marine water, all types of chemical, biological, and aesthetic parameters need to be controlled and monitored. The treatment processes in this case could be either the "conventional treatment followed by reverse osmosis" or the "thermal desalination process". Thermal desalination processes are not economical for SM-WSSs because of their higher initial construction cost. However, all these treatment facilities may operate at different efficiencies depending on skills of the operators, source water quality, and structural condition and age of plant components. Thus, the implementation of a well-structured water quality monitoring plan is always required to ensure the provision of safe drinking water to the consumer. Efficacy of this monitoring plan can be assessed through the PIs given in Table 17 and then through a comparison of these PIs with other similar SM-WSSs and the applicable water quality standards.

5.2.6. *Quality of service indicators*

Customer satisfaction is the most important characteristic of any WSS and can be assessed by using the PIs of quality of the service provided to the customers. Agencies have used different indicators to check the efficiency of the WSS in this context. Customers will only be satisfied when they get the best service at the cost they paid for the water. Cost of water may range from free (e.g., public stand post installed by an NGO in a S-WSS of a developing country) to very high (e.g., desalinated marine water in a M-WSS of a developed country). The satisfaction can be mainly correlated to the maximum coverage, adequate quantity (i.e., continuous supply at required pressure), acceptable quality (i.e., meeting with water quality standards and guidelines), prompt response to customer complaints, and less time taken to install a new connection or meter.

Customers may not receive a response to their complaints if the supplier's email spam filter prevents messages from coming through. As discussed earlier in the paper, in the case of privately

Table 17. Proposed water quality and public health indicators.

	Basic (start-up) indicators				
Use of the PI	Indicators	Calculation	Data variable	Additional indicators*	Advanced (long-term)†
T	Aesthetic water quality tests carried out (%)	[(Number of treated water aesthetic tests carried out during a year)/(number of treated water aesthetic tests required by applicable standards per year)] × 100	• Record of aesthetic water quality tests (taste, colour, and odour) of treated water • Applicable water quality standards or regulations	• Tests performed for taste • Tests performed of odour • Tests performed for colour	—
T	Microbiological water quality tests carried out (%)	[(Number of treated water microbiological tests carried out during a year)/(number of treated water microbiological tests required by applicable standards per year)] × 100	• Record of microbiological water quality tests of treated water • Applicable water quality standards or regulations	• Tests performed for pathogens • Test performed for viruses • Tests performed for helminths	—
T	Chemical water quality tests carried out (%)	[(Number of treated water chemical tests carried out during a year)/(number of treated water chemical tests required by applicable standards per year)] × 100	• Record of chemical water quality tests of treated water • Applicable water quality standards or regulations	• Tests performed for residual chlorine • Tests performed for dissolved solids • Tests performed for arsenic or other toxic chemicals	• Tests performed for chloramines • Tests performed for trihalomethanes and haloacetic acids • Tests performed for dissolved organics and inorganics
T	Radioactivity water quality tests carried out (%)	[(Number of treated water radioactivity tests carried out during a year)/(number of treated water radioactivity tests required by applicable standards per year)] × 100	• Record of overall radioactivity water quality tests of treated water • Applicable water quality standards or regulations	—	—
T/M/P	Population days with boiled water advisories (%)	[(Number of days with boiled water advisory during a year)/(total days in a year)] × 100	• Record of the days when boiled water advisories were issued	—	—
	—	—	—	—	• Reduction in number of illnesses, injuries and deaths resulting from the performance improvement
	—	—	—	—	• Risk-based drinking water management plan (Yes/No)
	—	—	—	—	• Public disclosure of drinking water performance (Yes/No)

*Can be added within a year.
†Might be suitable for medium-sized utilities in developed countries.

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Table 18. Proposed quality of service indicators.

	Basic (start-up) indicators				
Use of the PI	Indicators	Calculation	Data variables	Additional indicators	Advanced (long-term)*
M/P	Population coverage (%)	[(Resident population served by the water undertaking)/(total population of the study)] × 100	• Record of the population served (based on experts opinion, demographic surveys and analysis) • Total population of the area	• Building supply coverage (%) • Population coverage by service connections	• Household and business supply coverage (%)
M/P	Population coverage by public stand-posts – developing countries (%)†	[(Resident population served by the water undertaking through public stand-posts)/(total population of the study area)] × 100	• Record of the population served (based on experts opinion, demographic surveys, and analysis) • Total population of the area	• Population per public stand-post • Per capita water consumption in public stand-post	—
M/P	Operational water points and stand-posts – developing countries (%)†	[(Number of water points that are operational)/(total number of water points in the study area)] × 100	• Record of the operational stand-posts • Total number of stand-posts installed	—	—
T/M	Adequacy of supply pressure	[(Number of service connections at which pressure is equal or higher than the target pressure)/(number of service connections)] × 100	• Record of complaints regarding low pressure points • Results of pressure monitoring survey • Total number of connections	—	—
T/M	Continuity of supply (%)	[(Number of hours when the system is pressurized during a year)/(total days in a year)] × 100	• Record of the hours when the system was not pressurized	—	—
T/M	Water interruptions (%)	[(Number of hours when the system is pressurized during a year)/(total days in a year)] × 100	• Record of the hours when the system was not pressurized	—	—
T/M	Average frequency of unplanned interruptions (No./100 connections)‡	[(Total number of unplanned interruptions during the year)/(number of service connections × 100)]	• Record of the number of unplanned interruptions during the whole year • Number of connections	—	—
T/M/P	Days with restrictions to water service (hosepipe or sprinklers) (%)	[(Total number of days with water service restrictions during the year)/(days in a year)] × 100	• Record of the number of days with service restriction during the whole year	—	—
M/P	Water quality compliance of supplied water (%)	[(Total number of treated water samples complying with standards in a year)/(total number of tests performed in a year)] × 100	• Record of water samples analyzed	• Microbiological tests compliance • Chemical tests compliance • Aesthetic tests compliance • Radioactivity tests compliance	—
M	Total complaints per connection (No./100/year)‡	[(Total number of complaints during the year)/(number of service connections × 100)]	• Record of the number of complaints during the whole year • Number of connections	—	• Pressure complaints • Continuity complaints • Water quality complaints • Interruptions complaints • Billing and queries

Table 18 (*concluded*).

Use of the PI	Basic (start-up) indicators			Additional indicators	Advanced (long-term)*
	Indicators	Calculation	Data variables		
M	Total response to written complaints (%)	[(Total number of responses to written complaints)/(total number complaints in a year)] × 100	• Record of the written complaints in a year • Record of complaints responded	—	• Pressure complaints • Continuity complaints • Water quality complaints • Interruptions complaints • Billing and queries
	—	—	—	—	• Total telephonic complaints • Percentage of calls answered within 30 s by an operator
	—	—	—	—	• New connection efficiency • Time to install a customer meter • Connection repair time

*Might be suitable for medium-sized utilities in developed countries.
†Specific to developing countries only.
‡For small systems only, otherwise (No./1000 connections) should be used.

owned WSSs (e.g., England and Wales), customer expectations are too high proportional to the cost of water and the indicators used to assess customer satisfaction might not be practical in general. Depending on of the level of response to written consumer complaints, water suppliers in England and Wales whose response efficiency was higher than 99% (within 10 working days after the receipt of complaint) were given an incentive to increase their water charges (OFWAT 2010*a*). Therefore, the PIs of customer satisfaction need to be carefully selected, particularly for the purpose of cross-comparison.

A proposed set of quality of service indicators is presented in Table 18 (IWA 2006) for SM-WSSs. Aspects related to coverage and customer complaints are addressed in most of the indicator systems. Complaints are easy to record but might not reflect the actual performance of the water utility due to the fact that some customers don't complain about problems they experience. IWA (2006), OFWAT (2012), NWC (2012), and ADB (2012) have proposed other PIs in this category as well, for example, water restrictions (important in case of droughts), call response duration, supply pressure, efficiency of connection and meter installations. A lower number of complaints is an indirect measure of an efficient WSS. Water restrictions describe the indirect situation of availability of water resources in the supply area and effectiveness of water conservation plan. Sprinkler water regulations should be implemented throughout the year under present scarcity of freshwater all around the globe.

There are two main reasons for relatively larger numbers of indicators in this category as given in Table 18. Firstly, these are the most important indicators for assessing performance, particularly of a S-WSS because these WSSs usually have fewer routine maintenance staff and vehicles and customer complaints are the most efficient source of problem identification. Secondly, the data required to measure these PIs only need good recordkeeping instead of expansive data collection and analysis exercises. Through simple analyses and comparisons with similar utilities, efficient conclusions can be drawn on the overall performance of the WSS under study.

SM-WSSs frequently deal with agricultural customers. The connections to the agricultural sector are widespread and sometimes even the customer is unable to identify the problem location. In other cases, the customer is not using the water at all, based on crop water requirements, and instead the problem is a pipe break somewhere in the fields. In such cases, the customer will receive a bill much higher than expected, resulting in an indirect complaint regarding bill inaccuracy, which in reality is due to the pipe break. The PA team should relate the actual cause of the complaint to the relevant component of the WSS. This can be done through use of a well-developed customer complaint proforma. The response to the complaint should be indicated on the proforma and also whether the actual problem was the same as recorded by the customer or something different. Moreover, the proforma should record how many visits were required to rectify the problem, how much distance was travelled, etc. This data would be useful to estimate the cost of each response or repair activity. Later, on the basis of such analysis, the management of a SM-WSS can decide about the additional human and technical resources required in future to improve the performance of their system.

5.2.7. Financial and economic indicators

Different organizations have split the financial indicators into billing, pricing, asset, operating cost, and other categories (see Table 10 for details). There is no long list of financial indicators required to assess the financial performance of a SM-WSS. Practically, for a small municipality, it is more important to know whether or not its operating costs are being met with the revenues it is generating and whether or not it is serving its debts (WB

Table 19. Proposed financial and economic indicators.

	Basic (start-up) indicators				
Use of the PI	Indicators	Calculation	Data variables	Additional indicators	Advanced (long-term)*
M/P	Revenue per unit volume of supplied water ($/m³)	[(Operating revenues - capitalized costs of the constructed assets)/(authorized consumption during the year)]	• Operating revenue during the year • Authorized consumption during the year	—	• Sales revenues • Other (if applicable) revenues
T/M/P	Non-revenue water	[(Cost of the systems input volume) – (billed authorized consumption)]	• System input volume • Data of billed consumption • Unit cost of water	—	—
M/P	Unit total costs ($/m³)	[(Total costs including running cost and capital costs)/(authorized consumption during the year)]	• Running costs • Capital costs • Authorized consumption during the year	—	• Unit running costs • Unit capital costs
M/P	Unit investment ($/m³)	[(Cost of investments (expenditures for plant and equipment)/(authorized consumption during the year)]	• Cost of total expenditures for plant and equipment • Authorized consumption during the year	—	—
M	Average water charges ($/m³)	[(Water sales revenue from all types of customers)/(total authorized consumption during the year)]	• Total revenue from total water sold • Authorized consumption during the year	—	—
M	Operating cost coverage ratio	[(Total annual operational revenues)/(total annual operating costs)]	• Total operational revenue from total water sold • Authorized consumption during the year	—	• Delays in accounts receivable • Investment ratio • Average depreciation ratio • Late payment ratio
M/P	Debt service ratio (%)	[(Cash income)/(financial debt service)] × 100	• Total annual net income • Financial debt service contains the cost of interest expenses, the cost of loans and the principle repayment debt instruments	—	• Debt equity ratio
M/P	Liquidity (current ratio)	[(Current assets)/(current liabilities)]	• Current assets include cash in hand, receivable accounts, inventories, and prepaid expenses • Current liabilities include accounts payable, current liabilities, and current portion of remaining long-term liabilities	—	—

Table 19 (*concluded*).

Use of the PI	Basic (start-up) indicators: Indicators	Calculation	Data variables	Additional indicators	Advanced (long-term)*
T/M/P	Underground infrastructure renewed or rehabilitated (%)	[(Underground infrastructure renewed or rehabilitated annually)/(total underground infrastructure)] × 100	• Lengths of underground water mains renewed or rehabilitated in a year • Total lengths of mains	• Value of horizontal components of infrastructure renewed or rehabilitated (%) • Value of vertical components of infrastructure renewed or rehabilitated (%)	• Large diameter mains renewed or rehabilitated • Small diameter mains renewed or rehabilitated
	—	—	—	—	• Manpower cost • Electrical energy costs
	—	—	—	—	• Management functions cost • Financial and commercial functions costs • Customer service functions costs • Technical service function cost
	—	—	—	—	• Water resources and catchment management costs • Abstraction and treatment costs • Transmission, storage, and distribution costs • Water quality monitoring cost

*Might be suitable for medium-sized utilities in developed countries.

2011). IWA (2006) has provided a list of 46 financial indicators by splitting the cost according to type of cost (main functions of the water utility, technical functions, etc.), which might not be practical for SM-WSSs.

An effort is made in Table 19 to identify and propose the most important financial indicators for these systems. Utilities can also select additional and advanced indicators as per their requirements and data availability. Running costs of a water utility consist of overall O&M costs and the cost of permanent manpower, whereas the capital costs include net interest and depreciation during the assessment period. IWA (2006) recommended calculating the financial indicators for 1 year (assessment period); however, assessment periods <1 year can also be used with necessary explanation. Wyatt (2010) developed a financial model to optimally manage NRW in developing countries. He stated that bill collection in developing countries is not as efficient as in developed countries; thus, there is a need to differentiate between the water that is billed and the actual revenue collected. The situation could be worse in the case of SM-WSSs in developing countries. In such circumstances, the indicator in terms of revenue per unit volume of supplied water can provide a more rational basis for cross-comparisons, instead of using NRW on the basis of billed authorized consumption (refer to PIs 1 and 2 in Table 19).

The PIs of the unit total cost and the unit investment given in Table 19 will facilitate life cycle costing and long-term asset management by utility managers and decision makers. The indicator of the average water charges provides a rational basis for fixing the water charges based on the type and number of customers of each use (residential, agricultural, industrial, etc.). Operating cost coverage is the most important indicator for defining the operational efficiency in financial terms. For private organizations, or a WSS developed with loans, debt service ratio could be an important indicator even for a S-WSS. Indicators of investment ratio, depreciation ratio, and late payment ratio may not be important for SM-WSSs except high-value medium-sized facilities in developed countries. Therefore, these additional PIs can be selected on a long-term basis for such medium-sized WSSs. The NRC (2010) economic indicator (percentage of underground infrastructure renewed or rehabilitated) also seems to be useful for condition assessment and asset management. This indicator can easily be calculated by keeping a record of pipe lengths that have been renewed and rehabilitated in the past. Currency exchange rates should always be applied to all indicators for cross-comparison at international level.

6. Summary and conclusions

Performance assessment of WSSs. Water supply systems have generally been classified on the basis of their size according to their population, number of connections or the flow (water demand). However, the most commonly used classification is population served. Every water supplier wants to operate this important and valuable asset at its maximum possible efficiency with minimum cost throughout its design period. This can only be achieved by evaluating the existing efficiency of all the components of a WSS using a suitable PA framework, consisting of the relevant PIs and identification of areas that require improvements. The PA of SM-WSSs has specific constraints associated with data availability and accuracy, lack of technical personnel, public health risk, inefficient management systems, and lack of financial resources. Little work has been done on performance evaluation of the SM-WSS.

Categorization of PIs. Various agencies and organizations around the world have developed detailed performance evaluation frameworks including several indicators to comprehensively cover all aspects of a WSS. The selected PIs (sometimes further divided into subindicators) have also been categorized into groups and subgroups. This review revealed that the water resources, operational, customer services, and financial indicators have been given more importance in the past, whereas indicators associated with physical assets, personnel, water quality, and public health categories have been relatively neglected so far. Environmental indicators such as GHG emissions are relatively new but need to be considered even in cases of SM-WSSs.

Evaluation of PI systems. The review of the literature revealed that indicators should be comparable, which can only be possible if they are calculated as ratios and percentages. An indicator should also be simple to calculate and easy to understand. Moreover, the indicator system should be comprehensive enough to cover all important aspects of the performance of a WSS, but at the same time it should be simple to use and understandable by the utility managers of a smaller WSS. It can been found from the literature that the agencies who developed the performance evaluation frameworks have given more importance to the indicators of their interest related to site specific issues (e.g., limiting water resources) and objectives (e.g., auditing of funds allocations), or to maintain their general database.

The IWA (2006) system of PA is found to be the most rational one with wider applicability. The system covers almost all the possible aspects of performance of a water utility. The importance-based approach adopted in this system also provides an opportunity for use on SM-WSSs. The system provides a well-structured framework through linking the data with subindicators, indicators, groups, and subgroups in a systematic and simple way. In this paper, a conceptual performance evaluation system consisting of a list of PIs grouped into their respective categories has been proposed. The proposed system provides a stepwise approach to start the performance evaluation process with the most significant and easy to measure indicators for all types of S-WSSs and move to a relatively complex set of PIs for M-WSSs in developed countries.

Proposed PIs for SM-WSSs. It is well recognized that PIs would be different for developing countries than for developed ones due to variations and limitations associated with data availability. In this regard, selected PIs for SM-WSSs have been proposed in three stages (levels) after conducting a detailed review of the PIs used by different organizations in both developed and developing countries. Startup PIs are proposed for both developing and developed countries, requiring limited data to initiate the PA process; additional PIs are proposed for developed countries and for developing countries if the data can be collected; and advanced PIs are proposed for M-WSSs (having sufficient resources) in developed countries.

Expected applications. This review provides information regarding how various agencies have categorized various PIs, considering their specific requirements along with a list of suitable PIs for SM-WSSs. It is expected that the findings of this work would be useful for the operators, managers, engineers, and researchers working on PA of SM-WSS for the selection and implementation of the most relevant PIs.

Recommendations. This review provides guidelines to initiate and (or) improve the PA process of the SM-WSS using appropriate PIs. Consistent review and improvement of the selected PIs are recommended over time as per the site specific requirements of the WSSs under study.

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References

Arab Countries Water Utilities Association (ACWUA). 2010*a*. Key performance indicators and benchmarking for water utilities in the MENA/Arab Region, ACWUA 1st regional training course, supported by Alexandria water company, Alexandria, Egypt. 4–8 July 2010.

Arab Countries Water Utilities Association (ACWUA). 2010*b*. Key performance indicators and benchmarking for water utilities in the MENA/Arab Region, 1st Arab Water Week, Amman Jordan. 8–9 December 2010.

ADB. 2012. Handbook for selecting performance indicators for ADB-funded projects in the PRC, Asian Development Bank, cited on July 2012. www.adb.org/prc.

AECOM. 2012. National Water and Wastewater benchmarking Initiative - 2012 Public Report, Canada. www.nationalbenchmarking.ca.

Alegre, H. 1999. Performance Indicators for Water Supply Systems. *In* Drought Management Planning in Water Supply Systems. *Edited by* E. Cabrera and J. Garcla-Serra. pp. 148–178.

Alegre, H., Hirner, W., Baptista, J.M., and Parena, R. 2000. Performance indicators for water supply services, Manual of Best Practice Series, IWA Publishing, London.

Alegre, H., Bapista, J.M., Cabrera, E., Jr., Cubillo, F., Duarte, P., Hirner, W., Merkel, W., and Parena, R. 2006. Performance Indicators for Water Supply Services, Manual of Best Practice Series, IWA Publishing, London, UK.

American Water Works Association (AWWA). 2004. Selection and definition of performance indicators for water and wastewater utilities. Water://Stats 2002 Distribution Survey. AWWA, Denver, Colo., USA.

Arscott, A., and Grimshaw, F. 1996. Evaluating investment in the water network on leakage detection. *In* IIR conference on cost effective management of water pipelines and networks, London. pp. 24–25.

AWWA. 2008. Benchmarking - performance indicators for water and wastewater utilities: 2007 annual survey data and analysis report, USA.

Ayoob, S., and Gupta, A.K. 2007. Fluoride in drinking water: a review on the status and stress effects. Critical Reviews in Environmental Science and Technology, **36**(6): 433–487. doi:10.1080/10643380600678112.

Bari, M.A., Berti, M.L., Charles, S.P., Hauck, E.J., and Pearcey, M. 2005. Modelling of stream flow reduction due to climate change in Western Australia – A case study. International Congress on Modelling and Simulation. 12–15 December 2005. Modelling and Simulation Society of Australia and New Zealand, Melbourne. pp. 482–488. http://www.mssanz.org.au/modsim05/papers/bari.pdf.

Benson, A.S., Dietrich, A.M., and Galagher, D.L. 2011. Evaluation of iron models for water distribution system. Critical Reviews in Environmental Science and Technology, **42**(1): 44–97. doi:10.1080/10643389.2010.498753.

Berg, C., and Danilenko, A. 2011. The IBNET water supply and sanitation performance Blue Book, The International Benchmarking Network for Water and Sanitation Utilities Data book, Water and Sanitation Program, The World Bank, Washington D.C., p. 58849.

Braden, J.B., and Mankin, P.C. 2004. Economic and Financial Management of Small Water Systems: Issue Introduction. Journal of Contemporary Water Research and Education, **128**: 1–5. doi:10.1111/j.1936-704X.2004.mp128001001.x.

Brown, C.E. 2004. Making small water systems strong. Journal of Contemporary Water Research and Education, **128**: 27–30. doi:10.1111/j.1936-704X.2004.mp128001005.x.

Butler, M., and West, J. 1987. Leakage prevention and system renewal. *In* Pipeline Management Seminar 1987. Pipeline Industries Guild.

Chartres, C., and Williams, J. 2006. Can Australia overcome its water scarcity problems. Journal of Development in Sustainable Agriculture, **1**: 17–24.

Coelho, S.T. 1997. Performance in water distribution – a system approach. John Wiley and Sons Inc., New York, USA.

Coelli, T.J., Estache, A., Perelman, S., and Trujillo, L. 2003. A Primer on Efficiency Measurement for Utilities and Transport Regulators, World Bank Publications.

Corton, M.L., and Berg, S.V. 2009. Benchmarking Central American water utilities. Utilities Policy, **17**: 267–275. doi:10.1016/j.jup.2008.11.001.

Criminisi, A., Fontanazza, C.M., Freni, G., and Loggia, G.L. 2009. Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. Water Science and Technology, **60**(9): 2373–2382. doi:10.2166/wst.2009.423. PMID:19901469.

Cromwell, J., Nestel, G., Albani, R., Paralez, L., Deb, A., and Grablutz, F. 2001. Financial and Economic Optimization of Water Main Replacement Programs. Denver, CO: AWWA Research Foundation.

CSA. 2010. Activities relating to drinking water and wastewater services – Guidelines for the management of drinking water utilities and for the assessment of drinking water services, CAN/CSA-Z24512-10, National Standard of Canada, ISO, Standards Council of Canada & Canadian Standards Association.

CWA. 2011. National greenhouse account factors. Department of Climate Change and Energy Efficiency, Australian Government.

CWWA. 2009. Water conservation and efficiency performance measure and benchmarks within the municipal sector; An introduction of current practices and assessment of the feasibility of expanding their use, Municipal water conservation efficiency performance measures and benchmarks, Canadian Water Works Association, A report to the Ontario Ministry of Environment, Ontario, Canada.

Defaria, A.L., and Alegre, H. 1996. Paving the way to excellence in water-supply systems - a national framework for levels of service assessment based on consumer satisfaction. Journal of Water Supply Research and Technology-Aqua, **45**(1): 1–12.

Donald, P.R., and Dorothy, L.R. 1977, Actue toxicity of residual chlorine and ammonia to some native Illinois fishes, Report of Investigation 85, State of Illinois, Department of Registration and Education, Illinois State Water Survey, Urbana.

Dziegielewski, B., and Bik, T. 2004. Technical Assistance Needs and Research Priorities for Small Community Water Systems. Journal of Contemporary Water, **128**: 13–20. doi:10.1111/j.1936-704X.2004.mp128001003.x.

Farley, M., and Trow, S. 2003. Losses in water distribution networks. IWA Publishing, London, UK.

Fisher, L., Kastl, G., Sathasivan, A., and Jegatheesan, V. 2011. Suitability of chlorine bulk decay models for planning and management of water distribution system. Critical Reviews on Environmental Science and Technology, **41**(20): 1843–1882. doi:10.1080/10643389.2010.495639.

Ford, T., Rupp, G., Butter, F.P., and Camper, A. 2005. Protecting public health in small water systems, Report of an International Colloquium, Montana Water Center, USA.

Hamilton, P.A., Miller, T.L., and Myers, D.N. 2004. Water Quality in the Nation's Streams and Aquifers–Overview of Selected Findings, 1991–2001. USGS Circular 1265. Reston, VA, U.S. Geological Survey.

Hamilton, S., Mckenzie, R., and Seago, C. 2006. A review of performance indicators for real loses from water supply systems, UK House of Commons Report.

Hirner, W., and Lambert, A. 2000. Losses from water supply systems: Standard Terminology and Recommended Performance Measures. IWA website, www.iwahq.org.uk/bluepages.

ISO. 2007. Activities relating to drinking water and wastewater services – Guidelines for the management of drinking water utilities and for the assessment of drinking water services, Canadian Standards Association, Ontario, Canada.

IWA. 2006. Performance Indicators for Water Supply Services, Manual of Best Practice Series, IWA Publishing, London, UK.

Kalulu, K., and Hoko, Z. 2010. Assessment of the performance of a public water utility: A case study of Blantyre Water Board in Malawi. Physics and Chemistry of the Earth, **35**: 806–810. doi:10.1016/j.pce.2010.07.017.

Kanakoudis, V., and Tsitsifli, S. 2010. Results of an urban water distribution network performance evaluation attempt in Greece. Urban Water Journal. **7**(5): 267–285. doi:10.1080/1573062X.2010.509436.

Kirmeyer, G.J., Richards, W., and Smith, C.D. 1994. An assessment of water distribution systems and associated research needs. AWWA Research Foundation: Distribution Systems, Denver, Colo., USA.

Lafferty, A.K., and Lauer, W.C. 2005. Benchmarking – Performance Indicators for Water and Wastewater utilities: Survey Data and Analysis report, American Water Works Association (AWWA), USA.

Lambert, A.O. 2002. International report: water losses management and techniques. Water Supply, **2**(4): 1–20.

Lambert, A. 2003. Assessing non-revenue water and its components: a practical approach to water loss reduction, The IWA Water Loss Task Force, Water 21, Article No 2.

Lambert, A., and Hirner, W.H. 2000. Losses from water supply systems: Standard terminology and performance measures, IWSA Blue pages.

Lambert, A.O., and McKenzie, R.D. 2002. Practical experience in using the Infrastructure Leakage Index, Proceedings of IWA Conference – Leakage Management: A Practical Approach. Lemesos, Cyprus.

Lambert, A., and Morrison, J.A.E. 1996. Recent developments in application of 'bursts and background estimates' concepts for leakage management. Water Environmental Management, **10**(2): 100–104. doi:10.1111/j.1747-6593.1996.tb00017.x.

Lambert, A., and Taylor, R. 2010. Water loss guidelines, Water New Zealand.

Lambert, A.O., Brown, T.G., Takizawa, M., and Weimer, D. 1999. A review of performance indicators for real losses from water supply systems. Journal of Water Science Research and Technology – Aqua, **48**(2): 227–237.

Liemberger, R. 2002. DO you know how misleading the use of wrong performance indicators can be? IWA Specialized Conference. Leakage Management – A Practical Approach, Cyprus.

Liemberger, R., and McKenzie, R. 2005. Accuracy Limitations of the ILI: Is It an Appropriate Indicator for Developing Countries?, Conference Proceedings, IWA Leakage 2005 Conference in Halifax, Nova Scotia, Canada.

Liu, Z., Kleiner, Y., and Rajani, B. 2012. Condition assessment technologies for water transmission and distribution system, Office of Research and Development, National Risk Management Research Laboratory – Water Supply and Water Resources Division, USEPA, EPA/600/R-12/017.

Malaysian Water Association. 1996. Performance indicators for water supply, a proposal from the Malaysian Water Association for the consideration of member countries of ASPAC.

Maras, J. 2004. Economic and financial management capacity of small water systems. Journal of Contemporary Water Research and Education, **128**: 31–34. doi:10.1111/j.1936-704X.2004.mp128001006.x.

Matos, M.R., Bicudo, J.R., and Alegre, H. 1993. Technical and social-economical indicators in the scope of water supply, wastewater and solid waste systems, in Preparatory study for the definition of selection criteria for environmental projects to be funded by the European Communities, Vol. 2. Project contracted by the European Commission, report 107/93, LNEC, Lisbon, Portugal. p. 43.

Mcintosh, A.C., and Ynoguez, C. 1997. Second water utilities data book- Asian and Pacific Region, Asian development Bank's regional Technical Assistance No. 5694, Manila, Philippines.

McKenzie, R., and Lambert, A. 2002. Development of a simple and pragmatic approach to benchmark real losses in potable water distribution systems in South Africa: BENCHLEAK, Report TT159/01, published by the South African Water Research Commission.

Mitrich, S. 1999. Price and Subsidy Policies for Urban Public Transport and Water Utilities in Transition Economies, Working Paper No. 5. The World Bank, Washington, D.C. p. 2.

Mkhitaryan, L. 2009. Towards performance based utility sector in Armenia: Case of dirking water supply scenario, A Program of EURASIA Partnership, Program, financed by the Carnegie Corporation of New York, Grants to Support Social Science and Policy-Oriented, Caucasus Research Resource Centers (CRRC), Armenia, Research # C08-0198.

MMWR. 1999. Public Health Dispatch – Outbreak of Escherichia coli O157:H7 and Campylobacter among attendees of the Washington County Fair, New York. Morbidity and Mortality Weekly Report, **48**(36): 803–804. PMID:10499785.

Mutikanga, H.E., Sharma, S.K., and Vairavamoorthy, K. 2009. Apparent water losses assessment: the case of Kampala city, Uganda, International Conference of Water Loss-2009, IWA, Cape Town, South Africa, **1**: 36–42.

NRC. 1995. Committee on measuring and improving infrastructure performance, National Research Council, National Academy Press, Washington D.C., ISBN 0-309-050987.

NRC. 2010. Framework for Assessment of State, Performance and Management of Canada's Core Public Infrastructure, National Research Council Canada, Final Report B5332.5.

Nurnberg, W.H. 2001. Performance assessment of water supply systems, German National Report, IWA- World Water Congress-Berlin 2001.

NWC. 2012. National Performance Report 2010-2011: Urban Water Utilities, National Water Commission, Australian Government.

NWC/DoE. 1980. Leakage Control Policy and Practice, National Water Council, NWC/DoE. [S/L counter] 1 copy on S/L.

OFWAT. 2003. Regulating Economic Level of Leakage in England and Wales, World Water Week. Washington, DC.

OFWAT. 2010*a*. Service and delivery – performance of the water companies in England and Wales 2009-10. Available from www.ofwat.gov.uk [accessed July 2012].

OFWAT. 2010*b*. Financial performance and expenditure of the water companies in England and Wales 2009-10. Available from www.ofwat.gov.uk [accessed August 2012].

OFWAT. 2012. Key performance indicators – guidance. Available from www.ofwat.gov.uk. [Accessed August 2012].

PAGS. 2008. Water utility service quality monitoring for water systems in Armenia, USAID, Program Report No. 93.

Parfitt, B., Baltutis, J., and Brandes, O.M. 2012. From Stream to Steam Emerging Challenges for BC's Interlinked Water and Energy Resources, Canadian Center of Policy Alternatives (CCPA), Policy Project on Ecological Governance, University of Victoria.

Radivojević, D., Milićević, D., and Blagojević, B. 2008. IWA best practice and performance indicators for water utilities in Serbia – Case Study Pirot. Facta Universitatis, **6**(1): 37–50. doi:10.2298/FUACE0801037R.

Sadiq, R., Rodríguez, M.J., and Tesfamariam, S. 2010. Integrating indicators for performance assessment of small water utilities using ordered weighted averaging (OWA) operators. Expert Systems with Applications, **37**: 4881–4891. doi:10.1016/j.eswa.2009.12.027.

Sharma, S. 2008. Performance indicators of water losses in water distribution system, UNESCO-IHE Institute for Water Education, The Netherlands.

Stoeckel, K., and Abrahams, H. 2007. Water Reform in Australia: the National Water Initiative and the role of the National Water Commission. *In* Managing water for Australia: the social and institutional challenges. *Edited by* H. Karen and D. Stephen. CSIRO Publishing, Collingwood, Victoria.

Stone, S., Dzuray, E.J., Meisegeier, D., Dahlborg, A.S., and Erickson, M. 2002. Decision-Support Tools for Predicting the Performance of Water Distribution and Wastewater Collection Systems. USEPA.

Theuretzbacher-Fritz, H., Schielein, J., Kiesl, H., Kölbl, J.R., Neunteufel, R., and Perfler, R. 2005. Trans-national water supply benchmarking: the cross-border co-operation of the Bavarian EFFWB project and the Austrian OVGW project. Water Supply, **5**(6): 273–280.

Tynan, N., and Kingdome, B. 2002. A Water Scoreboard, Setting performance targets for water utilities, Public policy for the private sector, Note number 242, The World Bank, Washington DC.

UNSCEAR. 2008. Report: Sources and effects of ionizing radiation. Vol. I. Sources. New York, NY, United Nations, United Nations Scientific Committee on the Effects of Atomic Radiation. Available from http://www.unscear.org/unscear/en/publications/2008_1.html. [Accessed August 2012].

USEPA. 1997. Drinking water infrastructure need survey, First Report to Congress, Office of water, Washington DC, EPA 812-R-97-001.

USEPA. 2001. Drinking Water Infrastructure Needs Survey and Assessment, Second Report to Congress, Office of water, Washington DC, EPA-816-R-01-004.

USEPA. 2002. Community water systems survey - 2000, Washington DC, EPA 815-R-02-005A,B.

USEPA. 2005. Drinking Water Infrastructure Needs Survey and Assessment, Third Report to Congress, Office of water, Washington DC, EPA-816-R-05-001.

USEPA. 2006*a*. Distribution system indicators of drinking water quality, USEPA Office of Groundwater and Drinking Water, Washington DC.
USEPA. 2006*b*. Much effort and resources needed to help small drinking water systems overcome challenges, Report No. 2006-P-00026.
USEPA. 2007. Distribution system inventory, integrity and water quality, Office of Ground Water and Drinking Water, Total Coliform Rule Issue Paper, Washington DC.
USEPA. 2009. Drinking Water Infrastructure Needs Survey and Assessment, Fourth Report to Congress, Office of Water, Washington DC. EPA-816-R-09-001.
Van Der Willigen, F. 1997. Duth experience and viewpoints on performance indicators, IWSA Workshop on Performance Indicators for Transmission and Distribution Systems, Lisbon, Portugal.
WB. 2002. A Water Scorecard, Public Policy for the Private Sector, The World Bank Group - Private Sector and Infrastructure Network.
WB. 2010. A review in Bangladesh, India and Pakistan, benchmarking for performance improvement in urban utilities, Water and Sanitation Program, World Bank Report.
WB. 2011. The IBNET water supply and sanitation performance Blue Book, The International Benchmarking Network for Water and Sanitation Utilities Data book, Water and Sanitation Program, The World Bank, Washington, DC, p. 58849.
WHO. 2011. Guidelines for drinking-water quality, Fourth Edition, Geneva, Switzerland.
WHO. 2012. UN-water global annual assessment of sanitation and drinking water (GLASS) 2012 report: the changes of extending sustaining services, UN Water Report 2012, Switzerland.
WOP-Africa. 2009. Water operators partnership African utility performance assessment, Final Report, Water and Sanitation Program.
WSP. 2009. Benchmarking for improving water supply delivery, Water and Sanitation Program, Bangladesh Water Utilities Data Book, 2006–2007.
Wyatt, A.S. 2010. Non-Revenue Water: Financial Model for Optimal Management in Developing Countries, RTI Press Methods Report series, USA.
Yeppes, G., and Dianderas, A. 1996. Water & wastewater utilities: Indicators, 2nd edition. World Bank, Washington.
Zhang, Y., Love, N., and Edwards, M. 2009. Nitrification in drinking water systems. Critical Reviews in Environmental Science and Technology, **39**(3): 153–208. doi:10.1080/10643380701631739.