TECH-CHRONICLE
AN INTERNATIONAL E-JOURNAL ON
EMERGING TRENDS IN SCIENCE, TECHNOLOGY AND MANAGEMENT

"DEVELOPMENT OF WATER BALANCE TABLE FOR REDUCING NON REVENUE WATER IN WATER DISTRIBUTION NETWORK"

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***Abstract*- One of the major challenges facing water utilities in developing countries is Non Revenue Water (NRW). The water loss from distribution networks especially in developing countries has resulted in an increased water loss management concern. The water balance table becomes a valuable tool to manage resources, by getting a better understanding of what is happening to the water after it leaves the treatment plant. International water association & American water works association (IWA/AWWA) have developed a water balance methodology for the development water balance equation. They have developed water balance table as per their needs and tailored according to their specific condition. In India, peculiar characteristics exist such as intermittent water supply system, no reliable static and continuous data, poor infrastructure, poor record keeping. Due to these peculiar characteristics of water distribution systems, it is difficult to develop water balance equation to any water utility. As per Indian conditions water balance table with reference to water loss is modified to get clear and accurate insight to NRW. The development water balance table is based on top down water audit. A soft tool, water auditor, in VB.net have been developed, which will be helpful to water utility manager for strategic planning and to decide the appropriate action for reducing the water losses in water distribution network.**

Keywords: Water balance table, Non revenue water, Apparent loss, Real loss, Water distribution network.

I. INTRODUCTION

Water resources are becoming increasingly scarce everywhere in the country, even in areas previously thought to be rich in water. Being aware of the problem of different water balance formats, the International Water Association (IWA) has developed a standard international water balance structure and terminology (Alegre H. et al, 2000) and adopted by American Water Works Association (AWWA). This standard format has been adopted by national associations in a number of countries. Some countries have made changes according to their needs and conditions. In India, the private water audit companies are using the same water balance table develop by IWA to determine the water balance equation. The aim of this paper is to show, how the development of NRW table is important for water utilities to reduce the increased level of water losses. The introduction of NRW table will be the first step towards the strategic planning to reduce the losses and improve the efficiency of water utility.

1. WATER LOSSES IN DISTRIBUTION NETWORK

Water loss due to leakage is a major concern for utilities across the world. The leakage rates increase with pipe age; older networks tend to be affected more severely. Water loss represents inefficiency in water delivery and measurement operations in transmission and distribution networks (Wallace 1987). The amount of water leaked in water distribution systems varies widely between different countries, regions and systems, from as low as 3–7% of distribution input in the well maintained systems in Netherlands (Beuken et al. 2006) to 50 percent in some undeveloped countries and less well maintained systems (Lambert 2002; Mamlook and Al-Jayyousi 2003).According to a World Bank study, about 48 billion m^3 of water is lost annually from water distribution systems, costing water utilities approximately US$14 billion per year around the world (Kingdom et al. 2006). Outsourcing of water loss reduction activities is often the only feasible solution (Liemberger R 2002). The Water Losses for a whole system are calculated as the difference of systems input volume and authorised consumption. The Water Losses consist of real and apparent Losses.

Real Losses

It comprises of leakage from distribution system such as Leaks from the mains, booster stations, pipes, air valves, wash out valves, hydrant pipes, joints and fittings, leakage through service reservoirs floors and walls, bursts and overflows from the pressurized system, up to the point of metering on the service connections. In the assessment of real losses most of the advances have been based on the Burst and Background estimate (BABE) methodology, which was first developed in the mid-1990s by the UK water industry. The BABE techniques are well documented (UK Water Industry: 1994) since been widely accepted and used in many parts of the world.

Apparent Losses

It consists of all types of meter inaccuracies (input, output, and customer meters) reading errors, slow running meter, tampering with meters, broken meters, no meters, and unauthorised consumption (theft and illegal use), accounting errors i.e. administrative errors, data entry errors, delays and loss of records are often more significant. Considerable effort is being spent investigating the various components of the apparent losses, and some initial results were presented by Thornton and Rizzo (2002). According to a World Bank report (Kingdom et al. 2006), approximately 16 billion m^3 of water every year is apparent loss, causing utilities worldwide to lose revenue estimated at US$ 6.5 billion every year. Water meter inaccuracies are considered to be a significant component of the apparent losses in a water supply system (Rizzo and Cilia 2005). Many water utilities are increasingly migrating from traditional manual meter reading to automated meter reading and advanced metering infrastructure as a way of minimizing apparent losses due to meter reading and data handling errors (AWWA 2009). The innovative techniques Zigbee-based Automated Meter Reading (AMR), and a flow manipulation device; the Unmeasured Flow Reducer (UFR) is useful in reducing apparent losses. The customer meter error is often the main cause of apparent losses. The mechanical devices, 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 (Male et al. 1985). To minimize these losses, many researchers have developed tools and methodologies for water meter replacement based on meter testing, economic optimization, and operational research techniques (Arregui et al. 2011).

3. THE WATER BALANCE

The water audit refers to the conducting of periodic exercises to determine water supplied into the distribution system and water lost or used within the distribution system, the water balance is the tool used to enhance a meaningful water audit report. The water balance is of paramount importance because; it serves as a framework for assessing a utility's water loss situation, creates awareness of problems and gives direction of improvements. The water balance table recommended by International water association is mostly used to quantify the magnitude of non-revenue in developed and some undeveloped countries. A water balance table as per Indian conditions is developed as shown in figure 1.0. The water audit software v4.2. (AWWA 2010) developed by International water association cannot be used for the purpose because of some limitations. The IWA/AWWA standardized water balance methodology (Alegre 2006; AWWA 2009) used for quantifying water losses.

3.1 Component of Water Balance

In accounting terms, an audit is defined as confirming and compiling information gathered on the entity as a whole. The IWA water balance terminology is as follows.

i. System Input Volume (SIV): The total volume of treated water supplied to the infrastructure is the System Input Volume. System Input Volume includes: purchased surface or ground water, the water obtained through interconnects, or water obtained from other sources.

ii. Authorized consumption: The volume of metered and or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so for residential, commercial and industrial purposes. Authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, these may be billed or unbilled, metered or unmetered.

iii. Billed authorized consumption: Those components of authorized consumption which are billed and produce revenue. This may include both metered and unmetered consumption.

iv. Unbilled authorized consumption: Those components of authorized consumption which are unbilled and not producing revenue.

v. Billed metered consumption: Customer accounts whose meters are read and who are billed appropriately each month. Since this category determines revenue, these meters are most important regarding accuracy. All metered consumption which is billed. This includes all groups of customers such as domestic, commercial, industrial or institutional.

vi. Billed unmetered consumption: All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering.

vii. Unbilled metered consumption: The metered consumption but for any reason which is unbilled. The example includes metered consumption of the utility itself, water provided to institutions free of charge.

viii. Unbilled Unmetered Consumption: It is any kind of authorized consumption which is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning, etc. In a well-run utility it is a small component which is very often substantially overestimated.

ix. Water Losses: It is the difference between system input volume and authorized consumption. Water losses consist of real and apparent.

x. Revenue water: The water which provide revenue to the water utility.

xi. Unauthorized consumption: Includes water illegally withdrawn from hydrants, illegal connections, bypasses to consumption meter or tampering to meter reading equipment.

xii. Data handling error: Apparent water losses caused by data handling errors in the meter reading and billing system.

xiii. Customer metering error: Apparent water losses caused by customer meter inaccuracies.

xiv. Non-revenue water: The water which does not provide any revenue to the utility i.e., apparent losses + real losses + unbilled metered consumption + unbilled unmetered consumption

4. ESTABLISHING A STANDARD WATER BALANCE

The level of water losses can be determined by conducting a water audit with the results shown in a Water Balance table figure 1.0. A Water Balance is based on measurements or estimations of water produced, imported, exported, used and lost.

Step 1: Determining System Input Volume

When the entire system input is metered, the calculation of the annual system input should be a straight forward task. Ideally the accuracy of the input meters is verified, using portable flow measuring devices. If discrepancies between meter readings and the temporary measurements are discovered, the problem has to be investigated and, if necessary, the recorded quantity has to be adjusted to reflect the real situation.

Step 2: Determining Authorized Consumption

Billed Metered Consumption

The calculation of the annual billed metered consumption goes hand in hand with the detection of possible billing and data handling errors, information later on required for the estimation of apparent losses. Consumption of the different consumer categories, (e.g. domestic, commercial, industrial) have to be extracted from utility's billing system and analyzed.

Billed Unmetered Consumption

Billed unmetered consumption can be obtained from the utility's billing system. In order to analyze the accuracy of the estimates, unmetered domestic customers should be identified and monitored for a certain period, for example by measuring a small area with a number of unmetered customers.

Unbilled Metered Consumption

The volume of unbilled metered consumption has to be established similar to that of billed metered consumption.

Unbilled Unmetered Consumption

Unbilled unmetered consumption, traditionally including water used by the utility for operational purposes, is very often seriously overestimated. This might be caused by simplifications (a certain % of total system input) or overestimates for the purpose to reduce water losses. Components of unbilled unmetered consumption shall be identified and individually estimated, for example mains flushing, firefighting etc.

Quantifying Real and Apparent Losses

Once the volume of NRW is known it is necessary to break it down into real and apparent losses, which is always a difficult task.

Step 3: Estimating Apparent Losses

Unauthorized Consumption

It is difficult to provide general guidelines of how to estimate unauthorized consumption. The estimation of unauthorized consumption is always a difficult task and should be done in a transparent, component based way so that the assumptions can later easily be reviewed.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meters inaccuracies, namely under- or over registration, has to be established based on tests of a representative sample of meters. The composition of the sample shall reflect the various brands and age groups of domestic meters. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups. Data handling errors are sometimes a very substantial component of apparent losses.

Step 4: Calculating Real Losses

The calculation of real losses in its simplest form is now easy: Volume of NRW minus volume of apparent losses and this figure is useful for the start of the analysis in order to get a feeling which magnitude of real losses can be expected. However, it always has to be kept in mind that the water balance might have errors and therefore it is important to verify the real loss figure by one of the following two methodologies (i) Component Analysis and (ii) Bottom-up real loss assessment.

Step 5: Estimating Real Loss Components

Accurately splitting real losses into its components will only be possible with a detailed component analysis. However, a first estimate can be made using a few basic estimates.

Leakage on Transmission and/or Distribution Mains

Bursts on distribution and especially transmission mains are primarily large events; they are visible, reported and normally repaired quickly. By using data from the repair records, the number of leaks on mains repaired during the reporting period can be calculated, an average flow rate estimated and the total annual volume of leakage from mains calculated as follows:

Annual leakage volume = Number of reported bursts x average leak flow rate x average leak duration, and then a certain provision for background losses and so far undetected leaks on mains can be added.

Leakage and Overflows at Utility's Storage Tanks

Leakage and overflows at storage tanks are usually known and can be easily quantified.

Leakage on Service Connections up to Point of Customer Metering

By deducting mains leakage and storage tank leakage from the total volume of real losses, the approximate quantity of service connection leakage can be calculated. This volume of leakage includes reported and repaired service connection leaks as well as hidden leaks and background losses from service connections.

4.1 Detailed Quantification of Real Loss Components

Step 1: Top-Down Water Balance

In top down water balance the apparent losses are to be calculated first and then by subtracting it from total loss, the real loss is obtained. The accuracy of real loss depends on correct estimation of apparent losses. The real loss assessment can be done without an annual water balance; the total volume of real loss in water balance can be verified by night flow analysis.

Step 2: Component Analysis

The key data required for a real loss component analysis of a water distribution system are:

- Total length of pipe network and number of service connections
- Average service connection length between meter connection and customer meter
- Total number of distribution mains repairs per year (reported and unreported)
- Total number of service connection repairs per year(reported and unreported)
- Average system pressure across the entire network
- Estimates of the time periods for Awareness, Location and Repair duration
- Estimates of utility storage tank leaks and overflows

Most of this data is readily available in well-managed water utilities; however, the determination of the average pressure across the network is often difficult to estimate.

Calculation of Average Pressure

As the average pressure is a key parameter in any real loss analysis, it is certainly worth undertaking some detailed work to obtain a good estimate of the average pressure. Pressures should be calculated as 24-hour average values.

Calculation of Losses from Reported and Unreported Bursts

Two definitions have to be introduced: Reported Bursts are those events that are brought to the attention of the water utility by the general public or the water utility's own staff. A burst or a leak that, under urban conditions, manifests itself at the surface will normally be reported to the water utility. Unreported Bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties. After collecting the annual numbers of reported bursts on mains and service connections, flow rates and durations have to be established. The leak duration can be split in three elements time needed for:

(i) Awareness,
(ii) Location and
(iii) Repair; and estimates will have to be made for each of them:

Awareness duration: the awareness duration for reported bursts is generally very short, probably not more than 24 hours. The situation is quite different in respect to unreported bursts, which by definition are detected by active leakage control methods.

Location duration: the location of a reported leak will in general not take much time since it is visible and a quick check with a ground microphone will be sufficient to verify the leak location.

Repair duration: depends on the utility's repair policy and capacity.

Calculation of losses from leaking and overflowing storage tanks

Leakage and overflows at storage tanks are normally know if there are problems with overflowing storage tanks. Old underground storage tanks may leak, and if this is suspected then level drop tests could be undertaken.

Calculation of excess losses

Excess loss = Real loss from Water balance – Real loss component

In case this equation results in a negative value for excess losses, the assumptions for the real loss component analysis have to be checked and if necessary, corrected it accordingly.

Step 3: Bottom-up Real Loss Assessment

24 Hour Zone Measurements

Assuming that no DMAs are established, areas of the distribution network have to be selected which can be temporarily isolated and supplied from one or two inflow points only. Suitable areas shall be selected in various parts of the distribution system, with the objective of obtaining a representative sample of the system. In these areas, 24 hour inflow measurements will be carried out with portable flow measurement devices. These flow measurements shall always be done along with pressure measurements where pressures are recorded al the zone inlet point(s), at the average pressure point and at the critical pressure point. All relevant data on the zone shall be collected, such as:

(i) Length of mains,
(ii) Number of service connections,
(iii) Number of household properties and
(iv) Number and types of non-household properties.

Night Flow Analysis

The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The estimation of the real loss component at minimum night flow is carried out by subtracting an assessed amount of legitimate night consumption for each of the customers connected to the mains in the zone being studied. The result obtained from subtracting these legitimate night uses from the minimum night flow consists predominantly of real losses from the distribution network. The daily level of real losses- obtained from the minimum night flow analysis can be determined by applying the FAVAD principles (Lambert 2001).

Step 4: Compiling the Final Figures

At the end of the real loss assessment process, the advantage of the combined top-down, bottom-up and component analysis becomes obvious. Only by combining the three methods it is possible to get reliable results. The complete water balance table calculations are illustrated in figure 2.0 and figure 3.0.

5. STUDY AREA AND METHODOLOGY

Study Area: The city of Amravati is a district place in Vidarbha region of the state of Maharashtra (India). Amravati city is located on longitude 77°45″ & latitude 20°55″. Amravati Municipal Corporation comprises of Amravati city & Badnera Municipality. Amravati water supply scheme is maintained by Maharashtra Jivan Pradhikaran (MJP). The present scheme is designed for 156 MLD; Population in the year 2011 is 6 lakh souls & water is supplied at the rate of 135 LPCD in zone wise manner for the period 3-4 hours per day. Under SUJAL NIRMAL ABHIYAN, it is decided to convert this water supply to continuous (24X7) water supply from intermittent one. Initially, as a pilot 24X7 project Sainagar zone was proposed and commissioned in 2010. The new Elevated Storage Reservoir (ESR) for this zone is constructed and three DMA's are formed and are supplied through separate outlets from ESR. The other details are shown in table 1.0

Table 1.0: Details of DMA in Sainagar zone

SN	Description	DMA-1	DMA-2	DMA-3	Total
1	Population	4536	3525	4701	12762
2	No. of property	1049	798	1015	2862
3	No. of connection	602	846	655	2103
4	Daily supply as per main meter reading	7 Lakh liters	6 lakh liters	8 lakh liters	21 lakh liters

NRW management is not technically difficult, but it is complex. Proper understanding of components of real and apparent loss is a critical first step in moving toward an effective NRW reduction program. A diagnostic approach followed by the efficient and effective implementation of practicable and achievable solutions can be adopted in any developing country. It has been seen that most utilities in the developing countries do not have a proper methodology to efficiently implement on their NRW reduction program. They operate under an inadequate framework with a lack of expertise and technology.

The desk top water audit of DMA-3 in Sainagar zone is carried out. The result of a water audit will be an account of the water volumes used by and discharged from, and flow variations for, each operation - summed up for the whole facility. The level of detail in the water use audit will vary based on the information of system has available. All water systems lose some amount of water for a variety of reasons.

Firstly the apparent losses are calculated by using various approaches such as i) Metering inaccuracy ii) Meter under-registration iii) Meter reading error iv) Water theft v) Administrative error. The apparent losses are deducted from the total water losses to get the real losses. The real losses are checked by the Night flow analysis as well as component analysis. The water balance table and NRW table has been developed for DMA-3. The component of NRW are shown in figure 1.0

6. DEVELOPMENT OF SOFT AUDIT TOOL AND WATER BALANCE TABLE

The water audit soft tool in Visual Basic (VB.net) is designed and developed by considering the IWA terminology with definition of water balance table. The tool is based on top down water audit. The purpose of this tool is to track and quantify the water losses associated with water distribution network and evaluate the performance of the system. This formulated knowledge base tool will be helpful to water utility manager to decide the appropriate methodology and strategy to reduce the NRW by reviewing the water distribution network. The various approaches are used in quantification of apparent losses are incorporated in the present water audit tool. The disaggregation of real losses and apparent losses are made which suits to the Indian conditions.

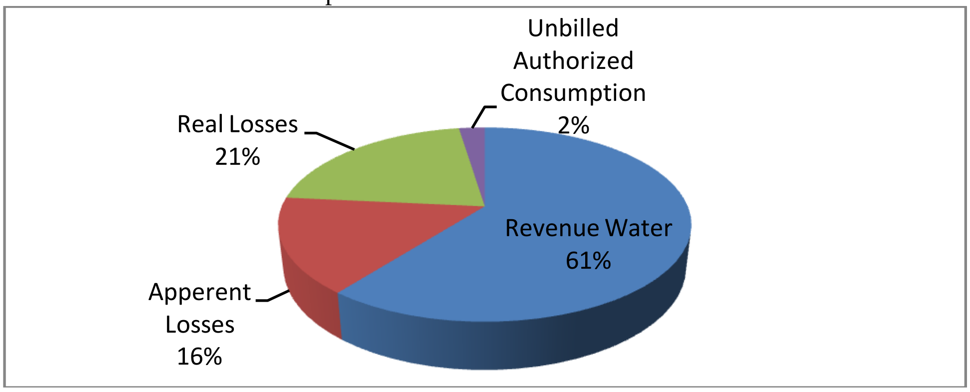

Figure 1: Revenue and Non revenue water for Sainagar DMA-3

Figure 2.0: Water Balance Table for DMA-3 (All values are in ML/year)

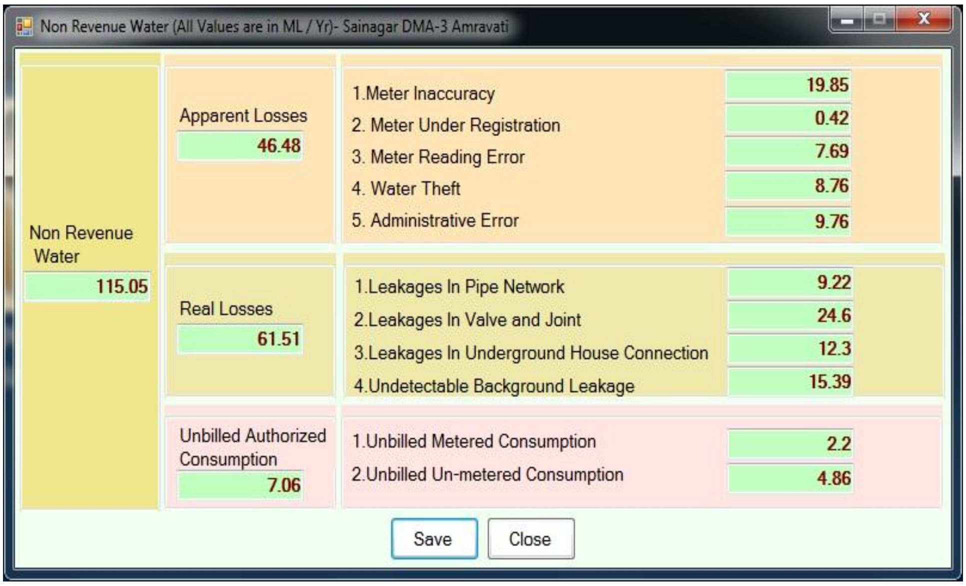

Figure 3.0: Non Revenue Water Table for DMA-3 (All values are in ML/year)

7. RESULT AND DISSCUSION

The NRW by volume for the Sainagar in DMA-3 is 115.05 ML / year that amounts to 39.40 %, of system input volume, which is higher than the national benchmarking value. It indicates that there is lots of potential for water and cost savings. In financial terms, this translates into 12 lakh rupees annually. The high levels of NRW typically indicate a poorly managed water utility. For developing country, reducing NRW should be the first option to pursue while addressing low service coverage levels and increased demand for piped water supply. Expanding water networks without addressing water losses will only lead to a cycle of waste and inefficiency. NRW is useful as a financial indicator; it is a first level operational indicator. It does not consider the most of the key factor on which the losses depends. It is, therefore, not very useful when comparing the water loss performance between utilities.

8. CONCLUSION

The actual performance of any water utility cannot be determined accurately without reliable static and dynamic data. The precise estimation of NRW figures from the water balance table depends on accurate measurement of the system input volume, apparent losses, and revenue water. However, NRW figures are in practice derived from the water balance components that are themselves subject to potentially large estimation errors. The study reveals that water balance is a powerful tool for evaluating the performance of water utilities. The proper NRW reduction strategy cannot be planned without quantification of real and apparent losses. The audit accuracy can be improved by addressing the customer metering inaccuracy and water theft.

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