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CHAPTER 11
WATER AUDIT AND LEAKAGE CONTROL

11.1 Introduction

The gap between potable water availability (WTP production, Ground Water extraction) and requirement (consumer demand) is increasing day by day. At one end, sourcing water is becoming difficult and expensive; at other end, water distribution losses are significantly high in any typical city or town in India.

When treated water is lost, water collection, treatment, and distribution costs increase, water sales decrease, and substantial capital expenditure programs are often promoted to meet the ever-increasing demand.

Water Audit is the first step in this direction followed by Water Loss Reduction Plan. Water audit provides fair estimation of water losses for different water supply areas depending on level of audit work. Accordingly, the areas with higher percentage of losses, can be identified for carrying out water loss control activities like leakage detection, network investigation, pressure management etc. It is very critical to understand the method and critical steps of this process in order to execute it in an efficient manner else, it may not provide desirable outcomes like water loss reduction and improved network efficiency.

11.1.1 What is Water Audit

Water Audit of a water supply scheme can be defined as the assessment of the total water produced by the Water Supply Utility and the actual quantity of water distributed to the consumer taps throughout the area of service, thus leading to an estimation of the losses termed as Non-Revenue Water (NRW) along with its components. NRW components are broadly classified in 3 categories: Real Loss also called as Physical Loss, Apparent Loss also called as Non-physical/Commercial Loss and Unbilled Consumption. More details on these terms are mentioned in subsequent section.

Water utility may include additional categories for audit study like Raw water Transmission and Water Treatment Loss optionally, termed as Transmission Main/Bulk Water System Monitoring but the primary focus is on getting clearer and faster understanding on potable water distribution system losses.

Condition to fulfil before initiating Water Audit:

i. The water utility should have a clear updated as-built drawings of the system and should know location and physical attributes like diameter, material, installation year of all inlets and outlets for the study area and inter-zonal crossing pipes by studying the GIS map.
ii. The water utility should have a flow measurement plan. In case of a utility with no/partial bulk flow meters, temporary flow measurement techniques can be used to collect flow data.
iii. The water utility should have consumption and other required data collection strategy. In case of a utility with no/partial consumer meter billing data history, meter sampling techniques can be used to collect sample consumption volumes.

11.1.1.1 Various Types of Water Audit

Water Audit can be done for entire utility or for an Operational Zone (OZ) or District Metering Area (DMA).

(A) Top-Down Water Audit

An Audit for entire utility is mostly a Desktop study with minimal site interventions, also called a Top-Down Water Audit provides input for planning overall improvements in the system. This approach requires minimal site measurements, and it can be done for both intermittent and continuous water supply systems.

(B) Bottom-Up Water Audit

Audit for an Operational Zone or DMA is more detailed, accurate and frequent study to get water losses per hour that helps in understanding the extent of Real vs Apparent losses also called a Bottom-Up Water Audit. This approach requires permanent measurements and analysis systems. It is implemented at Operation Zone/DMA level that is supplying 24x7 water (or in transition towards 24x7) where hourly flow and pressure data is captured and analyzed along with GIS data, Hydraulic Model and consumption information to get insights on areas that needs interventions to reduce Water Loss. This approach is performance oriented and focused on limited area instead of utility wide measurement. It provides clear visibility on water loss situation of the area and benefits achieved in terms of the loss reduction efforts. 24x7 water supply will be hard to maintain unless there is continuous monitoring of the area.

For ease of understanding, the Top-Down Water Audit is also termed as Utility-Wide Water Audit and Bottom-Up Water Audit as Continuous Monitoring of OZ/DMA. Various components of Water Balance table is explained in Section 11.3.

The objective of Top-Down Water Audit is to assess the following.

a. Average annual water volume produced, supplied and billed for a utility
b. Estimate annual water loss both real (physical) and apparent (commercial/non-physical)
c. To identify and prioritize components (real or apparent) and/or water supply areas that need immediate attention for water loss control.
d. To effectively plan strategy to reduce losses to an acceptable minimum over a limited timeframe.
e. To derive volume gains to meet additional demands with water made available from reduced losses, thereby saving on additional production and distribution costs.
f. To project revenue gain from the sale of water saved.
g. To capture utility’s Water Loss KPIs for planning better future operations leading to consumer satisfaction.

The objective of Bottom-up Water Audit is to assess the following.

a. Hourly water volume supplied and consumed for an OZ/DMA
b. Hourly water losses in the system and tracking of minimum night flow of the system

c. Continuous monitoring of inlet, average and critical pressure of the system
d. Segregation of real and apparent losses
e. Continuous monitoring of leakage volume and pre-localization of water loss for site intervention and reduction of losses
f. Continuous tracking of Water Loss KPIs for early warnings and timely network improvement planning to maintain the continuous water supply system

Transmission Main/Bulk Water System Monitoring is another useful Audit that is done for bulk water supply system of utility to keep track of treatment and transmission losses. It is best suited for Indian utilities that have enormous distribution tapings on transmission mains causing unequitable distribution and inefficient bulk water operations. The transmission main loss tracking will provide clear visibility on current level of losses and unknown tapings and will enable utility to reduce these anomalies and prompt actions on future leaks and unauthorized taping works. This continuous audit is possible for any water utility that is monitoring of bulk water supply system through SCADA or IOT based systems by deploying Transmission Main Monitoring and Analysis software to aggregate data from all sources and provide water loss reports for various sectors of bulk water system.

11.1.2 Water Audit Period and Frequency

11.1.2.1 Utility wide (Top-down) Water Audit

The ideal audit study period (for which the flow, consumption and other data is collected) for Utility wide (top-down audit) water audit is 1 year. If the expense of repeating temporary flow measurement is very high, and if it takes significant time and effort to complete this work, it may undermine the subsequent benefits in terms of water loss control. In such case, utility should evaluate the situation carefully, and find smart methods to collect data automatically using field data loggers and transmitters, implementation of SCADA and IOT based systems, Water Network Analysis Software deployment etc. to automate the process. In absence of these systems, the Audit frequency can be reduced to once in 2-3 years. Whenever there is a water network improvement project or continuous water supply project; the utility-wide water audit should be initiated and study results should be used for planning purpose.

11.1.2.2 Continuous Monitoring of OZ/DMA (Bottom-up audit)

A more detailed analysis is required for continuous water supply areas. Continuous monitoring of OZ (bottom-up audit) is regular hourly observation and daily analysis. For management and reporting purpose, weekly/monthly reports should be auto-generated by software for improvement planning in continuous water supply area.

11.1.3 Water Loss Reduction

Water Loss Reduction is not always a key component for major water network rehabilitation projects in India so far. Network performance gain is mostly achieved by replacing water networks only. But there are other effective methods to improve the system. A more focused approach is needed for continuous monitoring and timely intervention at smaller scale and at a granular level for sustaining service standards in long term. Key components of this approach are:

a) **Performance Visibility**: For tracking performance and efficiency of network interventions; certain Key Performance Indicators (KPIs) like NRW %, Water Loss per Connection, Real Loss %, Apparent Loss % etc. should be tracked and monitored continuously.
b) **Targeted Performance Improvement**: Annual Water Loss Reduction Plan can be made only for areas that need intervention. Field investigations and leak detection activities should be carried out for localized areas where water loss is significant. The strategy of water loss reduction should be decided based on Water Audit findings and factoring local conditions. It is mostly the visible and invisible leakages that cause water loss, some areas may have much higher pressures compared to other areas, and a pressure control strategy may be more suitable to curtail water loss due to leakages along with leakage detection. Some areas may have more unauthorized consumption and a social campaign for water wastage control may be more suitable than other methods. Yearly review of past year's action plan implementation should help in evaluating the strategies that worked in local conditions and should result in better planning for subsequent years.

11.1.4 Benefits of Water Audit and Water Loss Reduction Plan

Water audits and Water Loss Reduction plan can achieve substantial benefits:

(a) Reduced Leaks

Repairing the leak will save money for the utility, including reduced power costs to deliver water and reduced chemical costs to treat water.

(b) Financial Improvement

It can increase revenues from customers who have been undercharged, lower the total cost of wholesale supplies and reduce treatment and pumping costs.

(c) Improved reliability of supply system

Consumers tend to store water and drain it off to again store fresh water when the supply is not reliable. Considerable time & water is lost in this process. Hence, improving the reliability of the water supply system will encourage the consumer to reduce the wastage of water and use their time in a productive way.

(d) Increased Knowledge of the Distribution System

During a water audit, distribution personnel become familiar with the distribution system, including the location of main and valves. This familiarity helps the utility to respond to emergencies such as main breaks.

(e) More Efficient Use of Existing Supplies

Reducing water losses helps in stretching existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as new source, reservoir or treatment plants.

(f) Safeguarding Public Health and Property

Improved maintenance of a water distribution system helps to reduce the likelihood of property damage and safeguards public health and safety.

(g) Improved Public Relation

The public appreciates maintenance of the water supply system. Field teams doing the water audit and leak detection or repair and maintenance work provide visual assurance that the system is being maintained.

(h) Reduced Legal Liability

By protecting public property and health and providing detailed information about the distribution system, water audit and leaks detection help to protect the utility from expensive law suits.

(i) Reduced disruption

Improving the water supply network will reduce the breakdown of pipes and hence reducing the possibility of delivering substandard water quality. It will also reduce the wastage of treated water which is caused due to disruption/breakage of pipeline.

11.1.5 Water Audit and Water Loss Control Program

A utility may develop and follow its own Water Loss Control Program. It is a 3-Step program (see Figure 11.1). The critical first step is the water audit.

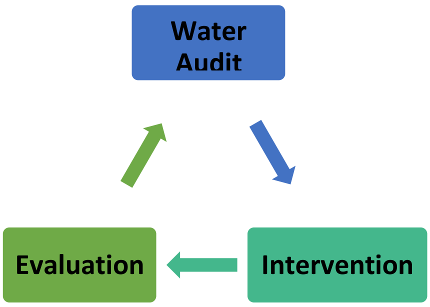

Figure 11.1: Components of a Water Loss Control Program

While Water Audit identifies & quantifies water uses & losses from a water system, the intervention process dwells upon the findings of a water audit to reduce or eliminate water losses. The evaluation step determines the success of chosen intervention actions.

Actions to be taken by a water system under the above-mentioned 3-step program are outlined below:

1. **Step 1: Water Audit** at Utility or Operational Zone level
2. **Step 2 Intervention Phase:** It includes strategic actions focused on reducing a component of NRW like:
    - Leakage detection and monitoring i.e. Real Loss Reduction
    - Improvement in billing & collection efficiency i.e. Apparent Loss Reduction
3. **Step 3 Evaluation Phase:** Continuous monitoring and analysis phase to answer questions such as
    - Whether goals of interventions were met ?

- Areas where more information is needed ?
- How often an Audit Intervention & evaluation process should be repeated?
- How can performance be improved?
- Assessment of NRW after completion.

11.2 Water Balance

The outcome of Water Audit is a Water Balance Table for entire utility area or zone/sub-zone wise. Explanation of terms used in Water Balance is as follows:

- **Non-Revenue Water (NRW):** It is water volume that is not billed, and no payment is received to the utility which is calculated using the Water Balance (Table 11.1). NRW is measured in the percentage of total clear water supplied to the system termed as System Input Volume.

Table 11.1: Various Components of Water Balance (IWA)

<table>
<tr><td rowspan="10">System Input Volume</td><td rowspan="5">Authorized Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracy & Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage in Transmission and Distribution Mains</td></tr>
<tr><td>Storage Leaks and Overflows</td></tr>
<tr><td>Service Connection Leaks up to Meters</td></tr>
</table>

- **System Input Volume:** The volume of treated water input to that part of the water supply system to which the water balance calculation relates. It may come from a utility's own sources and treatment facilities or external bulk suppliers. It is important to note that water losses at raw water transmission schemes and losses during the treatment process are not part of the annual water balance calculations. In case the utility has no distribution input meters, or they are not used, and the key meters are the raw water input meters, the system input has to be based on the raw water meters but must be adjusted by treatment plant water use. In either case, the measured volume must be corrected for known systematic bulk meter errors.

- **Authorized Consumption** refers to water utilized by known water system users. Authorized consumption is a known quantity that is equal to the sum of invoiced authorized consumption and unbilled authorized consumption, and water provided to other water systems is also included. This also includes water exported across operational boundaries. Authorized consumption may include items such as firefighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered, or unmetered.
- **Water Losses:** Volumetric difference between system input volume and authorized consumption is considered Water Loss for the system. Water loss can be considered as a total volume for the whole system or for partial systems such as transmission or distribution schemes or individual zones. Water losses consist of real (physical) losses and apparent (commercial) losses.
- **Billed Authorized Consumption:** This represents component of authorized consumption that is billed and produce revenue (also known as revenue water or billed volume). This is equal to billed metered consumption plus billed unmetered consumption. In case the water is being exported out of study area, the volume is added to the calculation as Billed Water Exported.
- **Unbilled Authorized Consumption:** This represents component of authorized consumption that is legitimate but not billed and therefore do not produce revenue. This is equal to unbilled metered consumption plus unbilled unmetered consumption.
- **Apparent losses**, also known as **commercial losses**, arise when water that should be included as revenue-generating water appears as a loss due to unlawful actions or calculation errors. Unauthorized consumption (theft or illegal use), inconsistencies/ inaccuracies in customer metering, and systematic data handling problems/ errors in the meter reading and billing processes are examples of apparent losses. Apparent losses are sum of;
    - systematic data handling errors
    - inaccuracies in customer metering
    - unauthorized consumption
- **Real Losses**, also known as **physical losses**, are actual water losses from the system that include leakage from transmission and distribution mains, leakage and overflows from storage tanks, and leakage from service connections up to and including the meter upto the point of customer use/ meter.
- **Billed Water Exported:** Sometimes, the water is transferred across operational boundaries or outside the utility study area for Water Balance. This volume component, if present, is considered Billed Water Exported.
- **Billed Metered Consumption:** This represents all metered consumption that is billed. This includes all groups of customers, such as domestic, commercial, industrial, institutional, etc.

- **Billed Unmetered Consumption:** This includes all billed consumption that 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.
- **Unbilled Metered Consumption:** It is the metered consumption that is for any reason unbilled. For example, this might include metered consumption by the utility itself or water provided to institutions free of charge.
- **Unbilled Unmetered Consumption:** It represents any kind of authorized consumption that is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component that is very often substantially overestimated.
- **Unauthorized Consumption:** It is unauthorized use of water that may include illegal water withdrawal (for example, for construction purposes), illegal connections, bypasses to consumption meters, or meter tampering and under-reading of customer meters because of meter reader corruption. This is considered part of apparent loss (water that is only "apparently" lost but causes a loss in revenue collection).
- **Customer Metering Inaccuracies and Data Handling Errors:** This is another part of apparent loss caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.
- **Leakage on Transmission and/or Distribution Mains:** It is the water lost due to leaks and breaks on transmission and distribution pipelines. These might either be small leaks that are not visible at the surface (e.g., leaking joints) or large breaks that were reported and repaired but did leak for a certain period before that and contributed, therefore, to the annual volume of real (physical) losses.
- **Leakage and Overflows at Utility's Storage Tanks:** This represents water lost from leaking storage tank structures or overflows of such tanks caused, for example, by operational or technical problems.
- **Leakage on Service Connections up to the point of Customer Metering:** This represents water lost due to leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems, this is the customer meter; in unmetered situations, this is the first point of use (stop tap/tap) within the property. Leakage on service connections might sometimes be visible but will predominately be small leaks that do not surface and run for long periods (often years).
- **Revenue Water:** It is often called billed volume, that includes those components of authorized consumption that are billed and produce revenue (also known as billed authorized consumption). This is equal to billed metered consumption plus billed unmetered consumption.
- **Non-Revenue Water:** It is the difference between System Input Volume and Revenue Water often represented in percentage.

  NRW % = 100 x (System Input Volume – Revenue Water) / System Input Volume

Note: NRW is sometimes also referred to as unaccounted-for water (UFW) but these are not synonymous because NRW includes Unbilled Authorized Consumption (Table 11.1) like firefighting, identified leaks, etc.; whereas UFW excludes it.

As an example, some utilities may include volumes from known leaks in “accounted-for” water categories and excluded it from UFW, thus underestimating actual leakage volumes, which is a loss to the water utility. NRW includes it and hence provides more clear picture of water loss.

11.3 Planning and Preparation for Water Audit

Planning and preparation for the audit work should include listing of location and operational status of existing flow meters and pressure loggers, availability of water supply network maps, count and status of existing and planned Operational Zones/DMA in study area and validation of Zonal/DMA meters if present. Plan may also include portable flow measurements if necessary. Past flow meter readings may be documented for reference purposes. Initial preparation or survey may be required for acquisition of all consumer and consumption volume data, known water loss locations and land use statuses (authorized/unauthorized areas) and public service water supply records available with utility. For utilities with limited consumption and billing data, include planning of meter sampling and estimation work to fill the gaps in utility data. Also review the requisite resources including trained manpower, tools, plans, plumbers, fitters, etc. to carry out Audit work successfully.

Level of Water Audit Study should be decided based on various factors like size of utility, status of isolation, ease of bulk flow data collection, ease of consumption and other data collection. A typical Indian Utility may conduct Water Audits at various levels:

1. **Utility wide Audit Study (Top-down):** The utility water network may receive potable water supply from 1 or more WTP and/or few distribution tubewells spread across the utility area. Utility wide water audit will require flow measurement at all these inlet points but no flow data is required at inter-zonal level. This is basic and quick audit study suitable for small utilities. If the utility is serving a bigger network and population (say 1 Lakh and above), it may become hard to get good insights about different parts/zones. Sometimes, Raw Water System Losses and WTP losses are included in this study if not already monitored continuously.

2. **Transmission Main/Bulk Supply System Continuous Monitoring/Audit:** Utilities mostly have Transmission Mains supplying water from Water Source to Supply nodes like UGR, ESR or distribution supply points. For monitoring, permanent flow meter, data logger & transmitter setup is required at all potable water source outlets and at the inlet of supply nodes like ESR etc. Hourly data should be captured and analyzed regularly to monitor water loss in the system. It will be cumbersome to collect this data and analyze manually. Utility should use Water Network Analytics Software for automated data collection, cleaning, analysis and reporting purpose. A water network GIS database and Hydraulic Model will also be helpful for more detailed analysis. Usual issues for implementation of this system is lack of centralized verified data on Transmission Main pipes and inter connections and

unauthorized tapings supplying water directly to distribution network. The benefits of Transmission Main Continuous Monitoring is clear visibility on transmission losses and unauthorized tapings, early information on system performance issues, monitoring and control of unauthorized tapings. The system may also be extended to capture raw water transmission losses, WTP losses and Distribution Main losses if required and found suitable by utility. **For utilities having Tank Water Balance issues and unauthorized tapings on Transmission Mains, these monitoring/audits will provide clear visibility of transmission system issues over time.**

3. **Continuous Monitoring/Audit of Operational Zone/DMA:** A water supply zone/sub-zone may have further division by multiple ESR Command Areas. An ESR command area may have one or more Operation Zones (OZ) and sometimes divided in many District Metering Areas (DMAs). For Operation Zone Continuous Monitoring/Audit, permanent flow meter, data logger & transmitter setup is required at inlets and outlets of the network along with key location pressure logger and transmitter installation (critical, average and inlet/outlet points). Ideally all consumers should be metered with monthly consumption readings, or at least sample meters should be installed across the OZ. The data should be captured continuously and analyzed regularly. It will be cumbersome to collect this data and analyze manually. Utility should use Water Network Analytics Software for automated data collection, cleaning, analysis and reporting purpose. A water network GIS database and Hydraulic Model will also be helpful for more detailed analysis. As it is much more detailed and continuous study that will require initial capital expenditure, hence it is important to prioritize the Supply Zone where this should be initiated first in order to maximize the benefits. Usual issues that utility may face are: lack of isolation of OZ/DMA, flow meter/pressure logger data capture issues, consumption data capture issues, lack of updated network maps and unavailability of Hydraulic Model data from previous design studies. Utility should try to do this study on pilot basis first, in order to understand and resolve the issues/improve the plan before Zone wide implementation. The benefits of continuous monitoring are: service level tracking and regular insights for service improvement, early warnings regarding water supply issues, data availability for better planning for future expansion as well as for taking informed decisions during Operation and Maintenance. **For an Intermittent to Continuous Water Supply System Improvement Project, these monitoring/audits are very important.** Table 11.2 summarizes which utility should go for what level of water audit.

Table 11.2: Summary of which utility should go for What Level of water Audit

Utility	Level 1	Level 2	Level 3
Small Utility looking for overall NRW situation	Yes		
Big Utility looking for overall NRW situation	Yes	Yes	
Utility with 24x7 Projects in various parts of the supply area		Yes	Yes

Utility	Level 1	Level 2	Level 3
Utility planning major water supply improvement project for various water supply zones	Yes		
Utility running 24x7 water supply for various operational zone/DMAs		Yes	Yes

Once the level of Water Audit is decided, various key activities like map data collection strategy, bulk flow data collection strategy, consumption and other data collection strategy should be planned before executing the Audit works. Following sub sections provide the details in this regard.

11.3.1 Verification and Updating of Maps

It is desirable to have maps of all water transmission and distribution lines ahead of Water Audit works. However no utility have 100% data up to date all the time. In this case, minimum required data is:

i. WTP Location and Command Area Boundary Map
ii. All Transmission Lines Map feeding to all zones/sub-zones
iii. Zone/Sub-zone Boundary Maps
iv. Inter-zonal crossing pipelines demarcation on Zone Maps
v. ESR location and bypass pipe location if any
vi. All Tubewell locations that are feeding to Potable Water System
vii. All Existing and Proposed Permanent Flow Meter Locations
viii. All Existing and Proposed Pressure Logger Locations
ix. All Existing and Proposed Operational Zone/DMA Maps

These maps should ideally be collected before starting the Audit work for efficient planning of measurement works. A distribution map is required but not mandatory for Zonal Water Audit. Basic details like ESR Operational Zone (or DMA) wise boundary, network length and consumer count should be made available.

Consumer and billing data availability should be verified from billing department ahead of Audit Work. If it is planned to carry out consumer survey, then ideally it should be done ahead or along with Audit work. If it is done along with Audit work then it should be combined with other Audit components like meter testing, meter sampling, average pressure assessment and consumer connection pipe information collection.

Utility-wide Water Audit is not a big Capex project and should be treated more as an overall study of the system with few site visits and data collection only for gap filling purposes. If there are a lot of street excavation, sizable amount of permanent bulk meter installation, or water network validation and investigation during Audit period itself, the purpose of Audit Study, which is to provide insights quickly for further Capex and Opex works, may not be fulfilled.

11.3.2 Bulk Flow Measurement Planning

Best case is when the water utility is already having bulk flow meters installed to collect total system input volumes and zone wise system input volumes. In case the flow meters are not installed or partially installed, it is necessary to carefully plan bulk flow measurement strategy.

The installation of permanent Bulk Flow Meter is a big Capex work and is usually combined with SCADA implementation. However, if the utility needs vital system performance inputs, then it is logical to prioritize installation of those Flow Meters first that will help in Audit work (first priority to System Input Flow Meters followed by Zonal Water Input Flow Meters). Ahead of complete SCADA implementation (or in case no SCADA is planned) installation work should be done along with automated data transmission system. This will help in continuous data capture without manual intervention, making future Audit work easier.

Audit work should ideally be taken up after permanent flow meters are installed for at least system input volume data collection. But it may not be possible for utilities looking for water network improvement planning in very near future. In such case, temporary flow measurement is the only option and priority wise bulk flow meter installation may be taken up as early as possible after first water audit is done.

It is expected that bulk meters will be required at the following locations for Water Audit, however, utility should carefully review the water network and plan the measurement strategy accordingly:

- All major system supply points.
- All tubewells that supply the system (Water Supply Tanks or Consumers) directly.
- Major transfer mains which are expressly required for audit.
- All water export points that is carrying water from system but delivering it to consumers outside the study area

For sizing, placement and selection of Flow Meter, please refer **to Manual Part A Chapter 13: Water Meters.**

The pressure logger placed with a Flow Meter provides additional data that can be interpreted to get additional insights about the system. It is not necessary but desirable to install pressure loggers along with Permanent Flow Meters.

11.3.3 Consumption Data Collection Planning

The consumption data capture is one of the biggest challenges in India as most of the cities have either no consumer meters, or meter readings are not captured regularly leading to average volume based billing for most of the consumers.

Best case is when the utility has monthly consumption data for almost all the consumers. But if it is not the case, sample consumption data capture can be planned.

Sometimes the utility is already planning 100% metering and volumetric billing in near future, that is a positive step towards getting better consumption estimates but it is important to plan metering activity in right manner to get maximum benefit. If 100% metering/replacement is planned for entire utility, it is recommended that the utility follows the prioritization as mentioned point wise below.

Water Audit team will get required minimum data as soon as work up to point number 2 is complete as mentioned below. Work mentioned in point 1 and 2 can also be carried out or bundled in Water Audit Study if there is no meter installation project planned by the Utility.

1. If there are water supply zones in the city, the priority should be to install new meters and replace/repair existing meters of non-residential consumers for a particular zone. Once sizable work is complete for one zone, the next zone should be engaged. Priority for the zone should be set based on non-residential demand figures available with utility billing department or by non-residential consumer survey.
2. Sample consumer meters should be installed for residential consumers before initiating 100% metering project. Ideally AMR meters should be chosen for these locations to minimize manual reading and to provide the ability to gather data more frequently and at a more granular level.
3. If there is already a DMA implementation plan for a city, 100% residential metering project should be implemented along with other construction work DMA by DMA. Other construction works include average and critical pressure point logger installation, boundary valve and end-cap installation and inlet/outlet bulk flow meter installation. If there are existing meters installed for limited consumers, it should be tested and replaced if needed along with 100% metering project of DMA. This will provide the best return of investment on consumer meter and billing system setup expenditure as not only billing data is available, but DMA wise water loss can also be tracked. If there is no DMA planning then Operational Zones (OZ) should be used to prioritize the implementation. Particular OZs that have higher volume supplied and with least complaints and higher service quality should be selected first for implementation. Once sizable work is completed for one OZ/ set of prioritized OZs, next OZs should be engaged.

Consumer Meter Sampling can be done keeping following points in mind:

a. All zones should be covered during meter sampling. A consumer database should be used to extrapolate it to get total consumption. If the data is not present, consumer survey may be carried out ahead or along with Water Audit.
b. Meter sampling is done for regular volume consumers like residential areas. Irregular volume consumers like institutions, industries etc. cannot be generalized, sampled and extrapolated for total consumption. Permanent consumer metering is the way to handle irregular consumers, preferably AMR type to reduce manual data collection errors.
c. GIS map is the best way to plan and check the spread of sampling. Latitude and Longitude should be captured while sample meter is installed.
d. Normally 1-5% sample size is enough for Audit purposes, however utility should assess and decide this range based on local conditions.

For existing consumer meters that are working and read regularly for billing purpose, meter testing should be planned. Following points should be kept in mind while planning this activity.

a. Meter testing should include all sizes of meters present in the network. Further categorization can be done based on installation/repair dates, manufacturer, water quality parameters etc. if available. The test results should be categorized and correlated with billing data base to get the extent and range of meter error.

b. Average slow or fast percentage of test recording of meters is known as correction factor. This average metered consumption multiplied by the correction factor is known as water used by consumer.
c. Sometimes it is not feasible to test all meters in labs, in this case onsite testing can be done by installing new or calibrated meter in series of existing meter. Detailed testing results may not be availed in this case but the coverage of testing can be increased easily this way.
d. GIS map is the best way to plan and check the spread of testing. Latitude and Longitude should be captured for tested consumer meter locations.
e. Normally 5-10% of testing is enough for Audit purposes, however utility should assess and decide this range based on local conditions.

11.4 Water Audit Strategy

11.4.1 Utility Wide (Top-down) Water Audit

The utility wide (top-down) water audit strategy is explained below.

The standard approach for an Indian town/city should be to start with utility level data collection that is to get total system input volume (Stage 1) and authorized consumption (Stage 2) to estimate total water loss, and then segregate apparent and real losses (Stage 3). The information should be gathered from existing records, data, and other relevant information available with the utility and then fill the gaps by temporary measurements wherever necessary using non-destructive methods. Sample consumption and pressure data should be collected if there are areas with no monitoring of consumption and pressure. In such case, consumer survey provides information to estimate total consumption and should be carried out ahead (or along with) the audit study.

11.4.1.1 Stage 1: System Input Volume Assessment

Before starting the Audit, water supply system boundary should be identified. Information should be collected for potable water volume produced. Utility may consider including additional calculation for Raw Water produced vs delivered at Water Treatment Plant (WTP) and Treatment loss estimation. However, for System Input Volume calculation, treated water volume should be considered.

While gathering data for the study, it is common practice to ask for the latest available data and longer duration records for better validation. It is also required to include the assumptions and considerations in the audit report. The purpose here is to provide the best estimates of water volumes with available data and temporary measurements without causing much delay and destruction.

Volumetric data should be captured and compiled from all utility water sources based on flow meter data preferably with an existing Flow Meter calibrated within last 12 months. If there is no flowmeter installed at these locations, then a temporary flow meter calibrated within last 12 months can be installed to capture regular flows. Hours of measurement will depend on flow pattern variation. Most of the supply points may have 24-hour cyclic pattern repeating itself daily with minor changes during the seasonal variation that can be captured by multiple measurements during study period. However, one must be careful to avoid days with unusual flow conditions due to ongoing construction or maintenance work. If the flow is irregular and varies every day in an unplanned manner, the temporary measurements may not be that useful for water audit and may result in erroneous calculation. Utility should prioritize installation of Permanent Flowmeters at such locations. If pump technical details are available, then volume estimates can also be derived from its discharge and pressure measurement. Pump operation logbooks can be used to estimate yearly volumes in that case. However, it is a less accurate method compared to permanent flow measurement.

Sometimes pipes are old and buried deep, thus making it impossible to take temporary measurements. If it is not possible to measure actual discharge, utility may be consulted to gather any previous records available or other possible considerations on a case-by-case basis to get an assumption on missing data. These assumptions should be clearly written in Audit Report. If most of the system inlet pipes fall under this category, the water audit quality will be very poor and may not be able to provide reliable inputs for future water loss monitoring and reduction plans. In such cases, permanent measurements of flow and pressure at system inlet points should be prioritized ahead of any detailed planning of water system improvements.

Once volumetric data is captured at all system inlet points, any water import or export points; System Input Volume is derived by the formula as mentioned below:

System Input Volume = Total Production of Water + Water Imported – Water Exported

11.4.1.2 Stage 2: Authorized Consumption Assessment

Quantification of Billed Authorized Consumption is done by collecting billing records from customer billing system. Depending on how billing is done, it is categorized under metered or unmetered volume.

Sample Meter Testing should be done for metered consumption accuracy estimation. It is recommended to test 5-10% of existing meters across entire study area and only for meters that are used for regular metered billing. Onsite testing by installing new/calibrated meter can be done if it is not feasible to send meters to meter testing lab.

Sample meter installation (or Meter Sampling) should be carried out to assess unmetered consumption. It is recommended to carry out Meter Sampling for 1-5% of reference residential consumers across entire study area.

For audit purpose, it is recommended to install sample consumer meters and get reference consumption data. There might be huge variations in daily consumption of different non-residential consumers that may cause significant deviation in audit calculation. So meter sampling may or may not provide enough data for general water consumption assessment of these non-residential consumers. Hence for non-residential consumers, if metered consumption is not available, it is recommended to install meters to

100% non-residential consumers as soon as possible. AMR (Automated Meter Reading) meters can be considered if data and human errors need to be minimized.

Once billed data is collected and meter testing, meter sampling and consumer survey (if required) is done; following formula can be used for billed consumption calculation.

Billed Metered Consumption = Sum of Billed Consumer's Metered Volume

Billed Unmetered Volume = Average Sample Meter Consumption x Average Billed Consumer Count

Sometimes a quantum of water is exported outside the system, e.g. to industries in ULB area, but still billed by Utility. This can be categorized as Billed Water Exported and calculated as below.

Billed Water Exported = Sum of Billed Consumer's Volume Exported Outside Utility Water System

Calculation of Billed Authorized Consumption is done by formula as mentioned below:

Billed Authorized Consumption = Billed Metered Consumption + Billed Unmetered Consumption + Billed Water Exported

Quantification of Unbilled Authorized Consumption is done by assessing various consumption volumes that are not billed but used for designated purposes like Public Stand Posts, Public Building, Public Gardens, Water Fountains, Swimming Pool, Construction Sites, Fire Fighting, Street Cleaning, Supply to Schools etc.

Quantification Unbilled Unmetered Consumption is done based on a combination of existing measurement, assumptions and consideration in discussion with Utility. If a particular category has significant count (say Public Stand Posts), sample meters can be installed at selective locations and consumption volume can be estimated based on average unit consumption measurement. Calculation of Unbilled Authorized Consumption is done by formula as mentioned below:

Unbilled Authorized Consumption = Unbilled Metered Consumption + Unbilled Unmetered Consumption

Calculation of Authorized Consumption is done by formula as mentioned below:

Authorized Consumption = Billed Authorized Consumption + Unbilled Authorized Consumption

11.4.1.3 Stage 3: Water Loss Assessment

Calculation of total water loss is possible after Authorized Consumption is assessed. It is done by using following formula:

Total Water Loss = System Input Volume – Authorized Consumption

Water Loss is further segregated between Apparent Loss and Real Loss.

Calculation of Apparent Loss Volume is done by assessing 3 components: Data Handling Errors, Customer Meter Inaccuracies and Unauthorized Consumption. If consumer and billing data is available for a long-term period of time, say, 3 years or more, it can be analyzed by data scientists to discover possible data errors. Customer meter inaccuracies are usually estimated by meter testing of a sample of existing installed meters. Unauthorized consumption is derived from utility consultation, site visits, known issue lists and appropriate assumptions.

Calculation of Real Loss Volume is done by formula as mentioned below:

Current Annual Real Loss (CARL) = Annual Total Water Loss – Annual Apparent Loss

For further subdivision of Real Losses, it is required to carry out additional measurements for transmission and distribution lines and is covered in subsequent sections. Most of the time, the hurdle is to get clear segregation on areas and water lines, which is very difficult in most of the cities/towns in India. This exercise will be fruitful only if validation and updates on network maps are carried out regularly. Refer to Part B Chapter 7: Distribution System.

Calculation of NRW is done by formula as mentioned below:

NRW (%) = 100 x (System Input Volume – Billed Authorized Consumption)/System Input Volume

Water Loss Per Connection is a good Key Performance Indicator (KPI). Calculation is done by dividing Water Loss by total number of consumer connections.

Water Loss Per Connection = Total Water Loss / Total Number of Consumer Connection.

The formula is good for higher connection density (say more than 20 connection/km of distribution mains. For lower densities, water loss per km of distribution is more suitable KPI.)

The Real and Apparent Loss can be utilized to calculate financial losses as per following:

Total Financial Loss to the Utility = Current Annual Real Loss x Variable Production Cost + Current Annual Apparent Loss x Average Consumption Billing Rate.

This calculation indicates total financial loss to the utility due to NRW and is a good parameter to assess possibility of performance based projects for NRW reduction.

11.4.2 Continuous Monitoring of OZ/DMA (Bottom-up Water Audit)

For utilities with 24x7 water supply areas, it is recommended to additionally carry out continuous monitoring of water loss components (Bottom-up water audit) for 24x7 supply areas. As this audit is usually carried out by automatic sensor data capture and analysis software; the strategy is to get the Water Loss components (as above) and KPIs but at a smaller granular level.

Additional KPIs can be calculated for an area with continuous water supply. As mentioned below:

Unavoidable Annual Real Loss (UARL) = ((18 x Lm) + (0.8 x Nc) + (25 x Nc x Lc)) x P

Where Lm is Length of Mains (km), Nc is number of service connections, Lc is average length of service connection and P is average pressure (m H_2O).

Infrastructure Leakage Index (ILI) = CARL / UARL

Other KPIs can also be calculated as required by the utility or regulatory authority. For more details, International Water Association's (IWA's) publications may be referred.

11.5 Extended Water Audit with Additional Measurements

Water Audit Study can be extended to include additional components as below.

a. Raw Water Transmission Mains
b. Water Treatment Plants (WTPs)
c. Potable Water Transmission Mains
d. Potable Water Distribution Mains

This exercise is faster when utility have permanent flow meters installed at inlet and outlet of these systems already. Temporary measurements can be done if required to fill the measurement gaps where no flow meter is installed. The total loss indicates mostly leakages apart from equipment and reading errors. This audit should ideally be done on daily basis with hourly data of measurement. This will ensure timely detection and measures for water loss control. If the level of automation is not sufficient to get hourly data, then monthly data should be collected to get estimated water loss per month.

Water loss estimation can be done using portable flow measurement techniques like clamp on type ultrasonic flow meters or insertion probe type electromagnetic flow meters. Pump logbooks along with individual pump flow rate measurements can also be used for quick estimates in cases where flow rates are fairly constant. These all methods are less accurate but provide faster assessment. For more detailed study, installation of permanent flow meter is the only option.

Potable Water Transmission Mains Audit provides transmission main losses in the system. Common issues with it are unauthorized tapings and service reservoir bypasses. It is not possible to segregate transmission and distribution losses without measuring flow in each and every distribution taping (feeder junction). If the count of such tapings is too high or if there are unknown tapings, it is not practical to install flow meters at each taping. Better strategy is to close all tapings and supply water to these areas via distribution systems. An intermediate strategy could be to close maximum tapings leaving only the ones vital to the distribution and put flow meters on these tapings.

Potable Water Distribution Mains Audit provides distribution main losses in the system. Common issues with it are segregating the Mains from Operation Zones/DMA network. The distribution system is traditionally designed as grids cross connected to have benefits like balanced network, equitable pressure and less water quality issues due to less stagnation. The drawback of such system is that flow measurement points are enormously high. It must be a fare balance between investment in flow measurement exercise and overall benefits in terms of water loss reduction.

11.6 Documentation and Resolution of Problems Faced in Past Audit Study

Common problems faced in the Audit Study are listed here that may vary from utility to utility.

- Proper network and other water components detail are not available in proper maps. Some maps are available, which are not updated with proper indication of appurtenances.
- Normally much attention is not paid by the Water authorities to the water audit of the water supply schemes.
- The results of audit findings are not made public and is considered a problem in itself not the diagnosis of underlying problems.
- Barring a few major cities, separate Water audit units are not available with the Authority. Wherever these units are available the water audit staff is not motivated enough to carry out the work. Skilled staff and private companies are limited in this field.
- By and large, water authorities are not equipped with the necessary equipment.
- Proper budgetary provision is not available for carrying out continuous and effective water audit.
- Lack of co-ordination between the Water Audit unit and operational and maintenance staff.
- No emphasis is given on Information Education and Communication (IEC) activities for conservation of water.

If there were hurdles or problems faced during the study, it should be documented and possible solutions should be listed down for future audit study. It is not unusual to have assumptions and considerations for various components of Water Balance to overcome the actual difficulty in data collection, utility must evaluate if the purpose of Water Audit which is to get insights on Water Loss Reduction Plan is fulfilled or not. If there are too many assumptions or theoretical/design consideration instead of practical data, the whole purpose of the exercise is defeated.

11.7 Analysis and Intervention of Water Audit Findings

The Water Balance will provide various components of losses in the system. Utility should review and analyze various components of water loss and plan subsequent actions for water loss reduction. Utility wide Audit study should help in assessing whether the utility should focus on Real Losses or Apparent Losses or Unauthorized Consumption. Zone wise Audit study should help in prioritizing the area of action:

1. Areas that need immediate leak detection and repair to reduce Real Losses
2. Areas that need social campaign and network investigation to reduce Unauthorized Consumption
3. Areas/Consumers that should be prioritized for meter placement or replacement planning
4. Areas that need levels of losses to be closely and continuously monitored.
5. Areas that appear to need no further work at the current time.

Post water audit, the water loss reduction planning should be done. The frequency of this plan may be kept yearly. All of these actions are discussed in subsequent sections. It should be noted that all actions cannot be taken simultaneously for entire utility and should be staggered across multiple years. Yearly review of actions taken in the previous cycle and improvisation for next cycle is the most important part of this strategy. The focus should be to act on reduction of highest component of water loss within limited time period within predefined budget and if possible, focused on limited area that is prioritized based on Audit findings.

11.8 Action Plan for Water Auditing/Continuous Monitoring of Water Loss

For a utility trying to control water loss, it is necessary to include a strategy for continuous data capture and analysis along with major capex projects. Following Table 11.3 provides recommendation based on key issues faced by Indian Water Utilities.

Table 11.3: Recommendation based on Key Issues faced by Indian Water Utilities

Utility Issues	Water Audit/Water Loss Monitoring Recommendation	Execution Strategy
Operational Zone improvement or 24x7 project / DMA creation	Continuous OZ/DMA Monitoring and Analysis	Throughout Water Supply Improvement or 24x7 Water Supply Project Maintenance Period
General Utility Water Loss Performance Assessment	Periodic Water Audits	Along with major system wide improvement project and post project execution / Yearly Audits
High Transmission/Storage Losses	Continuous Transmission Main Monitoring and Analysis	Along with SCADA Project/ Flow Metering Project
High Distribution Losses	Sectorization to isolate OZ/DMAs, followed by continuous monitoring	Along with NRW reduction project

Sectorization of the Water Network: If the utility have clear sectorization of Transmission Mains (Flow Meters at each inlet, taping and outlet) and OZ/DMA isolation, the NRW monitoring and reduction strategy can be implemented at a smaller scale e.g. an Operation Zone/DMA. This way utility may start small, in a cost effective way and learn from it before expanding the strategy to a Zonal level or Utility level.

Software for Continuous Water Loss Monitoring: SCADA and various Flow, Pressure and Level sensors generate huge amount of data that is impractical to be analyzed just by human efforts or excel sheets. For a utility, it is possible to implement a continuous monitoring and analysis software at a transmission grid level or a smaller scale like OZ/DMA. The analytical software may guide the utility towards leakiest OZ/DMA or a transmission sector that may have a new unauthorized taping. This way utility may focus its NRW reduction efforts on specific sectors optimizing overall resource utilization.

11.9 Action Plan for NRW Reduction

Action Plan for NRW reduction is divided in sub-components as explained below.

11.9.1 Apparent Loss Reduction

Apparent losses relate to water that is consumed but not paid for. Apparent losses are usually caused by water theft/ illegal connections, problems and errors in metering, data handling, and billing or revenue meter under-registration. While the first two causes are directly related to water utility management and may be reduced by improving company procedures, water meter inaccuracies are considered to be the most significant and hardest to quantify. Water meter errors are amplified in networks subjected to water scarcity, where users adopt private storage tanks to cope with the intermittent water supply.

11.9.1.1 Losses in Meters

Losses in meters happen due to the following reasons:

a) Customer meter leaks: Leaks can be caused by loose spud nuts on the meter, broken or damaged couplings, loose packing nuts, damaged or broken meter yokes, damaged or broken angle stops, or broken meters.

b) Improper meter sizing: Customer service connections and meters were typically sized based on the peak flow rates that the meter was expected to encounter. Because peak flows are uncommon, most meters recorded flows at the low end of their design range. Many flow meters are less accurate at the low end of their range, with very low flows not being captured at all. The current consensus focuses on the flow range most commonly encountered rather than rare peak flows.
On the other hand, meters that are undersized for the flow profile they will transmit much higher flows of water than they are designed to accommodate, resulting in a rapid loss of accuracy. Utility managers should monitor their billing data for unexpectedly high consumption for the existing sized meter and test these meters more frequently. Meters that have been proven to be undersized should be replaced with a larger model.
The high, average, and low consumption values can be used to determine whether a water meter is appropriately sized for the actual water consumption pattern. If most of the flow through a customer meter occurs at the high or low end of the meter's specified range, the meter is most likely improper for the application.

c) Correct installation: If fully functional water meters are not installed properly, they may be inaccurate. All meter manufacturers provide specifications and installation guidance for their water meters, and water utilities should follow this guidance. Water meters should be installed horizontally, with adequate spacing and appurtenances (strainers) as needed. A water meter should be installed in a location away from weather extremes and other stresses.

d) Non-functional Meters: Non-functional Meter is defined as any water meter showing no or less consumption. These meters are identified based on less than average consumption in the same month in the year immediately preceding, provided that said meter had been determined to be defective upon testing in the lab by the operator or the battery of the water meter is dead. Either way, the Utility managers should monitor their billing data for such unexpected changes, and appropriate action should be taken in time as this lead to loss of revenue as the consumer is billed on average consumption in place of actual consumption. Hence, the meters are required to be periodically tested and replaced if required.

e) Slow/ Aging Meters: Aging meters tend to deteriorate by many factors discussed above and lead to inefficient measurement of the flow. Hence, the meters are required to be periodically tested and replaced if required. As per studies conducted in many countries regarding NRW it has been found that water meters tend to go slow with its age. It is recommended during water auditing some meters 10 years and more than 10 years of age should be tested for its accuracy to workout factor of losses.

f) Multiple connections in a building: With Multiple connections in a building the consumption gets reduced abnormally as compared to a single connection. Water rates are on consumptions slab basis the revenue gets reduced abnormally.

Minimizing customer meter under-registration requires substantial technical expertise, managerial skills, and upfront funding. Customer meter management should be undertaken holistically, best described by the term “Integrated Meter Management.”

Case Study Maynilad Water Services: Integrated Meter Management

In the past, the responsibilities for metering-related activities were scattered throughout the organization of Maynilad Water Services Inc. As a result, metering efforts and resources (e.g., data loggers, service vehicles, and meters) were often uncoordinated and insufficient. With the establishment of the Integrated Meter Management (IMM) department and its integration in the Central NRW Division, Maynilad now has a one-stop-shop for all metering issues. The IMM department is a young team of highly specialized engineers responsible for all metering related issues—from the smallest customer meters to the largest raw water bulk meters.

The lack of good quality meter testing facilities, especially when it comes to larger diameter meters, and the lack of experience in how to best utilize such facilities is one of the problems. This makes it easy for manufacturers to supply meters from second-class quality manufacturing batches with little risk that the utility would ever find out.
Another common problem is the reluctance to invest in high-quality but more costly meters for large customers. Normally, the top accounts of a utility generate such a large portion of their revenues that any investment in more advanced meters can be economically justified. The payback time is often just a matter of months. Yet, many water utilities opt to maintain and calibrate old meters over and over again instead of taking appropriate action and installing new meters. To improve the situation a utility may follow stringent standards like MID and ISO 4064 for metering project.

11.9.1.2 Illegal Connections

While meter under-registration is more of a technical problem, water theft is a political and social issue. Reducing this part of commercial losses is neither technically difficult nor costly, but it requires making difficult and unpleasant managerial decisions that may be politically unpopular. The reason is that illegal connections are nearly always wrongly associated with only the urban poor and informal settlements. However, water theft by high-income households and commercial users, sometimes even large corporations, often accounts for sizable volumes of water lost and even higher losses of revenue.

In addition to illegal connections, other forms of water theft include meter tampering and meter bypasses, meter reader corruption, and illegal hydrant use.

Another common problem is “inactive accounts”. In cases where a customer’s contract has been terminated, the physical service connection, or at least the tapping point on the main, still exists and is easy to re-connect illegally. Stringent inactive account management and verification program can easily solve this problem.

Consumers may resort to many techniques to make a connection free or reduce their bills, as follow:

a) Bypassing the meters and illegal connection to consumer's own connection (bypass)
b) Tampering the meters
c) Hidden tap running from the water main
d) Illegal connection to a neighbor’s supply running along the wall of the property

11.9.1.3 Public Standpost

Water utility managers often neglect the water losses/ use from a public stand post, and hence the water supply to the public stand post remains unaccounted for. It is recommended to shift the population served by stand post to community connections/group connections.

11.9.1.4 Billing and Collection Inefficiency

The billing system is the only source of metered consumption data that can help determine the volume of NRW through an annual water audit. However, most billing systems are not designed to retain the integrity of consumption data. Rather, they are designed to deliver accurate bills to customers and correctly account for the bills. However, there are many day-to-day processes in operating a billing system that has the potential to corrupt the integrity of the consumption data, depending on the design of the particular system.

Issues that can affect consumption volumes include

- meter reading practices causing manual reading errors.
- handling of reversals of over-estimation
- processes used for dealing with complaints about high bills
- customer leaks
- estimation of consumption

- meter change-outs
- tracking inactive accounts, and
- the processes for the identification and rectification of stuck meters
- Poor follow-up with consumers who are not paying, having illegal / leaking connections.

A. Improvement in Billing and Collection Efficiency

Improving billing and collection activities has an immediate impact on the revenue streams of a service provider that can, in turn, help the service provider in improving services & reduction of NRW. However, while effective billing and collection practices depend on many internal factors (including customer databases, the extent of metered and unmetered service provision, tariff and billing structures, delivery of bills, and facilities for customer payments), the institutional arrangements under which service providers operate and provide services determine whether such practices will remain sustainable in the long term. Efficient billing and collection practices can set incentives for the provider to effectively charge and collect water bills while also fulfilling a commercial orientation to services.

Action to improve Billing and Collection Practices are as follows:

a) Monthly Billing System Based on a Volumetric Structure with Uniform/ Telescopic volumetric charges and ensuring bills are sent to the correct person for the right amount.
b) Computerized System of Billing and an updated and complete customer database.
c) Use of electronic interface such as mobile app based meter reading applications for AMR/Non-AMR meters.
d) 100 Percent Customer Metering and 100 Percent Billing Based on Metering should be followed
e) CCTV based inspection crawler robots that can go inside the pipeline as small as 90 mm, can identify the number of illegal connections on which further action can be taken.
f) The service provider must authorize a single point from which consumers can purchase their meters or provide the meters themselves so that a standardized meter is being used as authorized by the service provider. Service providers also need to have a meter checking, maintenance, and repair policy in place so that any faults identified by meter readers at the time of meter reading can be reported and addressed. Providers should also have in place metering checks where responsible staff could single out problem cases, especially those of incorrect consumption units recorded (data entered could indicate unrealistic consumption units such as negative units or excessive figures)
g) Operational Zone wide implementation of Automatic Meter Reading (AMR) for total consumption volume data capture. AMR systems can be either walk-by or drive-by. An endpoint is connected to the meter’s encoder register. The endpoint captures water flow and alarm data which is collected by utility personnel by walking or driving by with a data receiver in proximity to the device. After collection, the meter data is

transferred to a database where utilities can monitor and analyze usage, troubleshoot issues and bill customers based on actual consumption, rather than predictions that were often required with bi-monthly or quarterly manual reads.

h) Meter Reading Applications: A lot of data handling errors can be avoided by using Meter Reading Applications. The common technologies used by many water service providers worldwide are handheld devices or mobile/web based Meter Reading Applications that enable meter readers to record readings easily and reduced manual intervention.

i) These Apps are preloaded with a set of records or information based on which the water meter data needs to be collected. The Apps also generate alerts for incorrect entries or anomalies, for instance, in case meter readers enter erroneous data or if they do not read the meter but continue to generate readings on average monthly consumption. These Apps give meter readers two options for generating bills

   i. Spot billing, where they could generate bills on the spot and hand them over to the consumer once the meter readings are entered. This helps utilities streamline and implement effective billing systems, improve cash flows, and make the processes more customer-centric.
   ii. Batch billing, where meter readers can collect the required data and, at the end of the day, download the data in their office where the master database gets updated, and bills are generated according to the billing cycle.

j) Outsourcing the Billing and Collection Function

k) Incentives for Meter Readers for providing effective services in meter reading

l) Ensuring Regular and On-Time Payments by including the following actions:

   i. encourage consumers to connect legally to the network
   ii. for continuous default and nonpayment or in cases of illegal connections, using sanctions, such as water connection cutoffs
   iii. incentive schemes for customers who have huge arrears in their bills
   iv. encourage consumers to pay on time for services by simplifying the payment process

m) Resolving Customer Grievances: A call center is a must to ensure that a customer focus on service delivery is maintained. Such centers help service providers to respond to consumer grievances in a speedy, appropriate, and efficient manner by receiving constant feedback about the services that they are providing.

n) Real time pipeline and connection management dashboard can be developed to monitor the number of connections on the branch/ in each street. This can also be accessible on cloud

11.9.2 Real Loss Reduction

Real Loss Reduction includes following key activities mentioned in a simplified way (refer IWA Water Loss Task Force Recommendations):

- Active leakage detection and monitoring to limit unreported leaks

- Efficient and fast repair of leakages that are reported or detected
- Maintaining supply pressures to be within desired optimal range
- Keeping Water Network data up to date and timely replacement as and when required

11.9.2.1 Active Leakage Detection and Monitoring

Active leakage detection and monitoring refers to continuous monitoring of an area of supply, say, operational zone, and tracking its total loss, segregating it in real and apparent loss components and carrying out leakage detection work where the real losses have started to increase. Now if there are reported leakages, it is obvious to repair those in the first place. But if the OZ is still high on real losses, it clearly indicates utility is not aware of a massive amount of unreported leakages. This awareness time is directly proportional to water loss. Hence, an active leakage detection and monitoring program can help in reducing leak awareness time for utility. It is followed by field activities to detect the leakages, and can be monitored as average leakage location time. Once a leak is pin pointed, the average repair time should also be tracked for measuring performance.

The major activities in the leak detection work in the distribution system are as below:

- Preliminary data collection and planning
- Pipe location survey
- Assessment of pressure and flows
- Locating the leaks.
- Assessment of leakage.

A. Preliminary Data Collection and Planning

The water distribution drawings are to be studied and updated. The number of service connections is to be obtained and in the drawings of the roads the exact locations of service connections marked. The district and sub-district boundaries are suitably fixed taking into consideration the number of service connections, length of mains, pressure points in the main. The exact locations of valves, hydrants with their sizes should be noted on the drawings. The above activities will help in planning the conduct of sounding of the system for leaks or for fixing locations for conduct of pressure testing in intermittent water supply system before commencement of leak detection work or for measuring pressure and leak flow in the continuous water supply system.

B. Pipe Location Survey

Electronic pipe locators can be used during survey. These instruments work on the principle of Electromagnetic signal propagation. It consists of a battery-operated transmitter and a cordless receiver unit to pick up the signals of pre-set frequency. There are various models to choose from. Valve locators are metal detectors that are available which can be used to locate buried valves.

C. Assessment of Pressure and Flows

Data loggers are used to record the pressure and flows. It is an instrument which stores the raw data electronically so as to be able to transfer it to the computer with a data cable link. Two types of portable data loggers are used either with a single channel or dual channel. Single channel loggers are of the analogue type with built in pressure transducers. A simple push fit connection with the street main enables direct recording of pressure for future retrieval.

Dual channel loggers consist of an analogue type sensor for pressure and a digital type sensor for recording flow reading. A pulse head for picking up a flow reading and its conversion into an electronic pulse is required with this logger. The data of pressure and flows are stored into the data loggers during the test. Subsequent transfer of the data is made electronically into the computers magnetic storage for further processing.

In the absence of electronic equipment, the pressures can be ascertained by tapping and providing a pressure gauge. Flows can be assessed by using meters on a bypass line.

D. Locating the Leaks

To zero in on the possible location of leakages, the following methods or combination of methods could be adopted.

Leak Pre-localization Methods:

a. If Continuous Monitoring of Operational Zone/DMA is set, it provides primary level of information on area that needs to be investigated.

b. Calibrated Hydraulic Model, GIS Data, Leakage Data Analysis, Asset Condition Assessment etc can be used to pre-localize potential high water loss areas.

c. Step test can be carried out in monitored OZ/DMA to find leakiest pockets.

Once the area of investigation is identified, further localization is done by site investigation as mentioned below.

i. **Walking**
Walking over the main, looking for telltale signs of the presence of water.

ii. **Sounding**
Sounding is the cheapest and an effective method of detecting leaks in a medium-sized water supply system.

Sounding could be categorized into two types: Direct & Indirect

- Direct sounding is made either on the main or fittings on the main such as sluice or air valves; fire hydrants stop taps, or any other suitable fittings.
- Indirect sounding consists of sounds made on the ground surface directly above the mains to locate the point of maximum sound intensity. This method is a good supplement for confirming the location of leak noise identified through direct sounding

It is important to have good supply pressure in water lines for this method to be effective. Water escaping from a pressurized pipe emits a sound similar to the sound that can be heard when a seashell is held up to the ear. But it takes a lot of experience to distinguish it from other sounds.

The range of frequency of the sound depends upon many factors such as the nature of the leak, size of the hole through which water is escaping, the pipe material, nature of the ground in which the pipe is laid, etc.

The equipment used is:

Non-Electronic Equipment

These are also known as listening sticks. They are simple pieces of equipment consisting of a rod of any material with an earpiece.

Electronic

These are electronic listening sticks consist of a metal rod that is screwed onto a combined microphone and amplifier unit. The sound can be amplified using a volume knob and can be heard through earphones.

There is also a ground microphone consisting of a microphone unit and an amplifier unit; the microphone unit is attached to a handle that enables the unit to be placed on top of the ground, and the signal received is amplified and passed on to the user through headphones. Some equipment has indicators.

There are noise loggers that can record leak noise continuously from permanent or temporary locations that can be analyzed by experts or a computer program to filter, process and identify presence of a new leak in the system.

iii. **By the use of gas tracer**
A gas tracer is injected into the main and will surface out along with water at the point of the leak. A detector is used to search for the substance that escapes. Boreholes are made at frequent distances. The content of each borehole is sampled in turn using a hand detector to ascertain the presence of gas. This method is costly but can be used in systems that doesn't have good water supply pressure in line.

iv. **By using a Leak Noise Correlator**
The leak noise correlator is an instrument consisting of a Radio transmitter unit and a correlator unit. Both the units are placed on the test mains at the two ends of the stretch under correlation by attaching their magnetic sensors to the mains. The correlator unit identifies the various frequencies of leak sounds and calculates the distances of the leak points from the correlator unit automatically.

v. **By using a crawler based inspection system**
A crawler is a robotic device that goes inside the distribution pipelines as small as 90 mm in diameter and gives complete visual understanding of the defect inside the pipelines with their root cause. It needs an entry point every 200 to 500 meters depending on the diameter of the pipeline and pinpoints the location of the leak/seepage

E. Classification & Application of Leak Detection methods

The most common form of categorization is the leak detection principle applied, i.e., following the traces left by a water leakage - either the noise produced by the leaking water (acoustic), the fact that the lost water quantities are missing downstream (flow-rate), the temperature changes in the vicinity of the leak (thermal) or other principles. The methods are described in this order of classification.

Another possibility of classification is the difference in the application of the sensor technology. Here, four different categories can be identified: (1) methods where the leak sensors are guided through the pipe in a mobile way - so-called pigs, (2) methods where the sensor elements are placed near the pipe in the form of a cable, (3) methods where the sensors are attached at a point on or in the pipe and (4) methods where no contact with the pipe and also not with the water column is necessary. Table no. 11.4 shows both ways of classification.

Table 11.4: Classification & Areas of application of the different methods

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpo le loca
1	**By listening rods**	Acoustic	Contact sensor	□		Yes	Exceptionally with many access points	□		
2	**By ground microphones**	Acoustic	Contactless sensor	□		Yes (main use)	To some extent for, pinpointing			
3	**Leak noise correlation**	Acoustic	Contact sensor	□		Yes (main use)	To some extent, with hydrophones		□	
4	**Noise logging**	Acoustic	Contact sensor	□	□	Yes (main use)	To some extent, with hydrophones	□		
5	**Pushed hydrophones**	Acoustic	Pig	□		Yes (especially for connections)	Yes, but with different characteristics		□	
6	**Tethered**	Acoustic	Pig	□		In	Yes (almost		□	

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpo le loca
	hydrophones					exceptional cases	exclusively)			
7	Free-floating hydrophones	Acoustic	Pig	□		No	Yes (exclusively)		□	
8	Distributed Acoustic Sensing	Acoustic	Sensing cable		□	Possible	Yes (preferentially but not exclusively)		□	
9	Volume balance	Flow-rate	Contact sensor	□	□	No (see flow monitoring)	Yes (exclusively)	□		
10	District Metered Areas (DMAs)	Flow-rate	Contact sensor		□	Yes (exclusively)	No	□		
11	Flow monitoring	Flow-rate	Contact sensor		□	Yes (exclusively)	No	□		
12	Hydraulic Model Leak	Calibration	Contact Sensor			Yes		□		

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpo le loca
	Pre-Localization									
13	**Step test**	Flow-rate	Contact sensor	□		Yes (exclusively)	No	□		
14	**Hydraulic leak localization pig**	Flow-rate	Pig	□		Yes (especially for connections)	No		□	
15	**Thermal imaging cameras**	Thermal	Contactless sensor	□		No	No			
16	**Thermal imaging drones**	Thermal	Contactless sensor	□		Yes	Yes		□	
17	**Distributed temperature sensing**	Thermal	Sensing cable		□	Possible	Yes (preferentially but not exclusively)		□	

No.	Method	Classification		Areas of application						
		Principle	**Sensor type**	**Temporary leak detection**	**Preventive maintenance/ Daily Monitoring**	**Applicability in distribution networks**	**Applicability in large diameters (which cannot be interrupted, longer length, deeper)**	**Preliminary Identification of leak**	**Identifying more accurate location of leak**	**Pinpo le loca**
18	**Moisture sensing smart-cables**	Moisture	Contactless sensor	□		No	No			
19	**Moisture sensing cables**	Moisture	Sensing cable		□	Yes	Yes		□	
20	**Ground Penetrating Radar (GPR)**	Electromagnetic	Contactless sensor	□		Yes	Yes (for pinpointing)			
21	**Satellite radar**	Electromagnetic	Contactless sensor	□		Yes	Yes	□		
22	**Tracer-gas**	Chemical	Contactless sensor	□		Yes	To some extend with, bubble creators		□	□
23	**Sniffer dogs**	Chemical	Contactless sensor	□		Yes	Yes		□	□
24	**Negative**	Pressure	Contact		□	Only in	Yes	□		

No.	Method	Classification		Areas of application						
		Principle	Sensor type	Temporary leak detection	Preventive maintenance/ Daily Monitoring	Applicability in distribution networks	Applicability in large diameters (which cannot be interrupted, longer length, deeper)	Preliminary Identification of leak	Identifying more accurate location of leak	Pinpo le loca
	Pressure Wave Method		sensor			combination with other methods	(exclusively)			
25	**Soil probes**	Mixed	Contactless sensor	□		Yes (main use)	To some extend for pinpointing			□
26	**In-pipe Crawler**	Visual	Camera			□			□	□

11.9.2.2 Leakage Repair Techniques

There are a number of different techniques for repairing pipes that leak. These techniques depend on the severity of leak, type of break in the pipe, the condition of the pipe and the pipe material. Repair techniques are explained in detail in Chapter 4 “Transmission of Water” and Chapter 7 “Distribution System” in Part B of this manual.

11.9.2.3 Use of Water Efficient Plumbing Fixtures

Water leakages after consumer connection (meter) is not reflected as loss in utility water audits. But practically, there is a huge number of average or no bill consumers for a typical water utility. So role of efficient plumbing fixtures can’t be ignored. Water-efficient plumbing products should be installed in all public buildings, and other major consumers considering the important role that such products can play in reducing water consumption without compromising personal hygiene and customer satisfaction. Further details can be seen from Chapter 15: Water Efficient Plumbing Fixture in Part A of this manual

11.9.2.4 Prevention of NRW in Consumer Connection

For domestic connection galvanized iron pipes are mainly used. After a period of time these pipes get choked due to corrosion/tuberculation. For house service connection, non-corrosive pipes can be used. The water supply drawing should have correct layout of the pipes, diameter, material, valves etc. This would facilitate proper maintenance.

11.9.2.5 Pressure Management

The supply pressure is a key factor connected to water lost through leakages. Low pressures are not desirable from service quality point of view and high pressures will cause high volume of leakages. The situation is more aggravated in undulated terrain. Cross connecting different operational zones or transmission systems also adversely affect the pressure ranges, leading to areas with very high and very low pressures. So there are design and operational issues that should be tackled first, followed by advanced methods like pressure management valves to maintain optimal pressures in the OZs/DMAs.

11.9.2.6 Network Asset Update and Replacement

The network is continuously changing to cope up with ever increasing demands. Utility mostly struggle to keep up with this pace and a lot of network data is mostly missing from central GIS repository, or in worse case, there is no GIS repository at all. If the network data is not available, various network analysis and renewal prioritization can’t be thought of. And ultimately, an improvement project will have to consider 100% replacement due to lack of existing network information and uncertainly about its condition. This is not sustainable and desirable if the service standards are to be maintained. Hence, the first thing is to fix the basic issue of not routing all network capex and opex changes to a central repository. Followed by various analysis and prioritization for optimal renewal of network infrastructure.

11.10 Instrumentation and Software for NRW monitoring and Reduction

This section devotes itself to describing applications of digital tools to reduce physical water losses and increase the energy efficiency of water utilities. Globally, digital applications have been developed for leak detection, pressure management, energy-efficient pumping & energy management.

11.10.1 Digitalization to Reduce Physical Water losses

Innovative digital techniques are discussed here under:

(i) Remote Acoustic Instruments
(ii) Data Analysis Software
(iii) Smart Pressure Management Valves
(iv) Digital Dashboards with citywide pipeline management

(i) **Remote Acoustic Instruments**: Remote acoustic instruments can be used with various acoustic tools like noise loggers. This enables utility to continuously track and analyze the data over a long period of time without physical access to the instrument for data exchange.

(ii) **Data Analysis Software:** For utilities with very high levels of NRW, the precision for leak detection should commence after water loss is localized to Operational Zones/DMAs. Analysis software can provide sector wise total loss, hourly losses summary for last day, segregation of real and apparent loss component for 24x7 water supply, consumption anomalies etc. SCADA and consumption data combined with Hydraulic Model of the network can also be used for network calibration and leak pre-localization. Pin pointing leaks are not possible by data analysis tools but it may guide field teams to the right operational zone and prepare leak detection routes based on analytical prioritization.

(iii) **Smart Pressure Management Valves:** With reference to NRW, the high pressures lead to leaks in old pipelines. With smart pressure management valves, different inlet pressures can be set for day and night based on consumption requirement analysis. That will help in controlling unnecessary pressure rise during night and keep water loss due to leaks under control.

(iv) **Digital Dashboards with citywide pipeline management:** By using a cloud based digitalization platform data analytics, & machine learning based prediction algorithms, the expected deterioration & condition of the pipelines can be identified that can help municipalities take preventive maintenance actions.

Aided by the crawler robots specifically designed for distribution lines, the leak detection process can be advanced and the features like geo tagging of defects and risk grading of pipeline networks can be managed in the cloud based dashboard.

It will help take data driven decisions before project DPRs and thus increasing the efficiency of assets. Accurate assessment in the DPR will reduce the pressure on the O&M with complaints on a regular basis about defects in the pipelines leading to shutdowns or blockages & save lots of resources & cost in the future.

11.11 Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure is an integrated system of water meters, communication networks and data management systems that enables two-way communication between meter endpoints and utilities. Unlike AMR, AMI doesn't require utility personnel to collect the data. Instead, the system automatically transmits the data directly to the utility at predetermined intervals. Meter data is sent to utilities via a fixed network. The utility can use the data to improve operational efficiencies and sustainability by effectively monitoring water usage and system efficiency, detecting malfunctions and recognizing irregularities. With a fixed network, utilities work with specific vendors to get their infrastructure and technologies up and running. And today, existing cellular networks, designed to minimize downtime, can be used to make sure meter data is collected securely and without interruption. A network of smart water meters and intelligent infrastructure that provide continuous and historical data to improve system intelligence, visibility, automation and control. Smart water solutions are credited with:

- Enhancing meter reading efficiency
- Assuring long-term meter accuracy
- Improving customer service processes
- Decreasing non-revenue water
- Streamlining billing processes
- Supporting security to deter tampering

A common misconception is that smart water solutions are only available for utilities with a certain population size or that dedicated utility resources are required to maintain an AMI network after it is deployed, but neither of these statements are true. Smart water solutions using existing cellular networks are available for utilities of all sizes and locations. There are three steps utilities can take to use AMI leak detection to conserve water: metered leak detection, district metering leak detection and acoustic leak detection. Each method leverages specific aspects of AMI technology to detect leaks in different ways. AMI solutions transform data collected through the system into valuable and actionable intelligence for users across the utility, empowering the entire organization to address conservation and revenue protection.

Approach 1. Metered Leak Detection

With certain AMI systems, a leak flag is sent whenever continuous flow of a metered account is detected over a specific timeframe. A communication module takes a consumption reading at the top of every hour and records this reading into its memory. When the reading is taken, the module can detect if there has been flow over the previous hour or if there has been no consumption. If there is one week of non-zero consumption (continuous flow), the communication module marks this as a potential leak and includes a leak flag with its next data transmission.

The data passes through the AMI collection engine and ultimately is accumulated in a data repository where leak and other data can be viewed. The user can see consumption values over time to see when the potential leak began, if it is improving or getting worse, and the day it was repaired.

Figure: Typical leaks at a joint

Approach 2. District Metering

Performing district metering is another way utilities can utilize AMI for water conservation. This involves grouping and aggregating stored data in a software application. The process consists of three steps:

1. Identify the meter or meters that feed water into the district (i.e. the master meter).
2. Identify the group of meters in the district and combine the total consumption of these meters on an interval-by-interval basis. Accrue the combined consumption of the district into a virtual meter.
3. Compare the net consumption of the master meter with the metered consumption of the aggregated district on a time-synchronized interval-by-interval basis. Any difference between the net consumption of the master meter and the aggregated consumption of the virtual meter is considered non-revenue water, which can include leaks. The precise time-synchronization of all readings to the top of the hour or some other reference point is a key component of this analysis. In other words, one cannot compare consumption of the master meter today to the aggregated consumption of the virtual meter

from a different day. It must consist of an instantaneous comparison of water-in to water-out at the same moment for accurate analysis.

Non-revenue water can result from leaks, theft or mis-metering. However, when a district metering analysis has been performed, much more information is available regarding where to look for leaks throughout the network.

Approach 3. Acoustic Leak Detection

Acoustic leak detection is another way utilities can account for and identify non-revenue water. The combination of acoustic leak sensors, AMI technology and data analysis software enables proactive leak mitigation. Using a communication module with an integrated acoustic leak sensor, water providers can collect and analyze vibration patterns from anywhere in the distribution system, improving their ability to maintain critical water infrastructure. Having a proactive acoustic leak detection system reduces non-revenue water and conserves water resources through early leak warnings. Utilities can lower repair costs by finding and repairing leaks before they become costly main breaks. By pumping and treating less water, utilities extend the lives of their facilities.

Metered leak detection, district metering and acoustic leak detection allow utilities to be more sustainable by reducing the number of leaks in a system and the amount of water that would otherwise have been wasted. Using AMI to detect leaks can maximize water supply availability by detecting new, evolving and pre-existing leaks automatically. It also can mitigate pipeline accidents and infrastructure leakage with an eye toward improving utility operations, maintenance and capital improvement decisions. Ultimately, this technology enables utilities to focus on conservation and create a more resourceful future. The utilities in the region can build successful leak detection and prevention programmes by utilising mobile automatic meter reading (AMR) and fixed network advanced metering infrastructure (AMI) systems.

Utilities conduct audits to determine how much water pumped into the distribution system is actually metered. AMI data can make these audits more accurate by helping utilities identify where loss may be occurring. For example, AMI data can identify meters that are not recording properly, either because they are broken or have been bypassed through theft. Unmetered water usage, whether authorised or not, is a key source of NRW loss.

In addition, a major NRW culprit is using the wrong-sized meter in an application, such as when a high-water-use business (e.g., a laundromat) moves into a commercial building originally developed for light industrial use. If the wrong meter is used, it may not record all the water that is used, which results in lost revenue.

Underground leaks in the distribution system are a primary cause of NRW loss but can be difficult to locate. Acoustic loggers integrated into a fixed-network system can cost-effectively identify small, underground leaks before they become big problems.

The loggers send data to the utility over the fixed network, where web-based application software automatically correlates the data and identifies and locates high-probability leaks. This approach simplifies acoustic leak detection, eliminating the need to send crews into the field and providing the means to manage the process from the utility.

Once the units are installed, operators can monitor the system and analyse results at the utility office. No manual or drive-by data collection is required. The system can be deployed stand-alone or added on to the AMI network system, and which operates with minimal operator involvement.

Several smart metering companies have deployed the technology, which use the system to find underground leaks that occur on several lengths of galvanized service lines and cast-iron pipes.

When considering automation of meter reading, utilities should weigh the benefits of a fixed AMI network for a truly smart infrastructure.

Improvements in customer service, conservation efforts, quantification of non-revenue losses, leak discovery, and operations improvements provide long-term, benefits over both drive-by and walk-by systems.

11.12 Assessment of NRW after Completion

After completion of all the improvements a review of the number and nature of complaints received before, during and after the project should be undertaken and may be tabulated as given in Table 11.5.

An independent survey is to be carried out on the consumers after completion of the NRW works and the consumers are to be surveyed to give their opinion on issues of water supply, e.g., defective water supply (the duration of supply, the pressure available, etc.), Water Leaks, Water quality and Billing & Metering.

The overall assessment of these figures will give the impact of the NRW exercise.

Table 11.5: Analysis of Complaints Received in the Division before and after the NRW works

Timeline	Nature of Complaint			
	Defective Water Supply	Water Leak	Water Quality	Billing and Metering
2 months prior to work				
Month prior to work				
During work				
Month after work				
2 months after work				

The report should also include general data as follow:

a. Name of Division
b. Total No. of connections

c. No. of connections tested
d. Month/Year completed
e. % of Division covered

11.13 Capacity Building

Capacity building can address the shortcomings and help the ULB staff to deal with governance, management, and technology issues. In-house training center – for continuous staff training and capacity building at all levels and staff with different specializations (i.e., engineering, plumbing, accounting, consumer relation, etc.) should be developed.

The activities against real and apparent losses require a comprehensive water loss control program that comprises technical and social aspects of management to locate and reduce these water losses and thus maintain or increase revenue for the maintenance of water utilities.

Water utility managers need specific answers to Who? What? When? Where? Why? How often? and How much? These questions should be discussed for each of the following aspects during capacity building programs:

- Record keeping
- Audit/balance performance indicators and benchmark analysis
- Economic analysis
- Metering – locating, sizing, initial installation, validation, replacement
- Meter reading or Automatic Meter Reading (AMR)
- Additional system monitoring, including Supervisory Control and Data Acquisition (SCADA) – Data transfer – billing, data error analysis
- Leakage management program
- Periodic leak detection sweeps
- District Metered Area (DMA), zone flow analysis, and other forms of leak testing
- Leak locating – method and training
- Leak repair
- Repair, rehabilitation, or replacement analysis, design, and execution
- Pressure management

11.14 Periodic Operational Staff Training

Periodic Operational Staff Training can bridge the gap in the skills of individuals in many areas, such as:

(a) Leak detection and repair,
(b) Quality studies and analysis of water losses,
(c) Meter management and effective technical approaches to managing water losses
(d) Monitoring leakage levels
(e) Location of leakage using equipment such as leak noise correlator amplifiers and listening sticks.

(f) Leak detection methods are possible under different conditions.
(g) Improve awareness
(h) Increase motivation
(i) Transfer skills
(j) Introduce best practices/appropriate technology

11.15 Case Studies of Water Audit of Indian Water Utilities

Case Studies on (a) Water Loss Reduction in Bangalore City and (b) Spot Billing Initiative (Hyderabad, India) are given at Appendix – 1 and Appendix-2 respectively.

Appendix 11.1: Case Study – Water Loss Reduction in Bangalore City

Background

Bangalore, the information technology centre of India has seen a massive growth in its population in last three decades. The city needs 1620 million litres of potable water every day to serve its 12 million residents. This water demand is fulfilled through two sources. The city receives 1440 MLD water from River Cauvery and the rest of the demand is met through ground water from deep borewells installed by residents in their properties.

The city water supply system has a history of over 120 years. Bangalore Water Supply & Sewerage Board (BWSSB) constituted in the year 1964 had taken over the then existing system and has been active since in covering the length and breadth of the city with piped network to distribute treated surface water. BWSSB has created and managed one of the finest infrastructures in India for treatment, pumping and transfer of treated water from River Cauvery to Bangalore City. It currently manages over 8750 km water pipeline network serving over 10 lakh customers.

While there are varying estimates for the total water loss in the system between the source and customer tap, all suggest a loss between 35-40%. Very old leaking pipelines in the core city areas and high density of connections laid out in congested narrow city lanes, pose tremendous challenge in reducing losses. The BWSSB administration realised much early, the importance of conserving water and has implemented major scheme for reducing water losses in the distribution system. BWSSB was among the first utilities in the country to introduce water metering. The organisation has robust water metering program with efficient meter reading, billing system. It generates sizable revenue from volumetric water tariff in domestic and non-domestic categories, which also helps reduce consumption and wastage. With bulk water meters installed at various levels in the supply system, there is a reliable estimation of losses which help undertake control measures.

Water loss reduction measures

The first pilot project to reduce water losses was implemented between 2003 -2006 in the city's central business district under Cauvery Stage 4 Phase I scheme financed by the Japanese International Cooperative Agency. The Unaccounted-for Water (UFW) loss reduction & control and water distribution system rehabilitation project covered 370 Kms pipeline network and roughly 32000 connections in 16 Sq. Km area. A template for systematic study, measurement, reduction and control of water losses was established through this pilot project. First, the entire pipeline network was surveyed, traced and mapped on a geographical information system. The data accuracy was improved through field works, testing and record updates as the work on UFW reduction progressed. Based on the mapped information, District Metered Areas (DMA) were designed and constructed, a concept globally accepted and recommended to measure water losses and take up reduction measures in distribution network. Hydraulically discrete DMA boundaries allowed accurate measurement of flows into and out of the DMA, consumption within the DMA boundary to calculate UFW which is the difference between the water supplied and consumption. Water Balance as per International Water Association (IWA) methodology and estimation of real and apparent losses was carried out to prioritize reduction measures in each DMA. Active leakage control with detection and repair of visible and invisible leaks, customer meter testing and replacement, leaky pipeline and house service connection replacement, detection and control of unauthorised consumption was undertaken while continuously monitoring reduction in leakage and UFW levels. The leakage level were reduced from 56% to 26% while the UFW was reduced from 64% to 38% in the pilot project area within a period of 40 months.

Important insighted were gained in the pilot project based on which BWSSB framed major policies. First was to replace all cast iron pipe of size below 100 mm and non-metallic pipes with new Ductile Iron pipes. The old cast iron pipes were found to be heavily clogged from inside due to deposits and corrosion and had badly leaking lead joints. Second, new age Medium Density Polyethylene (MDPE) pipes were introduced for replacement of galvanised iron (GI) house service connections. Third, all meter in service beyond 7 years were decided to be replaced with standard Class B rating brass body multi-jet type meters.

Following success of the pilot project, BWSSB introduced three more projects between 2012-2014 for reducing Unaccounted for Water (UFW) in the South, West and Central Zones. These were financed under Cauvery Stage 4 Phase II scheme financed by the Japanese International Cooperative Agency (JICA). These projects covered 133 Sq. Km and about 300,000 connections in the core city zones. The water loss reduction scope and methodology was similar to the pilot project. The works in all these projects were completed by 2018, maintenance of DMAs and leakage reduction works by the respective contracting agencies has continued till 2022. The current average UFW level in these projects is 23% and reducing further. BWSSB has initiated similar UFW reduction project in part of North East Zone covering 25 Sq. Km where works are in progress.

BWSSB in 2015 took up Helium tracer gas based hidden leak detection project in the East and South East zones. It covered 1750 Kms network in 65 Sq Km area. The unique technique detects leaks flowing underground which are very difficult detect and pinpoint. Such leaks go undetected and continue to flow for long years. The technology claims over 90% accuracy in finding and pinpointing hidden leaks. Other competitive technologies based on acoustics fail in low pressure, noisy conditions in water pipe networks as prevailing in Bangalore. BWSSB had very good success in resolving contamination complaints by tracing the exact source using Helium leak detection method. The overall impact of just leak detection and repair works is estimated to be 20% reduction in UFW level.

UFW reduction and control is a continuous process. The city is seeing major advance in providing reliable daily water supply coverage to all areas. It is planned with a mix strategy of increasing supply through augmentation of treatment and transfer capacity on one hand and reducing losses in the system on the other.

Appendix 11.2: Case Study – Spot Billing Initiative (Hyderabad, India)

In order to encourage meter readers to generate water bills on time, the **Hyderabad Metro Water Supply and Sewerage Board**, in Hyderabad (India), introduced a spot billing scheme for billing its water connections (Year 2001) and has outsourced the billing function to a private party that has relevant experience in such practices and, through handheld data logger machines, can generate bills on the spot and deliver them to customers as well. The scheme has been in operation for about 70 percent of the Board's service area.

Spot billing had been a success, with the billing cycle being reduced from three weeks to one day, resulting in increased cash flow.

Employee Incentives and Addressing Community Behavior (Phnom Penh, Cambodia)

In Phnom Penh, the public utility was able to reduce NRW by 91% in 15 years through strong commitment and a comprehensive network replacement and physical loss reduction program. On top of that, simple but unique measures were taken to reduce commercial losses. For example, if a meter reader of an area did not, or could not, find an illegal connection, but one of his colleagues did, the colleague received a reward and the meter reader was penalized.

The public was also made aware of the problem of illegal connections. Those customers found to have illegal connections were heavily penalized, and anyone who reported an illegal connection was rewarded. Inspection teams were set up to search for, find, and eliminate illegal connections. As a result of these and other actions, the number of illegal connections discovered dropped from an average of one per day to less than five per year by 2002. At present, it is highly unusual to find even one illegal connection

Employee Incentives (Hyderabad, India)

The Hyderabad Metro Water Supply and Sewerage Board has been concentrating on incentivizing its staff for ensuring timely collection of bills. One of the initiatives was collection drivers on meter readers, where meter readers were rewarded US$0.025 per bill for collections made manually. Meter readers were also incentivized for collecting bills from 'Never Paid Customers' through financial rewards of 3 percent of total collections made from these customers. The Board has about 40,000 customers who have never paid their water bill and who are located mostly in circles I and II in the walled city area. As of 2005, the Board has been able to collect about US$2.5 million across two years with collections from about 10,000 consumers.

Meter readers have also been set collection targets, based on current demand estimates and arrears. Meter readers are incentivized to meet these revenue targets since the chief minister of the state awards the best performing circle and division for revenue collection. To generate competition internally within the circle, the chief general manager of each individual circle ranks the divisions according to their achieved revenue realizations. Some chief general managers also monitor revenue collections for each O&M division under them on a daily basis. Indicators like daily revenue targets and the number of consumers to be contacted daily are monitored regularly. The Water Board set a collection target of US $ 0.4 million for O&M division VII for 2005. As of May 2005, the actual collections for the entire division were US $ 0.23 million, which then increased to US $ 0.29 million in June 2005 as a result of these initiatives.

Employee Incentives (Bangalore, India)

The Bangalore Water Supply and Sewerage Board has implemented some measures for streamlining its billing practices. In a typical month, the first half of the month is reserved for billing practices with the balance month reserved for collection initiatives. There are approximately 250 meter readers, each responsible for 1,000–1,500 connections

Reading is to be done on a fixed day for every household, and if the meter reader is unable to read the meter, it is indicated on the bill and the household is charged on the basis of average consumption over the last six months. Billing on a prefixed date also ensures that the concerned household knows that it will receive its bill on that particular day. At the time of meter reading, the reader also checks whether the meter is in working condition or not, reporting the status on the water bill. Typically, readings get translated into a household water bill on the third day from the day the meter has been read.

Once bills are generated, meter readers at the Bangalore Water Board are expected to ensure that the consumers pay their bill on time. The divisional head (executive engineer) at each Bangalore Water Board division level also sets specific collection targets for meter readers, on the basis of current demand plus 10–15 percent of arrears

Constant monitoring by the divisional head ensures that meter readers meet their collection targets. The divisional heads also use the threat of transfer for ensuring that revenue performance is up to the mark.

While this practice has been found to be successful in incentivizing meter readers for improving collections in the cities of Bangalore and Hyderabad, this is not necessarily a best practice that could be replicated elsewhere. Such practices could turn out to be dangerous for the utility or service provider since meter readers could be robbed after a day's collection.

Integrated Meter Management

In the past, the responsibilities for metering-related activities were scattered throughout the organization of Maynilad Water Services Inc. As a result, metering efforts and resources (e.g., data loggers, service vehicles, and meters) were often uncoordinated and insufficient. With the establishment of the integrated meter management (IMM) department and its integration in the Central NRW Division, Maynilad now has a one-stop-shop for all metering issues. The IMM department is a young team of highly specialized engineers responsible for all metering related issues—from the smallest customer meters to the largest raw water bulk meters

Connecting Poor Populations (Bangalore, India)

In Bangalore (in the state of Karnataka, India) the water utility, the Bangalore Water Supply and Sewerage Board, mobilized low income communities and successfully helped them connect to the network through innovative means such as subsidized connection fees, options for group connections, and simplified and easy methods for application for a new connection. The initiative was partnered with AusAID during 2000-2002; the project's Community Development Component examined and tested options for improving service delivery to urban poor populations in three pilot slums including Cement Huts, Sudhamanagar, and Chandranagar.

Nearly 850 connections (individual and shared) were installed during the pilot phase. After successful implementation of the pilots, the Board decided to replicate the results in other slums. Today about 6,000 connections across 46 slums in the city are served with water. They receive bills and make payments willingly for getting an improved and reliable service. By connecting all slums to piped water, the Board is reducing its nonrevenue water component and hopes to slowly phase out the 15,000+ public taps that operate within city limits.

One-Time Settlement Scheme (Hyderabad, India)

The Hyderabad Metro Water Supply and Sewerage Board devised an incentive scheme for its customers through its One-Time Settlement scheme. This applied to customers who had huge arrears in their bills. A close look at the billing statistics of the Board revealed that there were as many as 0.28 million customers who had not paid their water cess to the Board.

To encourage customers to settle their arrears, the Board launched the scheme in June 2004, giving a discount of 10 percent to those who would pay their water cess arrears upfront. Alternatively, an installment facility of 10 installments was made for those who could not make upfront payments of arrears all at one time. There was a huge response to the scheme with a record collection of US$4.71 million in June 2004, the highest-ever recorded in the history of the Board. The scheme, which was due to expire in August 2004, was later extended till September 2004. The collection in September 2004 was also high, totaling US$4.16 million and an all-time high of 0.16 million customers.

Credible Disconnection Policy (Manila, Bangkok, Bangalore, and Hyderabad)

Manila Water has a credible disconnection policy whereby customers who are in arrears for 60 days after a due date are given warning notices prior to disconnection. As of December 31, 2004, about 63,837 connections had been disconnected. Of these disconnections, about 70 percent were later reconnected.

Bangkok-based **Metropolitan Waterworks Authority** has a credible disconnection policy in place for unpaid bills. A customer is given 12 days to pay the bill, after which a duplicate copy is sent as a reminder. In case the bill still remains unpaid for the next 15 days, the inlet valve is sealed and a fine of US$3.35 is imposed. In case the bill is still unpaid for the next 15 days, the meter is taken off and a fine of 10 percent of the connection fee is imposed. In case of further non-payment for the next three months, the customer will have to apply for reconnection and pay a fine of 25 percent of the connection fee. For any time period beyond this, the case is considered as a new connection and the customer would need to pay fresh connection fees for taking a connection

In Bangalore, the water utility, **Bangalore Water Supply and Sewerage Board**, has a disconnection policy whereby connections are initially clamped off at the street level, after which legal notices are sent. In the event that no action is taken, the Board could resort to disconnection. While this policy does exist, the Board does admit that it is not used very often.

In Hyderabad, too, a disconnection policy for penalizing customers who either default on payment or have tampered with their meters is in place. A fine of US$1.25 per month has been imposed on those who have faulty meters and who have failed to repair their meters. In case of continuing default, meter readers along with disconnection staff of the **Hyderabad Metro Water Supply and Sewerage Board** are authorized to disconnect. They sometimes also clamp the connection at the street level, and in case this does not work, then resort to disconnection. However, the Board acknowledges that its disconnection policy is not used much

Water Adalats

Water adalats (literally, courts) are used in Hyderabad and Bangalore to resolve long-standing issues and complaints related to service delivery. Consumers are usually informed about water adalats through all the major English and vernacular newspapers; they are required to register their complaints or cases in advance to facilitate collection of required information and documents from the concerned zone or circle of the water utility so as to ensure speedy complaint resolution.

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