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Non-Revenue-Water Assessment in Urban Water Supply

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Abstract— *Supplying hygienic and adequate drinking water has become crucial in India. Water losses in water distribution network is an important issue and challenge for water utilities in urban water supply. In India 50 to 60 percentage of treated and supplied water is lost during transmission from water service reservoir to customer service connections. Non-Revenue-Water (NRW) is the portion of water placed by a water utility into the distribution system but could not generate revenue for utility. It consists of sum of Un-Billed Metered, Un-Billed Un-Metered consumption, Real Losses and Apparent Losses. Water utilities are losing revenue because of these high levels of NRW and in turn affecting their financial viability. The main objective of water utility is to deliver wholesome water to consumers in sufficient quantity at adequate pressure, continuity and maximum coverage by reducing losses. In this regard a study was conducted in Vijayawada city water utility by using water audit software Water Balance developed by International Water Association (IWA). This study implemented District Metered Area approach by isolating a small area of water distribution network and conducted Minimum Night Flow Analysis to determine the flows of water. This paper provides a review on assessment of present levels of NRW and a strategy to be implemented for reducing NRW. This paper also discusses about the necessity of targeting appropriate performance indicator which is a benchmark for any water utility.*

Keywords— *Apparent Losses; District Metered Area; Minimum Night Flow Analysis; Non-Revenue-Water; Performance Indicator; Real Losses; Water Balance.*

I. INTRODUCTION

Water demand is getting increased rapidly due to urbanization, increase in population and industrialization whereas water resources are diminishing. Numerous problems are being faced by the utilities in providing sufficient water supply to the rapidly growing population and the developing countries. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem (Bereket, 2006). Moreover, managing and reducing losses of water at all levels of a distribution system remains one of the major challenges facing many water utilities in most developing countries including India.

Vijayawada is the second largest city in the state of Andhra Pradesh after Visakhapatnam and one of the important commercial and transport centres of the state. The city has grown as a major administrative, economic, and cultural nerve centre of costal Andhra due to its location as an important railway junction and also because of National Highway-5 and National Highway-9 traversing the city. The city also has a few places of historic importance. The city is situated at the foot of a low range hills on the northern bank of the river Krishna and it is located at 16^0 31' North latitude and 80^0 37' East longitude, around 70 km away from the coast. The climate of Vijayawada is tropical in nature with hot summers and moderate winters. The mean daily maximum temperature is 47^0 C, while minimum is 27.7^0 C in this region. April and May are the hottest months. The lowest temperatures of any year can be seen in months of December and January. During these two months, the mean daily maximum temperature is about 290 C while minimum is about 190 C. The city receives an average annual rainfall of 965 mm. Two third of the annual rainfall can be seen during southwest monsoon.

Total area is 61.88 square km with a population of 20,00,000. The present water demand is 39 MGD. The source of water supply is from Krishna river. Present water distribution covers 80 percentage area and water is supplied twice a day. Approximate total water supply pipe length is 960 km with water supply service connections of 1,08,712 numbers. The Vijayawada water utility is facing high NRW due to a severe water loss from the pipe network in the form of leakages on account of the poor & aged infrastructure, intermittent water supply without proper pressure management, water misuse & theft, inadequate metering polices and low tariff structures which are forcing the water utility to augment the requirement of treated water in an attempt to satisfy the water demand. The water utility distribution system components were built decades ago and the problems related to the water loss are yet to be investigated which is currently in need of attention to develop the strategies for the future is more urgent than ever.

The objectives of this study are the assessment of the existing water losses, identifying the strategies to reduce the water losses in Vijayawada and fixing the target of performance indicator for the water utility.

II. METHODOLOGY

The Water Audit Method recommended by American Water Works Association (IWA/AWWA) and International Water Association is implemented for quantifying volume of water supplied from service reservoir throughout the

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distribution system, customer consumption, and volumes of real and apparent losses.

The auditing process was involved at three levels, each adding increasing refinement.

1. Top-down approach – the initial desktop process of gathering information from existing records, procedures, data, and other information systems.
2. Leakage-component-analysis – finding the leakage volumes as per the nature of leak occurrences, leakage durations, and various occurrences by looking at the nature and duration of the occurrence.
3. Bottom-up approach – the top-down results shall be validated with field measurements of leakage losses calculated from District Metered Area night flows. Similarly, physical inspections of customer properties to uncover apparent losses.

A preliminary assessment of water loss is obtained by gathering available records and placing data into the water audit worksheet. The data from the water audit was entered in the water balance, which compared the distribution system input volume with the sum of customer consumption and losses of estimate or known. The sum of all components in each column of the water balance are equal, and therefore in balance, as shown in Fig. 1.

<table>
<tr><td rowspan="9">Volume From Own Sources</td><td rowspan="11">System Input Volume</td><td>Water Exported</td><td colspan="3">Billed Water Exported</td><td></td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuries</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Imported</td><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Point of Customer Meeting</td></tr>
</table>

Source: AWWA

Fig. 1. Water balance.

The top-down approach was conducted in the following sequence as recommended by AWWA

Task 1 – Quantify the volume of water supplied to the distribution system: The water supplied volume was calculated automatically by the Audit Software after the individual inputs of volume from own sources, water imported, water exported and their respective master meter error adjustments are quantified and input by the auditor. This task demonstrates how much water enters the treated retail water distribution system and where it originates.

Task 2 – Quantify Authorized Consumption: Authorized consumption is any water delivered for consumptive purposes that are authorized or approved by the water utility, thereby providing a benefit to the community. The Authorized Consumption volume is calculated by the Audit Software as the sum of the four subcomponents of Billed Metered Consumption, Billed Unmetered Consumption, Unbilled Metered Consumption, and Unbilled Unmetered Consumption.

Task 3 – Calculate water losses and quantify Apparent and Real Losses: Water losses are made up of apparent losses and real losses. Apparent Losses are comprised of systematic data handling errors, customer metering inaccuracies and unauthorized consumption. The audit software calculates Current Annual Real Losses simply as total water losses minus apparent losses.

Task 4 – Calculate Non-Revenue Water: NRW consists of the sum of Unbilled Metered and Unbilled Unmetered Consumption, Apparent Losses and Real Losses. NRW can also be calculated as the water supplied minus the sum of Billed Metered and Billed Unmetered Consumption.

Task 5 – Collect Distribution System and Cost Data: In this task length of mains, the number of active and inactive service connections, average length of customer service line, average operating pressure, total annual cost of operating water system, and customer retail unit cost to be calculated.

Task 6 – Determine System Attributes: In this task Unavoidable Annual Real Losses (UARL) which represents the minimum level of leakage that could be achieved in a system that is well managed and in good condition, at a given average pressure level and cost impact of apparent and real losses are to be calculated.

$$\text{UARL (gal)} = (5.4Lm+0.15Nc+7.5Lc) \times P \times 365 \text{ d/year} \quad (1)$$

Where:

Lm = length of water mains
Nc = number of customer service connections
Lc = total length of service connection line (miles)
P = average operating pressure in the system (psi)

Task 7 – Performance Indicators: The IWA/AWWA Audit Method published in Performance Indicators for Water Supply Services (Alegre et al. 2000) includes a highly useful array of performance indicators, which represent one of the greatest strengths of the method. With this methodology, multiple indicators of varying detail became available to water utilities, allowing a realistic assessment of water loss standing.

IWA suggested two types of performance indicators like Financial Performance Indicators comprises non-revenue water by volume and non-revenue water by cost and Operational Performance Indicators comprise apparent losses and real losses performance indicators in which ILI is the best real losses performance indicator for comparisons among systems

$$\text{ILI} = \text{CARL/UARL} \quad (2)$$

Where:

ILI = Infrastructure Leakage Index
CARL = Current Annual Real Losses in gallons
UARL = Unavoidable Annual Real Losses in gallons

Task 8 – Compile the Water Balance: After all data was entered into the audit software quantities from the key

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consumption and loss components can be shown on the water balance.

Task 9 – Assess the Data Validity Score: After all the data was entered into the audit software and performance indicators were reviewed, the data validity score was reviewed which was calculated for the water audit.

A small discrete area in Srinagar of Vijayawada identified with 750 service connections as Sub-DMA and MNF analysis was implemented to find out the Real Losses in WDN.

The first level of water audit top-down approach was largely a desktop exercise, with minimal field testing or investigations required. To refine the top-down water audit and formulate strategies to cut losses, work then was shifted to the bottom-up approach. In bottom-up approach a temporary DMA was constructed to conduct minimum night flow analysis. A DMA is a small zone of the distribution system, typically encompassing between 500 and 3000 customer service connections and a Sub-DMA is between 500 and 1000 customer service connections with measured supply input flow of sufficiently small volume that individual leakage events can be quantified, thereby guiding leak detection deployment decisions.

The MNF is the time typically between 12:00 a.m. and 04:00 a.m. when the consumption by the residents within DMA is at its lowest.

Apparent losses were quantified by taking the density of service connections and the base demand per service connection since the Srinagar is partly metered.

III. RESULTS & DISCUSSIONS

Water Balance (Fig. 4) generated by water audit software reflects that the summation of the component volumes in each column moving left to right is 64627 ML which fulfilled the balance sheet concept.

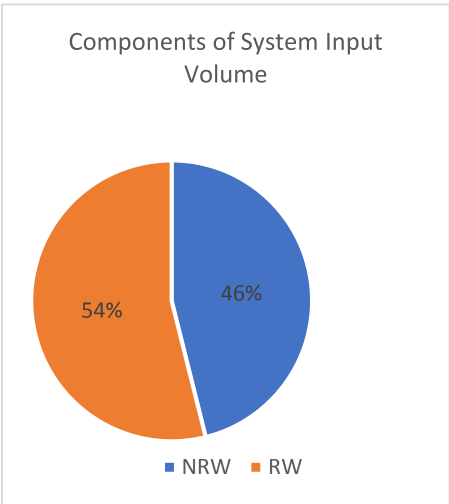

Fig. 2. Components of SIV.

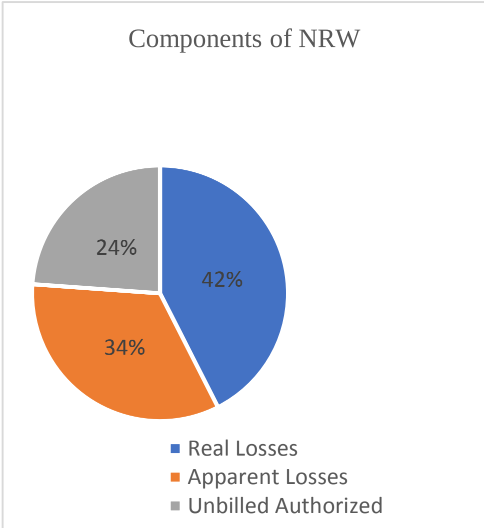

Fig. 3. Components of NRW.

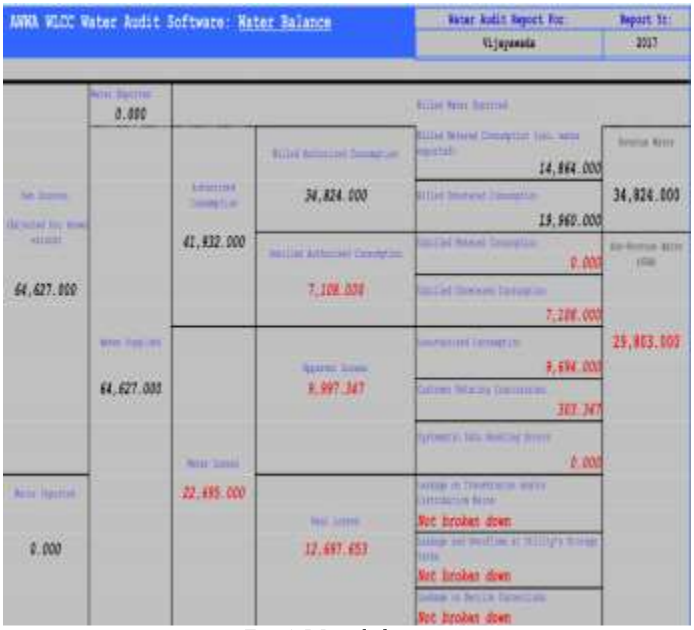

Fig. 4. Water balance.

As the most of the area was not having meters the billed-unmetered consumption 19960 ML was registered which was higher side compared to the billed-metered consumption. Because of insufficient metering water utility has been charging monthly for a predetermined quantity irrespective of the actual consumption resulting in higher quantities of Apparent Losses.

The Financial Performance Indicators NRW as percentage by volume and NRW as percentage by cost were calculated and found as 46% (Fig. 5) and 52.20% (Fig. 5) respectively which are very high. The acceptable NRW as percentage by volume for any water utility is 15%.

As the water supply of Srinagar is by gravity with average pressure of 15 meters head the UARL and ILI Operational Performance Indicators are not suitable for this utility.

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The other Operational Performance Indicators found were apparent losses per service connection per day with 251.95 litres and real losses per service connection per day 320.00 litres (Fig. 5) were very high.

IV. CONCLUSIONS & RECOMMENDATIONS

Conclusions and strategy for NRW reductions are as follows

1. It is found unauthorized consumption more because of intentional vandalism of meters by residents and collusion of utility personnel with residents in preparation of bills. Water utility should conduct awareness programs for public and utility personnel to instil the importance of water resource and stringent actions are to be implemented in case of noncompliance.
2. Presently meters are fixed only for some connections and charging fixed amounts to the remaining connections. These charges are disproportionate with the occupancy and usage of water by the particular residence on account of which utility is losing heavy revenue. Utility should take immediate action to fix meters for all service connections. Existing vandalized, non-functional meters to be replaced and calibration of meters is to be done without fail in regular manner.
3. Automatic Meter Reading (AMR) system for reading meters and logging the data in regular manner is to be implemented.
4. Supervisory Control and Data Acquisition System (SCADA) is to be implemented for online monitoring of levels of storage tanks, water flow in mains, leakages at fittings and pressure at various nodes.
5. Present water supply of water utility is intermittent and proper pressure management is not in place. For any water utility ILI performance indicator is the benchmark for their efficiency for the implementation of same minimum pressure of 26 meters is to be maintained.
6. Because of the intermittent and irregular timings in water supply people are habituated to draw and store excess water and throwing away the previously stored water at the time of next water supply on account of which lot of water and revenue is being lost by utility. Intermittent supply is causing damages to the pipe network due to abnormal fluctuations of pressure inside the pipe network and utilities are facing difficulties to upkeep the pipe network. So, continuous water supply with proper pressure management is recommended to address the above issues.
7. ILI of 4 is to be targeted in the course of five years' time period for which proper leakage management is to be in place.
8. The second step of water audit Leakage Component Analysis is not in place presently. The exhaustive data of occurrence of leakages, their duration and repair done time, expenditure details are not recorded. Proper documentation of leakage components like Reported Leakage, Unreported Leakage, and Background Leakage is recommended which helps the utility to effectively plan the budget, fixing the NRW reduction target and to meet public satisfaction.

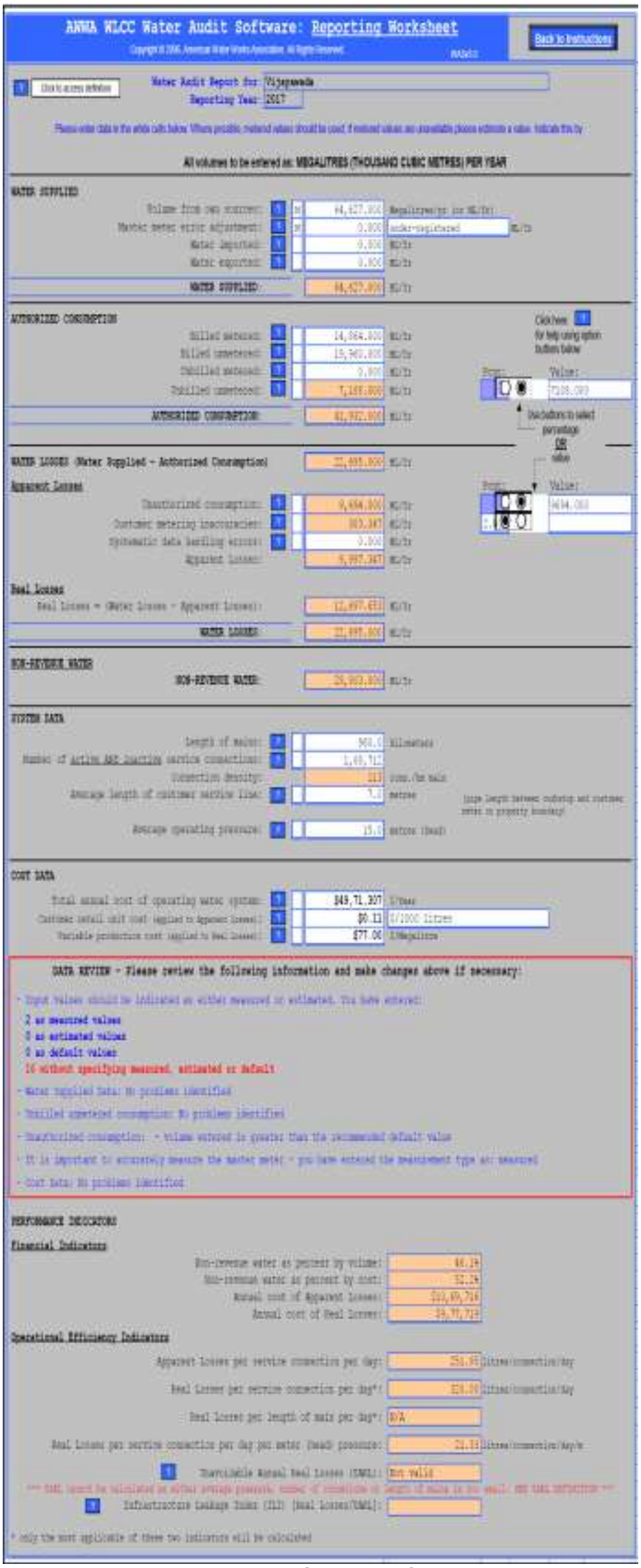

Fig. 5. Water audit reporting sheet.

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