How to know how efficient is our water distribution network-Bahrain case study

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Abstract

Being a water-stressed country that has least water resources, Bahrain is exposed to the water supply problems if its water service is unwell managed. Though Bahrain suffers from scarcity of water, its Non-Revenue Water (NRW) is considered to be relatively high compare to other countries. Reducing NRW remains the primary concern in Bahrain. Bahrain's Electricity and Water Authority (EWA) chose to reduce its NRW. Thus the Water Distribution Directorate is developing and implementing a comprehensive strategy to reduce both the apparent and real aspect of NRW and its target to achieve 15% over the next 3-4 years.

The strategy selected by EWA (Bahrain) in order to address and reduce water loss within their water distribution systems involves; (i) implement District Metered Areas (DMAs); (ii) Pressure Management Areas (PMA) through system optimization; (iii) commercial/metering audits; (iv) infrastructure management utilizing GIS and telemetry; (v) Establishing water loss control system and; (vi) Smart network Advanced Measurement Infrastructures (AMI) and Smart Grids; (vii) Modelling and calibrating hydraulic, and (viii) Education and training of water utility personnel. First stage in development of applications for EWA is creation of the document "Water Loss Management Program" with above main elements involved.
This paper aims to demonstrate the needs of reducing NRW for urban water resources sustainability. It also describes the activities and the results achieved by EWA through the implementation of the strategy. It indicates that the primary stage in designing a NRW strategy is to quantify water uses and losses and understand the network operation and performance. In general there is no one standard approach and the strategy must be tailored to each individual water utility. It is true to say that in any distribution system there is a "Natural Rate of Rise" in NRW.
The conclusion indicates that apparent losses caused by meters have an effect on overall NRW level and each case has to be dealt with separately. hence continue with both leak detection and apparent losses elimination activities to reduce NRW and concentrate more on apparent losses. Besides most meaningful result is the number of activities we initiated or improved, is to ensure we are properly maintaining our system, which consecutively will reduce NRW along the way. Key recommendations of the study were to impose water legislation, strengthen meter management processes and implement an Automatic Meter Reading system for capture of billing data, speed to locate and repair leaks, and raising the awareness of NRW and changing the attitudes of water users. These recommendations are currently being piloted.

1.0 Introduction and background

1.1 *Bahrain Location and Demographics*

According to the official census the estimated 2017 population of Bahrain is 1,49 million people. It is expected to reach 2.128 million in 2030, The population growth rate is 7.4% on average. The population is distributed across five Governorates (the Capital Manama, Muharraq, Northern, Central and Southern). Bahrain id very densely populated with 1,627 people per square kilometre which ranks 7th in the world. The climate is characterized by high heat and humidity during the summer, and very mild winters. Average Annual precipitation 70 mm.

1.2 *Water scarcity considerations and Identification of the environment*

Water, as a valuable natural resource, needs to be managed in a sustainable manner, and waste of this resource should always be minimised. Excessive leakage and excessive consumption, especially in areas of water scarcity and drought. Water consumption on a global scale is estimated by the United Nations to increase by up to 30% by 2030, which will lead to an even greater supply gap for countries already facing water stress. With a 'business as usual' approach and average economic growth, demand for water will outnumber known available freshwater resources by 40% in less than 20 years from now. Future demand for water therefore requires a strong focus on efficient water management, operation and not least reduction of NRW.
In the arid Gulf region potable water is expensive to produce with the vast majority of it coming from desalination of seawater. With the removal of water subsidies in the Kingdom of Bahrain, this results in water losses having as high an economic value as anywhere in the World.

Bahrain is located in arid region and characterized by a harsh desert environment with no surface water (rivers or lakes). Its fresh water resources consist of limited quantities of groundwater. It also relies on non-conventional water resources. Bahrain is exposed to the water supply problems if its water service is unwell managed. Water is a scarce resource in Bahrain, and supplies are severely limited. Accordingly reducing and controlling water losses is seen as key to more sustainable water management, and it is attained through the application of a holistic strategies**.** thus Reducing NRW remains the primary concern in Bahrain. Bahrain's Electricity and Water Authority (EWA) chose to reduce its NRW. Thus the Water Distribution Directorate is developing and implementing a comprehensive strategy to reduce both the apparent and real aspect of NRW to 20% over the next 3-4 years. The action plan included implementation of KeyZones, pressure management, active leakage detection and optimisation of operation procedures.

1.3 *Water efficiency and Non-Revenue Water (NRW)*

Water efficiency is the long term ethic of saving water resources through the use of water-saving technologies and practices. A related concept is water conservation, which is more narrowly focused on reducing water loss, waste or use.

NRW is the difference between the quantity of water that enters the water system and the quantity of water that gives revenue to utility. NRW is an important indicator of water distribution efficiency and customers satisfaction. "***A lot of people misconceive that all non-revenue water is due to leaks****, A* ***significant portion of it is actually in the apparent loss category****." (Smith, 2011).*

- NRW = water put into the distribution system - water billed to consumers.
- (NRW) = Physical Losses (Leakage) + Apparent Losses (Billing System).

During last decade large effort was made by many organizations including Bahrain to reduce NRW and water losses, nevertheless NRW level in many countries is not under control and continue to increase. The next section outlines the strategy being taken by EWA in Bahrain to manage NRW more effectively/effeciently and reduce real and apparent losses.

2.0 Strategic approach to reducing and controlling NRW

As documented by (Covas and Ramos. (2014) Leakage reduction and control can only be achieved with the implementation of an integrated leakage control system that includes the identification and the characterisation of leakage in the hydraulic systems, leaks' detection and location, leaks' repair and, finally, the implementation of a continuous monitoring system. In the kingdom of Bahrain the Authority has succeeded in reducing its water losses, by adopting an integrated strategy of action plan through a number of interventions such as leakage detection and repair, pressure reduction, pipe replacement program. This was achieved by a combination of real and apparent loss reduction processes. The strategy selected by EWA in order to address and reduce NRW within their water distribution systems are discussed in following sections. It includes methods, techniques and equipment used currently and emphasizes those more adequate to particular conditions and those with better performance in general cases.

2.1 Real (Leakage) losses Management Practices

Real losses are specified as

- Reported Burst: visible, phoned by customer
- Unreported Burst: non-visible, located during a leak detection survey
- Background leakage: very small; difficult and uneconomic to detect and repair

Real losses can be reduced by speedy response and repair of burst leaks and repair meter leaks, while invisible leaks are detected through active leakage control of waste zones.

Once the topology of the network is known and leakage is assessed, and an economic analysis has proved that the implementation of an organised strategy to reduce leakage is profitable, utility must proceed with its implementation. The first step is to organise the network in different zones or areas and then apply leakage detection and location methods.

As far as leakage/*real (physical) losses* are concerned, numerous contributions have increased our theoretical knowledge. The main activities used to reduce the real losses are: District Metered Areas or (DMA) operation; active leak detection; and pressure management; together with optimised asset management programmes. New tools have been developed over the last decade and performances have been improved year by year leak detection based on; leak noise correlators; leak localising equipment; and mobile or permanent correlating noise loggers. These are frequently linked to IT systems: GIS (Geographical Information System), SCADA (Supervisory Control and data Acquisition System) and internet tools. Real losses can be reduced by speedy response and repair of burst leaks and repair meter leaks, while invisible leaks are detected through active leakage control of waste zones.

2.1.1 District Metered Areas (DMAs) operation

In order to assess the performance of water distribution systems in terms of leaks and troubleshoot water loss in a distribution system., it is necessary to quantify the volume of water entered and consumed in the systems with a certain accuracy. This balance should be implemented by sub zones of the network. Therefore the network should be divided in several zones - District Metered Areas (DMA) - according to the topology and topography

of the system, and the number of consumers. DMA - An Effective Technology to Assess and Reduce the Volume of Real Losses (Covas and Ramos, 2014).

The DMA technique divides the distribution system into smaller, more manageable segments by establishing permanent boundaries. Flow meters are then introduced at strategic locations in each segment (DMA) that allow the manager of the distribution system to monitor flows in specific areas of the network to more effectively determine water loss locations. The implementation of DMAs depends on the complete knowledge of the network in terms of pipe characteristics, location of valves and reservoirs. For the efficient implementation and accomplishment of this task, it should be used a Geographical Information System (GIS) where all the components of the water distribution network would be mapped and characterised.

Bahrain started implementing DMAs in 2013. It is planned to establish 182 all over Bahrain. in all Governorates. 112 (61.5%) DMAs were established. Table 1 below shows the progress in establishing DMAs.

Table 1. DMAs Establishment per Governorate

Governorate	Planned	Established	In progress	Not started
Southern	52	49	3	0
Northern	44	19	25	0
Capital	51	9	10	32
Muharraq	35	35	Completed	
Total No.	182	112	38	32

*2.1.2 Pressure **management An Effective Technology for Real Loss Reduction***

Adequate water pressure is required to distribute water throughout the system and meet customer expectations but, lowering distribution system pressure can minimize leaks. DMAs present an additional opportunity to reduce pressure in each segment of the system, thus reducing the flow rate and frequency of annual pipe bursts. In order to balance these two goals, EWA has installed pressure reducing valves to reduce pressure in areas where it is higher than necessary. EWA also has performance measures requiring it to maintain a minimum water pressure value to ensure customer needs are met. This balanced approach requires careful monitoring and management of the distribution system.

The DMA approach has been working well for WDD in Muharraq and Southern governorates, and the network now has less inspectors dedicated to leak detection because the number of leaks being identified and isolated has risen so quickly. In fact, on one occasion Muharraq found low flow in the system and was able to identify the issue as a product of reduced flow into the system from one of its suppliers. In the past, it may have taken months or more to find the source of a low-flow scenario of this sort, but the segmentation of the network enabled the source to be isolated to a supplier-fed area.

2.1.3 Speedy response and repair of reported leaks within limited time hours

From records, EWA has a service obligation to its customers to repair visible leaks within 6 hours of them being reported. This involves taking action on complaints received from consumers, and dealing with burst or leaking pipes that disrupt water supply. Complaints received by the Customer Service (Call) Centre are submitted to the Maintenance Unit (MU) for them to proceed with repair work and resolve the problem(s) at the very earliest opportunity. The MU is equipped with adequate machinery, tools and equipment, and well trained personnel to ensure that repairs are carried out efficiently and effectively. In 2017, the MU received and attended to several customer complaints (Pipe Leaks Complaints,

Short Water Complaints, and Customers' Water Meter Leaks/defects). EWA aims to resolve 95% of complaints within limited hours and, on average in 2017, over 92% of complaints were resolved within 6 hours. Currently targeting to reduce it within 4hrsTable 2 and Figure 1 below show number of complaints resolved in year 2017.

Table2 Number of complain resolved in 2017

Type of complaint (2017)	*Number*
Visible pipe leak/burst	**20739**
Short water/low pressure	**19066**
Customer water meter leaks	**11935**

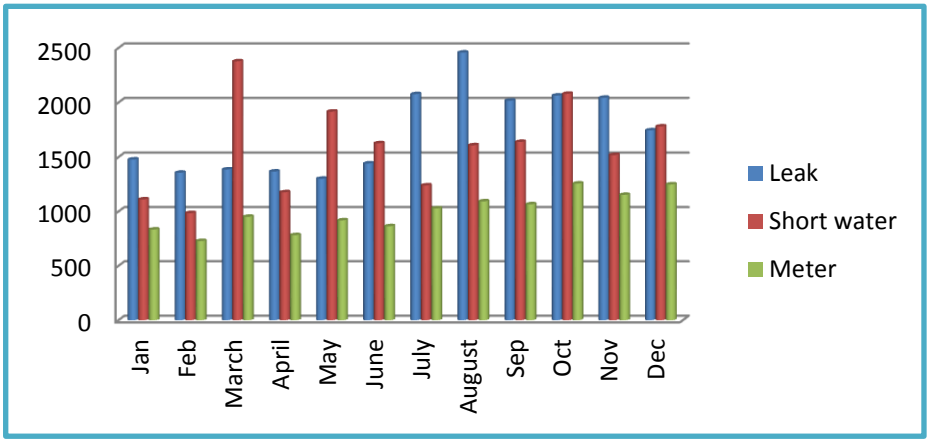

Figure 1. Customer Complains resolved monthly wise in 2017

2.1.4 Improving leak detection and repair programme

A Leakage Detection and Control Group (LDCG) was established in 1985 with responsibility for detecting and repairing unseen leaks. Its employees hold National Qualification Certificates in leak detection. Every year, a planned leakage detection programme surveys DMA established the entire distribution network, using equipment that varies from a simple listening bar to noise loggers, depending on the type and scope of investigation carried out. Figure 2 shows the total leaks identified and repaired during leak detection exercises in each Governorate in 2017.

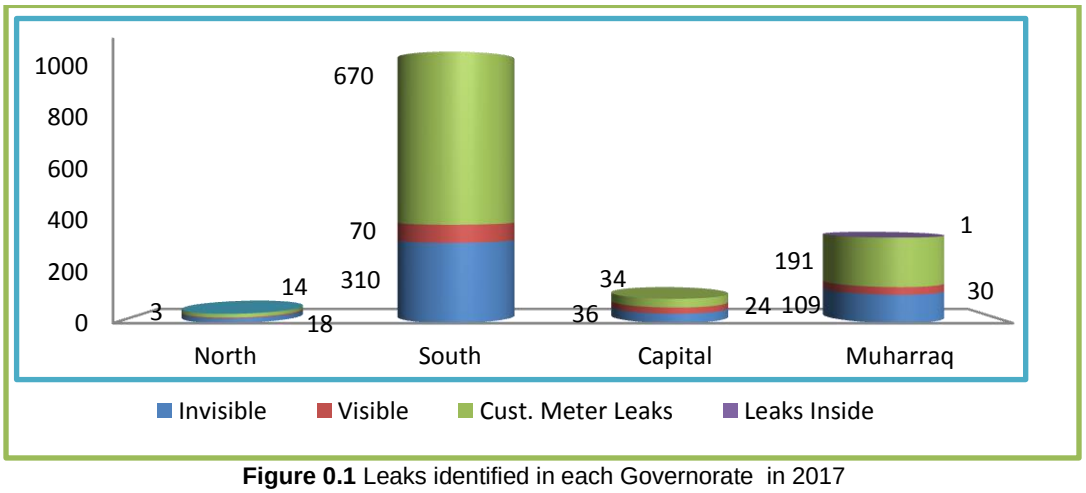

Figure 0.1 Leaks identified in each Governorate in 2017

2.1.5 Avoiding physical losses by minimizing leakages in pipes or valves

Water loss adds significantly to operating costs. Leakages can be caused by leaks in the pipes, valves or joints, e.g. caused by valves that are not drop-tight or have worn-out stem sealing.

Once equipment has been installed below the ground as a part of the distribution system, it is very difficult to control the valves, pipes of or other installations. Thus there is needs to investigate the conditions. In 2017 A total number of 23180 Valves/FH were attended and maintained . Figure 3 below indicates number of Valves/FH attended and maintained per month . While minor pipe replacement due to repeated leaks is shown in Figure 4

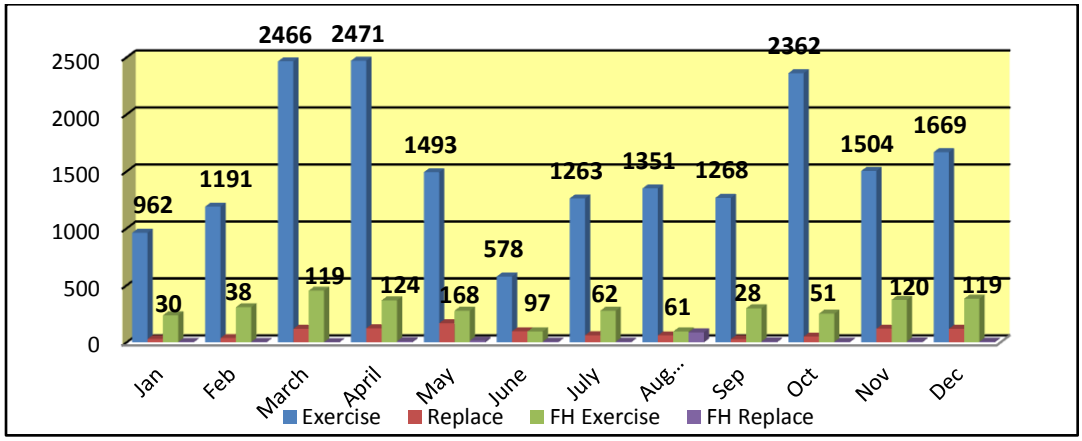

Figure 3 Number of valves and FH maintained/replace per month in 2017

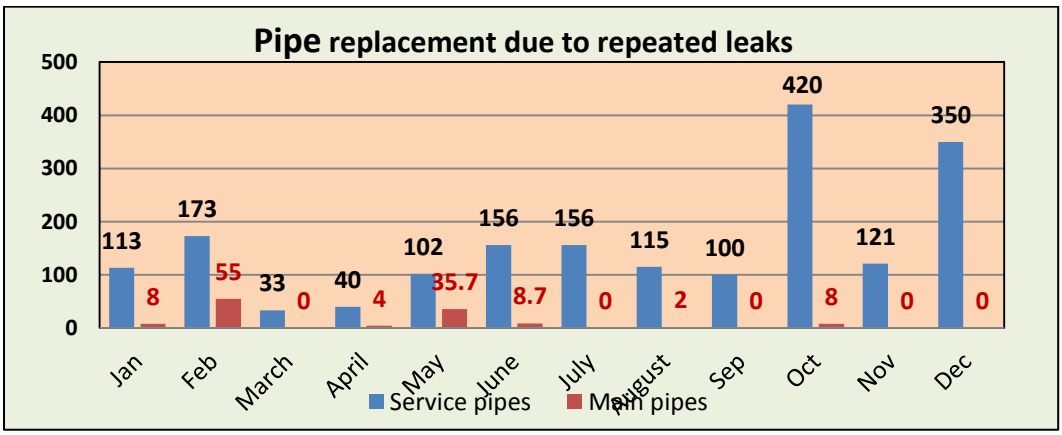

Figure 4 Pipe replacement due to repeated leak in the service pipe and main pipe

.2.2 *Apparent loss reduction*

The activities used to reduce *apparent (commercial/administrative)* losses include: efficient customer management; customer meter maintenance and replacement, and the introduction of measures to fight unauthorized consumption. New techniques and equipment have also been developed to address the apparent losses: improved accuracy of water meters; automatic meter reading; and ever-better performing software to manage meters, customers and water consumption altogether.

However, these techniques and tools can produce good results only when they are used within the framework of an effective and efficient action planning process - based on a holistic approach combining the various tools and techniques.

2.2.1 *Reducing water loss with accurate metering*

Metering is the most essential capability that a drinking water system needs to obtain in order to have an understanding of how much water the system uses and loses. Meters

need to be calibrated and in good repair to provide accurate data. Age and damage to meters can lead to deterioration and incorrect readings, making it difficult to detect leakage.
Stopped, inaccessible and buried water meters lead to consumption estimations; and inaccuracies in registering water usage occur with meters that are blocked or damaged, and those that do not record flows accurately because they have exceed their recommended economic life-spans. Damages to meters may be caused either by water quality deficiencies or vandalism. More efficient data collection and reporting (during meter reading cycles) and a structured meter replacement programme would considerably minimize commercial losses, by minimising estimation or under-recording of flows. Meter Replacement plan is one of the action which reduce commercial loss in water distribution network.
EWA has a policy to replace stopped meter, replace all aged 12 mm domestic meters every six years, and relocate buried meter. Table 3 shows meter maintenance carried out in 2017.

Table 3 Meter maintenance carried out in 2017

Nature of work	Year 2017
Meters replaced due to stoppage	60524
Meters removed	1183
Relocating Buried meter	1352

EWA started meter reading outsourcing as one of the solutions for tackling this issue, in order to improve billing and revenue collection. In addition to relocate buried meters. Another solution is GSM loggers Automatic Meter Reading **(AMR)** systems for non-accessible areas (8 fixed at the customer bulk meters for evaluation) as recommended by EPA, (2010). AMR is a technology that automatically collects data from the meter and transfers it to a central database for analysing and billing.

WDD has implemented Advanced Metering Infrastructure (AMI) in Galali Block 254 in 2015. Later in the year 2016, an interface between the AMI (Izarnet) and CSS software for direct automatic of meter reading to customer bills has been created.
Towards the national strategic plan of implementing smart cities, EWA has put a plan for Implementing WDD A Advanced Metering Infrastructure (AMI) all over the Kingdom of Bahrain for a period of 2015-2020. the plan comprises of four main stages, based on the kingdom Governorates. The first stage is to implement WDD AMI in Muharraq Governorate (meter replacement and Automatic Meter Reading (AMR) network. In regard with replacing the mechanical meters to smart meters in the suggested Muharraq area. Figure 5 shows that the highest replacement is in the 50 mm (2”), however, nil numbers of replacement in above 2” meters were found. Figure 5 indicates percentage of maintained and Replaced meter in Muharraq.

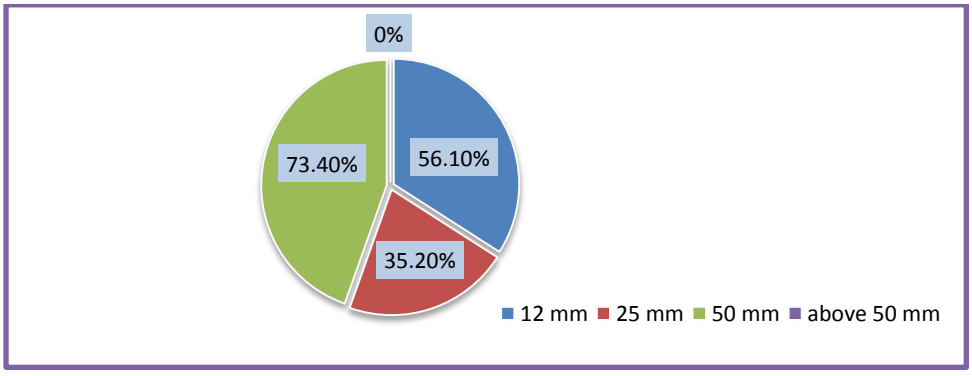

Figure 5. Maintenance Replacement Program Summary 2017 Muharraq Governorate

2.2.2 Minimize and eliminate illegal connection and unauthorised use

The Leakage Detection Unit was also given responsibility to detect illegal connections,. reported illegal connections, illlegal pumps,abandoned connecions, customer meter defects cases & connections with no meters. These were found in the exercised & patrolling areas during the customer meter inspection process. Figure 6 Below shows the total illegal connections, illegal pumps, abandoned connections, meter defect cases and connections with no meters reported per governorat in 2017. Recently there is a team responsible for direct survey.

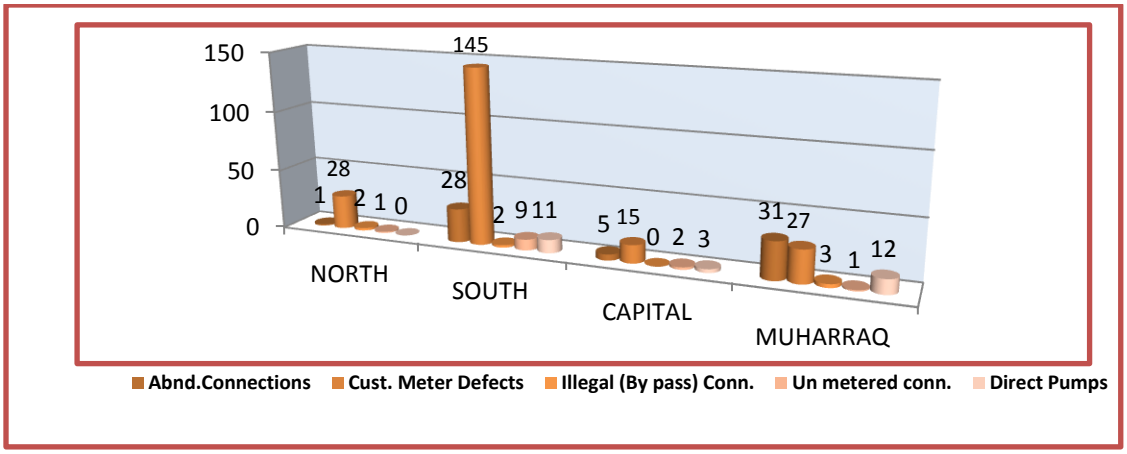

Figure 6. Customer Connections Defects Reported in each Governorate in 2017

It is apparent that the quality of installed components or equipment (pipes, valves, pumps and meters etc.) plays a key factor in reducing real water losses. An important argument for choosing high quality products is the Total Cost of Ownership. Since replacements and repairs are often far more expensive than the product itself, the expected operating costs and lifespan of installed products should be included in the selection criteria of the tendering process.

2.3 *Continuous monitoring of the water distribution system*

An efficient management of a water distribution system and leakage control requires the implementation of a continuous monitoring system of network. The basic idea is to associate the presented strategy to reduce leakage to a SCADA system (Supervisory Control and Data Acquisition), with measurements of head and flow in several sections of the network, defined by the DMAs, allowing the supervision and permanent control of the network, in terms of leakage evolution occurrence of new ruptures, consumption variation, conservation of pipes and operating control of other hydraulic devices.
Since leakage phenomenon increases gradually in time, it is necessary to keep active a continuous monitoring system of control, detection and location that overcomes this natural increase. It must include several phases - detection and control, approximated location, accurate location and repair - each of whom has several alternatives and different equipment available.

2.3.1 Smart asset management

As well as faster leak awareness time and 'find and fix' times, accurate records of underground assets are crucial for driving down leakage to lower levels. This means faster awareness times - identifying leaks as they propagate - but how quickly can you become aware of a leak? The latest technologies available today introduce the 'smart' concept to the management of buried assets, both today and into the future. This system enable utilities to: monitor and diagnose problems remotely; prioritize and manage maintenance issues; and use data to optimize all aspects of a water distribution network.

2.3.2 Water distribution system modelling and smart grid technology

In order to study how information and technology can be used to improve water management, smart grid technologies were introduced into the water industry. The integrated system is a powerful tool for routine planning and emergency response and also for remote leakage detection and prediction of pipe burst. The capabilities of the integrated system can greatly assist in the decision making processes for network asset inventory, rehabilitation requirements, and financial planning.

2.4 Training and Knowledge transfer

A comprehensive re-evaluation of the water utility's priorities as well as support and full understanding of the importance of NRW reduction from the management level and all the way down in the organization is needed. The technical staff in EAW are participating in seminars and workshop related to water loss, give presentation at EWA training Centre for other staff. They also receive training in how to use new tools like GIS, hydraulic models, leakage monitoring systems, noise loggers and smart meters.
Conducting Weekly directorate presentation about activities carried out by each department within WDD for the staff. Hand-on experience with leak detection at the training Centre.
The technical staff are receiving training in how to use new tools like GIS, hydraulic models, leakage monitoring systems, noise loggers and smart meters. The training programme should include staff at all levels and be tailored to the specific needs of the different work functions.

2.5 Balance Score Card (KPI) Implementation

Strategy map for WDD is finalized in line with the EWA corporate strategy indicating various objectives under the heads of 4 major themes. WDD took major initiatives to reduce NRW such as Introducing Key Performance Indictor for NRW management and control at cooperate and directorate levels.
There are four KPI measures for the directorate level dealing with NRW; Percentage Proactive leakage detection and repair; physical loss, performance of service order, and percentage of NRW. Other measures are understudy.

1. To maintain and replace 1800 valves per month
2. To repair ;leaks within 6hrs
3. Replace defective meter
4. Real losses per Dam in L/P/H

2.6 High-quality materials ensures long lifetime

By choosing high-quality shut-off valves, leakages from the valve itself can be avoided. Gate valves with high-quality gasket of rubber ensure that the valves are 100% drop-tight. Regularly revise Material specification is required

2.7 Results

As indicated earlier that efficiency of network is measure by low level of BRW. By implementing the strategy activities it was managed to reduce NRW and improved water efficiency. Author carried out analysis s evaluating each measure on the efficiency. The overall NRW efficiency was 3.2 that indicates utility is doing quite well improved water efficiency. Figure 7 below shows the overall NRW efficiency by evaluating each measure in strategy implemented

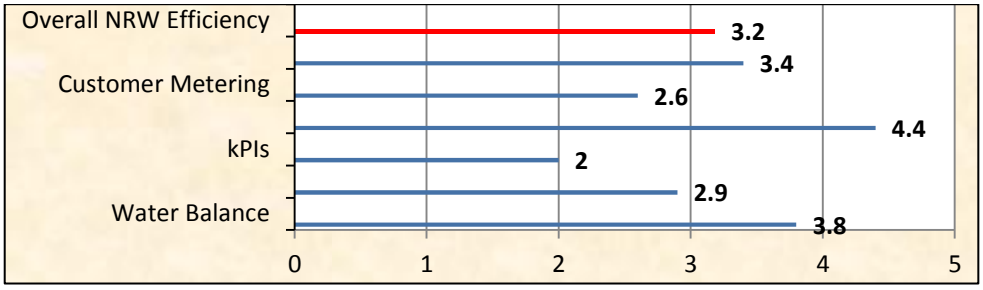

Figure 7 Overall NRW Efficiency

NRW rating	Efficiency Performance Category and Relevant Action Needed
Less than 2	Highly inefficient use of resources, NRW reduction programs
2 to 3	Poor NRW performance, intensify actions to reduce NRW
3 to 4	**Potential for further improvements through focused actions**
4 and above	Potential for further improvements through focused actions

2.8 Conclusions and recommendation

- Strategies need to be based on true facts rather than fictional information
- The situation of NRW and associated water loss is one that will never go away.
- Revenue meters will under-record with time resulting in revenue loss and distorting water balance calculations.
- Implementation of NRW reduction schemes is only the first step.wstabkishing DMAs is second step
- Apparent losses component of NRW is the major factor affecting NRW, especially related to meter accuracy and illegal connection.
- NRW is global problem, if no action is taken it will generate water war among regions.
- Continue with both leak detection and apparent losses elimination activities.

It is recommended to

- Assess status of existing distribution networks and replace the old sub-mains as necessary.
- Use of state of the art materials, snd Revise specification of equipment (pumps, meters etc.).
- Ensure rigid legislations for illegal connects.
- Introduce high technologies for leak detection, training of staff.
- Increase awareness on the impact of non-revenue internally and externally.
- Introduce NRW benchmark that is applicable to the Arab region.

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