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Challenges in Water Loss Management of Water Distribution Systems in Developing Countries

R. R. Dighade[1], M. S. Kadu[2], A.M.Pande[3].

Associate professor, Department of Civil Engineering, YCCE, Nagpur-10, Maharashtra, India[1]

Professor and Head, Department of Civil Engineering, RCOEM, Nagpur-13 Maharashtra, India[2]

Dean, R&D and Professor, Department of Civil Engineering, YCCE, Nagpur-10, Maharashtra, India[3]

ABSTRACT: Leakage in water distribution systems is an important issue which is affecting water companies and their consumers worldwide. It has, therefore, attracted a lot of attention of practitioners and researchers as well over the past years. The need to manage leakage in pipe networks of most of the municipalities became more urgent in recent years due to water shortages caused by recent draughts, increasing the demand along with environmental, social and political pressures. High value of non-revenue water reflects huge volumes of water being lost through leaks, not being invoiced to customers. It seriously affects the financial viability of water utilities through lost revenues and increased operational costs. The overall objective of a distribution system is to deliver wholesome water to the consumer at adequate residual pressure in sufficient quantity and achieve continuity and maximum coverage at affordable cost. To attain this objective the organization has to evolve operating procedures to ensure that the system can be operated satisfactorily, function efficiently and continuously as far as possible at lowest cost. This paper provides a comprehensive insight of the issues pertaining to the challenges in water loss management of water distribution systems in developing countries.

KEYWORDS: Real losses, apparent losses, meter accuracy, water audit, Performance indicators.

I. INTRODUCTION

Water, the precious gift of nature, is the source of prosperity, life and wealth for the people. It is most crucial for sustaining life; and is required for all human activities. The available water sources throughout the world are getting depleted; and this problem is further aggravated by climatic change and the rate at which populations are increasing especially in developing countries. Urban settlements in the developing countries are, at present, growing five times as fast as those in the developed countries. In developing countries urban population is predicted to grow from 1.9 billion in 2000 to 3.9 billion in 2030, averaging 2.3% per year. On the other hand, in developed countries, the urban population is expected to increase, from 0.9 billion in 2000 to 1 billion in 2030 overall growth rate 1% [8]. This has brought into focus the urgent need for planned action to manage water resources effectively. The development, conservation and use of water, therefore, form one of the main elements in country's overall development. The rainfall is confined to few monsoon months and is unevenly distributed both in space and time even during monsoon months. As a result, while large tracts of the country are drought prone, some parts are affected by floods. The problem of water scarcity in urban areas is of particular concern. For example, it is estimated that by 2050, half of India's population living in urban areas will face acute water problems [24]. In many water distribution systems a significant percentage of water is lost as leakage while in transit from treatment plants to consumers. Leakage is not just an economical issue as it is oftenperceived and presented by water companies but it isalso an environmental, sustainability and potentially ahealth and safety issue Colombo and Karney[9].Cities all over in developing countries are facing global pressures [10, 22, 26]. Due to these pressures, providing safe water supply, basic sanitation and maintaining the environment is likely to be more difficult in the future. Intermittent supply leads to many problems including, severe supply pressure losses and great inequities in the distribution of water. Another serious problem arising from intermittent supplies, which is

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Vol. 3, Issue 6, June 2014

generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system (Vairavamoorthy et al., 2007a). Water loss represents inefficiency in water delivery and measurement operations in transmission and distribution networks. Many water utilities have been developing new strategies to reduce losses to an economic and acceptable level in order to preserve valuable water resources. Thus water utility benefits by (a) saving the production costs of the water, (b) increasing revenues through sales of water saved, (c) deferring the system expansion and capital expenditures through the capture of lost water, and (d) reducing increases in utility rates, and thus maintaining better consumer relations. In pursuing a continuous water supply, cities in the developing world must ensure that their water systems become more efficient and effective by reducing water losses, gradually increasing water tariffs, improving revenue collection, increasing staff productivity, and securing safe and reliable water supplies. When efficiency gains are ensured, investments in new infrastructure will lead to more effective and efficient water services [3]. The most municipalities need to manage leakage in their pipe networks. During this century, water will be a scarce resource and therefore, needs to be harnessed in a scientific and efficient manner.

II. WATER LOSSES IN DISTRIBUTION SYSTEM

Water loss occurs on all the systems. It is only the volume that varies, and it reflects the ability of a utility to manage its network. The water losses consist of real and apparent losses. The real losses consist of water lost through burst pipes, leaking joints, fittings, service pipes, and connections. The apparent losses result from illegal connections, under-registration of customers meters, inaccurate meters, stopped meters, vandalized meters, bypassed meters, billing errors, inadequate meter reading policy, bribery and corruption of meter readers. To understand the reasons why, how and where water is being lost; the managers have to carry out an appraisal of the physical characteristics of the network and the current operational practice. The condition of the infrastructure and the renewal or rehabilitation policy is perhaps one of the main reasons for the variation in leakage across the world. This problem is more pronounced in the developing countries with ageing infrastructure [11]. A high level of real loss reduces the amount of precious water reaching customers, increases the operating costs of the utility and makes capital investments in new resource schemes larger. Reducing water losses is a special concern of every water supply utility.

III. QUANTUM OF WATER LOSSES IN DEVELOPED AND DEVELOPING COUNTRIES

One of the major issues affecting water utilities in the developing world is the considerable difference between the amount of water put into the distribution system and the amount of water billed to consumers called “Non-Revenue Water” (NRW). Current statistical surveys indicated that NRW in developing countries is around 45 to 50% i.e. half of the total system input volume. Although, it is widely acknowledged that NRW levels in developing countries are very high, in fact, very few data are available in the literature regarding the actual figures. This is largely because most water utilities in the developing world do not have adequate monitoring systems for assessing water losses and many countries lack national reporting systems that collect and consolidate information on water utility performance. Currently, the water supply system in developing countries does not meet the need of people and industries. High levels of water losses are indicative of poor governance and poor physical condition of the WDS [16, 19]. The amount of water loss in water distribution systems varies widely between different countries, regions and systems from as low as 3–7% to as high as 50 % of distribution input volume in the well maintained systems of developed countries and less maintained system in developing countries respectively [14,16,17]. The WDSs in the Netherlands are probably the most efficient in the world as low leakage levels in the range of 3 to 7 % of system input volume have been reported [7].

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Table 1: Water losses in developed and undeveloped countries

Countries	Level of NRW (excluding unbilled authorize consumption) % system input volume	Real losses (%)	Apparent losses (%)	Loss volume (billion of m^3/year)		NRW Volume billion of m^3/year
				Real losses	Apparent losses	
Developed countries	15	80	20	9.8	2.4	12.2
Undeveloped countries	35	60	40	16.1	10.6	26.7

Table 2: NRW Estimates and Values in Asia

Region	Urban Population with Service Connections (in millions)	System Input Volume		Non-Revenue Water		Physical Losses	Commercial Losses	NRW	Value billion $/year
		L /c/d	m^3/d	%	(m^3/d)	(Billion m^3/year)			
Central and West Asia	29	450	13050000	40	5220000	1.4	0.5	1.9	0.6
East Asia	605	230	139150000	25	34787500	9.5	3.2	12.7	3.8
Middle East	167	250	41750000	360	12525000	3.4	1.1	4.5	1.4
South Asia	202	180	36360000	35	12726000	3.5	1.2	4.7	1.4
Southeast Asia	133	280	37240000	35	13034000	3.6	1.3	4.9	1.5
Total Asia	1136		267550000		78292500	21.4	7.3	28.7	8.6

Source: Urban Population: WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation 2006 data. NRW estimates: Roland Liemberger)

It is observed from the figure given in table no, the estimated annual volume of NRW in urban water utilities in Asia is in the order of 29 billion cubic meters. Assuming a value of water of \$0.30 per m^3, Asia's water utilities are losing nearly \$9 billion per year. If the physical losses reduce to half the present level which is technically feasible, 150 million people could be supplied with water. Reducing total NRW to half the present level and assuming an average reduction cost of \$500 per m^3 per day. NRW reduction, the total investment needed would be around \$20 billion. Spread over a 10-year period, \$2 billion would have to be invested annually in water loss reduction projects. When this reduction is achieved, the revenues of Asia's urban water utilities will increase by an estimated \$4.3billion annually [20].

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Vol. 3, Issue 6, June 2014

IV. ISSUIES IN DEVELOPING COUNTRY

Municipal water pipe networks deteriorate naturally over the period of time and subsequently leakages occurs in the pipe network. Deterioration is caused by corrosive environment, soil movement, poor construction practices and workmanship, fluctuation of water pressure, and excessive traffic loads and vibration. Water utility managers in developing countries will invariably face greater challenges including the rapid urbanization, diminishing water supply, intermittent water supply system with very poor supply hours, increased NRW, very poor system pressure, inequitable distribution of the available water, out-dated and poor infrastructure, poor operations and maintenance policy, poor metering, apparent losses particularly illegal connections, poor record-keeping systems, inadequate technical skills and technology, political, cultural and social influences, community behaviour, greater financial constraints due to revenue collection policy. The important issues are discussed in subsequent sections.

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Intermittent supply system

The distribution system is usually designed as a continuous system based on the assumption of continuous supply. However, in most developing countries water supply is not continuous but intermittent. A serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system. Intermittent supply creates doubts in the minds of the consumers about the reliability of water supply. During the supply period the water is stored in all sorts of vessels for use in non-supply hours and when the supply is resumed, the stored water is wasted and fresh water again stored. During non-supply hours polluted water may enter the supply mains through leaking joints and pollute the supplies and create the health related problem. Further, this practice prompts the consumers to always keep open the taps of both public stand posts and house connections leading to wastage of water whenever the supply is resumed. Intermittent systems which require frequent valve operations are likely to affect equitable distribution of water mostly due to operator negligence. The problem of water scheduling caused by an intermittent supply results in leakage, with a cyclic pressure situation created due to having the supply turned on and off, increased levels of leakage are experienced due to stress being inflicted on the pipes causing them to rupture. Due to high levels of water loss, a continuous supply is not available resulting in water schedules. The elimination of water schedules becomes the desired goal.

Poor Infrastructure

In developing country, it has been observed that pipe network is very old which is laid many years ago. With age there is considerable reduction in carrying capacity of the pipelines due to corrosion. In most of the places the consumer pipes get corroded and leaks occur resulting in loss of water and reduced pressure. All these materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear and result in increased leakage in the network. It is, therefore, necessary to replace older mains so that less leakage occurs. Preventive maintenance of distribution system assures the twin objectives of preserving the bacteriological quality of water in the distribution system and providing conditions for adequate flow through the pipelines. Incidentally, this will prolong the effective life of the pipeline and restore its carrying capacity. Some of the main functions in the management of preventive maintenance of pipelines are assessment, detection and prevention of wastage of water from pipelines through leaks, maintaining the capacity of pipelines, cleaning of pipelines and relining.

Non-Revenue Water

Large quantity of water is wasted through leaking pipes, joints, valves and fittings of the distribution systems either due to bad quality of materials used, poor workmanship, corrosion of pipe, age of the installations. This leads to reduced supply, loss of pressure and deterioration in water quality. Leakage can be controlled at the point of house connection

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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 6, June 2014

and in the consumer pipe by adopting correct plumbing practices and improving the methods used for tapping the main and strict quality control on the pipe material used for service line connection. Illegally connected users will contribute to the reduction in service level to authorized consumers. Sometimes, even legally connected users draw water by sucking through motors causing reduction in pressures. There are a significant number of illegal users of water within distribution system in developing country. The number of households who do not pay water rates but receive water from its distribution system is not known. As a consequence, they contribute significantly to apparent losses and revenue loss to the water authority. Illegal connections are therefore, of significant concern of water utilities.

The level of water losses from potable water distribution systems is one of the key efficiency issues in developing country. Water utilities in developing countries are struggling to provide customers with a reliable level of service, often via aged water distribution infrastructure, with poor networks and restricted budgets. As a result, some of the techniques and methods used for water loss management in developed countries cannot be applied directly in developing countries. There are no appropriate tools and methodologies which are specifically suitable for water loss management in developing countries. In addition, utility managers often do not pay enough attention to NRW because of weak internal policies and procedures which contributes to rising NRW levels. Many utility managers do not have access to information on the entire network which would enable them to fully understand the nature of NRW and its impact on utility operations, its financial health, and customer satisfaction. Successful NRW reduction is not about solving an isolated technical problem, but is instead tied to overall asset management, operations, customer support, financial allocations, and other factors.

Water metering policy

A water meter is a scientific instrument for accurate measurement of quantity of water distributed to the consumers. The customer meter error is often main cause of apparent losses. In developing country metering is not 100% and hence consumer is wasting more water. The water meters are mechanical devices, which normally deteriorate in performance over time. It has been observed that 20 to 50% of the installed meters remain non-working due to their poor quality [6]. The mechanical water meters typically decline in accuracy with usage over the period of time, causing revenue losses to the utility and giving rise to unequal billing policy [16].Sometimes tampering of the meters by the owners has also been noticed. Moreover, the repair facilities for water meters are not adequate in most of the Water Supply Boards, which delay their repairs and early reinstallation. In the absence of working meters, billing for water consumed is often estimated, either on average basis or on flat rate, as the case may be. As per the prevailing practice, the consumers own the domestic meters, as such, they have direct access to the meters. However, it is perhaps worthwhile to explore the possibility of owning such meters by the respective water supply agencies to ensure that the consumers do not have direct access to the meters so as to avoid possible tampering of the meters. In general, if a water meter goes out of order due to any physical damage and is beyond economical repair it should be replaced with immediate effect. The performance of a water meter is required to be watched continuously with suitable history sheets. Any abnormality noticed needs immediate action. While testing the meter, it is to be ensured that it is not only installed correctly but that it is the correct meter for the application. A review of the metering policy may be required to ensure financial sustainability of the organization.

Supply hours and system pressure

In intermittent water supply system most water supply agencies provide water to its consumers at an average of 2–3 hours per day to 70% of the population in its area of responsibility [4]. Shortage of water sources and frequently failure of power supply may cause reduced supply hours and hence reduction in quantity of water supplied. The pressure in distribution system is very poor varying from 0.3 to 1.0 kg/cm^2. Most of the consumers have two storage tanks for storing the water , one below the ground level and one overhead tank due to less residual pressure.

Poor record keeping

The necessity for good maintenance records is often overlooked. System maps, designs of the network and reservoirs and historic records of the equipment installed in the distribution system are often not available, whereas minimum

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Vol. 3, Issue 6, June 2014

information is required to operate and maintain the system efficiently. The top down audit cannot be performed without maintaining the accurate data. Awareness can be created among the managers of water supply system about the importance of good maintenance of record.

Community Behavior

Water loss is not just an engineering problem but also reflects a socio cultural situation that requires changes in community behavior and attitudes toward water usage. Many utilities that have been successful in addressing NRW have gone beyond technical measures to address community behavior that drives illegal connections and pilferage. Addressing this challenge, some Asian cities are also harnessing communities to reduce NRW. Technical measures have been complemented by efforts to address illegal connections by walk-through surveys and authorizing illegal connections by legitimizing them and adding them to the network.

V. OPERATION AND MAINTENANCE

It has been observed that lack of attention to the important aspect of Operation and Maintenance (O&M) of water supply schemes in several towns often leads to deterioration of the useful life of the systems necessitating premature replacement of many system components. As such, even after creating such assets by investing millions of rupees, they are unable to provide the services effectively to the community for which they have been constructed, as they remain underutilized most of the time. Some of the key issues contributing to the poor Operation & Maintenance have been identified as follows

- Lack of funds and inadequate data on Operation & Maintenance
- Inappropriate system design and poor workmanship
- overlapping responsibilities
- Inadequate training of personnel
- Inadequate emphasis on preventive maintenance
- Lack of operation manuals
- Lack of real time field information.

Therefore, there is a need for clear-cut sector policies, legal framework and a clear demarcation of responsibilities and mandates within the water supply sub-sector.

VI. EVALUATION OF WATER LOSSES

In developed country water losses have been assessed before and after the leakage detection survey by two different approaches. The first is top-down annual water balance [1, 23] and the second is the bottom-up approach based on minimum night flow analysis[15]. The MNF is the lowest flow supplied to a hydraulically isolated supply zone, usually measured between 2.00 to 4.00am [25]. In developing countries mostly top down water audit is conducted as per the guidelines suggested by IWA. Due to lack of accurate input data and advance technology, separation of water losses into real and apparent is a big challenge for strategic planning. Due to lack of advance equipment, it is very difficult to detect real losses in distribution system and hence water balance equation cannot be used correctly for assessment of real and apparent loss.. The assessment of real loss by bottom-up approach during the night does not hold the good result because in intermittent supply system consumers always keep tap open in house connections to fill storage tank. Therefore it is difficult to calculate component of legitimate use of water and hence real losses. Secondly, it is difficult to calculate night day leakage factor for intermittent system.

VII. STRATEGY FOR WATER LOSS MANAGEMENT IN DEVELOPING COUNTRIES

A diagnostic approach reinforced by the implementation of solutions which are practicable and achievable, can be applied to any water distribution system in developing country, to develop a water loss management strategy.

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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 6, June 2014

Water audit

Water audit determines the amount of water lost from a distribution system due to leakage and other reasons such as theft, unauthorized or illegal withdrawals from the systems and the cost of such losses to the utility. Comprehensive water audit gives a detailed profile of the distribution system and water users, thereby facilitating easier and effective management of the resources with improved reliability. It helps in correct diagnosis of the problems faced in order to suggest achievable and practicable solutions. It is also an effective tool for realistic understanding and assessment of the present performance level and efficiency of the service and the adaptability of the system for future expansion and rectification of faults during modernization. It helps in identifying problem and risk areas and a better understanding of what is happening to the water after it leaves the source point. Such investigation should provide enough information to set specific objectives for a water efficiency program.

Performance indicator and bench marking

A performance indicators (PI) system can be considered as a key assessment tool for the achievement of targets, by applying a coherent set of indicators. Performance indicators help the utility to-(a) better understand water losses (b) set targets for improvement (c) measure and compare performance (d) develop standards (e) monitor compliance and (f) prioritize investments. Water utilities should include standard performance indicators to measure performance to facilitate comparisons with other utilities. The annual volume of water loss is an important indicator of water distribution system efficiency. Expanding water networks without addressing water loss will only lead to a cycle of waste and inefficiency. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational and maintenance activities. Performance Indicators (PIs) and Benchmarking are identified as the appropriate tools for water supply systems' performance evaluation. The worldwide many experts have identified PIs which may be used to measure the efficiency and effectiveness of a utility in achieving its objectives [1,2].The most widely used performance indicator in developing countries for water loss performance is Non-Revenue Water (NRW) which is expressed in terms of system input volume. Although, it is an important PI, many practitioners tend to overlook its shortcomings for properly assessing water losses because it is highly dependent on supply time, average operating pressure and level of consumption. In developed countries NRW is used as financial indicator and not as an operational indicator, whereas the Infrastructure leakage index (ILI) is used as a technical performance indicator for real losses [10]. While using ILI in the developing world, most utilities do not have reliable information on the actual network length; Maps often show only a fraction of the existing network and hence ILI is overestimated. The pressure data and pressure loggers are not available and hence estimated average pressure usually too high, therefore ILI is underestimated. It is, therefore, the need of the hour to develop suitable performance indicators that could be appropriately used under different circumstances in various countries. Performance indicators and benchmarking efforts should lead toward the vision of 24x7 water supplies for all.

Pressure Management

A technique for leakage reduction is pressure management, which considers the direct relationship between leakage and pressure. The rate of leakage in water distribution systems is a function of the pressure applied by pumps or by gravity head. There is a physical relationship between leakage flow rate and pressure. Leakages are directly proportional to the pressure having hydraulic exponent N [21].Burst rates are also a function of pressure. Pressure management is one of the fundamental elements of a well-organized leakage management strategy. It should be an integral part of the strategy because it has a number of benefits such as i) it reduces amount of leakage to help meet water conservation targets ii) improves the reliability and continuity of supply by reducing pipe breaks iii) reduces pressure fluctuations to achieve more consistent water pressure across the system iv) extends the life of our water supply pipes and assets.

VII. CONCLUSION

The study presented the current water loss perspectives in developing countries. Application of top down and bottom up approach to distribution systems will result in better understanding and knowledge of the components of

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uncontrolled flow rate, real losses and apparent losses. This paper has attempted to put forward the current situation of water loss in developing countries. Besides, it proposes direction and strategy to arrive at appropriate solutions for the reduction and control of water loss.

1. Reliable static and continuous data should be collected shall be collected and mailed on priority basis which can be suitably used for performance evaluation purpose.
2. NRW in high levels typically indicate a poorly managed water utility. For developing country, reducing NRW should be the first option to pursue while addressing increased demand for piped water supply. This can be achieved by conducting water audit.
3. An appropriate approach to estimate the apparent loss component shall be developed so that strategic planning can be decided.
4. It is observed that sensitivity of the water meter decreases with the age of meter increases and hence there should be appropriate policy for testing and replacement.
5. An appropriate technical performance indicator for real losses shall be developed for developing countries so that one can understand the condition of infrastructure.
6. In most of the intermittent supply system, operating pressure and supply hours are very poor. Due to scheduling of water, valves are operated frequently and therefore more leakages are concentrated at valves. This can be avoided by transforming intermittent to continuous water supply.
7. Water loss is not only engineering problem but it can be reduced by creating awareness and changing behavior of people by educating them.
8. Operation and Maintenance of network is very essential to increase the life of network, therefore, operation and maintenance policy needs to be developed.

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