# WATER DEMAND MANAGEMENT:

## A Case Study of the Kingdom of Bahrain

**By**

**Hana Husain Al-Maskati, BSc (Eng), MSc (Eng)**

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**Department of Civil and Building Engineering**

# Dedication

## *This thesis is dedicated*

To my late mother **Layla Ebrahim Al-Arayedh**, on the tenth anniversary of her demise, for her special care and love to me from birth, through to maturity; and for her inspiration in the reminder of my journey of life;

**And**

To my late father **Husain Mahdi Al-Maskati** on the first anniversary of his demise, for his support without his encouragement it would not have been completed.

**Hana Al-Maskati**

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# Abstract

This research used an Integrated Water Resource Management approach to investigate how Water Demand Management (WDM) measures at government, utility and end-user levels could contribute to providing sustainable water supply to Bahrain, which is in an arid to semiarid region.

The main driver for this research was the supply-driven orientation favoured by policy makers and practitioners in Bahrain with little consideration for demand management. This leads to a high estimated gross per capita consumption 525 l/c/d as of 2010. There was also a need to investigate the institutional environment for managing water resources and delivering sustainable water supply to Bahrain.

The research adopted a case study methodology which included qualitative analysis of interviews and documents from the water authority, and quantitative analysis of questionnaire surveys and pilot studies. The research adopted a cross-sectional approach to the analysis of activities associated with WDM practice in Bahrain. All findings and conclusions were evaluated/validated using surveys distributed to water experts and customers. Based on their feedback, findings and conclusions were revised.

The main finding of this research was that the tariff is highly subsidized by the government and there is no encouragement for water savings. The low tariff leads to low revenue which in turn affects the budget allocated to the relevant departments and units at the Electricity and Water Authority (EWA). This impacts negatively on their activities. It was found that there is no effective strategy for integrated water resources management; there is a high level of Non Revenue Water (NRW) (38%); and limited reuse of grey water and water use saving devices. In addition there is a lack of public awareness and understanding of the benefits of WDM among all levels of society including professionals and water supply providers.

The research concluded that improving water use efficiency in Bahrain should be a priority due to the current high water supply costs. There is a need for proper legislation that enforces the use of WDM; establishment of a national WDM committee with the Water Resources Directorate, and for water resource professionals to follow WDM oriented policies. The research proposed six areas to be further investigated to achieve more efficient use of water: (a) Water tariff reform to recover full water supply costs; (b) institutional reform through activating and enforcing Water Resources Council roles; (c) promoting public awareness about WDM and its benefits; (d) reducing non revenue water; (e) applying positive economic sliding scale incentives for customers who reduce their water consumption; and (f) enhancing public participation at all water planning and management stages.

**Keywords**: Tariff, Bahrain, water demand management, water bylaw, water legislation, leak detection, water reuse, water management.

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# List of Acronyms, Abbreviations and Units of Measurement

| | |
|---|---|
| CIO | Central Information Organisation |
| CSO | Central Statistical Organisation |
| EDB | Economic Development Board |
| EMR | Eastern Mediterranean Region |
| ETs | Electronic Taps |
| EWA | Electricity and Water Authority |
| GCC | Gulf Cooperation Council |
| GDP | Gross Domestic Product |
| GW | Groundwater |
| IBT | Increasing Block Tariff |
| ILI | Infrastructure Leakage Index |
| IRP | Integrated Resources Planning |
| IUWRM | Integrated Urban Water Resources Management |
| IWA | International Water Association |
| IWRM | Integrated Water Resources Management |
| LFC | Low Flow Control device |
| LLI | Linear Leakage Index |
| MAA | Ministry of Municipalities and Agriculture Affairs |
| MENA | Middle East and North Africa |
| MEW | Ministry of Electricity and Water |
| MOW | Ministry of Works |
| MSF | Multistage flash |
| NGOs | Non-Governmental Organisations |
| NRW | Non Revenue Water |
| RO | Reverse Osmosis |
| TDS | Total Dissolved Solids |
| TSE | Treated sewage Effluent |
| UAE | the United Arab Emirates |
| UARL | Unavoidable Annual Real Loss |
| UFRs | Unmeasured-Flow reducers |
| VIC | Very Important Customer |
| WCD | Water Conservation Department |
| WDD | Water Distribution Directorate |
| WDM | Water Demand Management |
| WDMI | Water Demand Management Instruments |
| WDMM | Water Demand Management Measures |
| WM | Water Meter |
| WPCC | Water Pollution Control Centre (Tubli) |
| WRC | Water Resources Council |
| WRS | Water Resources System |
| WSM | Water Supply Management |
| WSSD | World Summit on Sustainable Development |
| WTD | Water Transmission Directorate |

## Units of Measurement

| | |
|---|---|
| BD | Bahraini Dinar |
| BD/month | Bahraini Dinars/month |
| l/c/d | litre per capita per day |
| $m^3$/c/y | metres cube per capita per year |
| $m^3$/d | metres cube per day |
| $m^3$/month | Metres cube per month |
| mg/l | milligram per litre |
| MGD | Million Gallons per day |
| ML/d | Megalitres/day |
| Ml/day | millilitres per day |
| Mm | mega-metres |
| Mm | millimetres |
| $Mm^3$ | Million Cubic Metres |
| $Mm^3$/y | Million meter cube per year |

## Unit Currency

| | | |
|---|---|---|
| 1BD | = | 1000 Fills |
| 1£ | = | 0.6 BD |
| 1US$ | = | 0.378 BD |

# Chapter 1: Introduction and Background to the Research

## 1.1 Introduction

Water is one of the most valuable resources on earth and its availability differs from one region to another (Gibbons, 2007). It is a vital resource in socio-economic development and for supporting the ecosystem. Arid and semi-arid regions are particularly likely to experience water shortages if the water infrastructure and management are poor.

Bahrain is a member of the arid to semi-arid six Gulf Cooperation Council (GCC) countries. The GCC includes the United Arab Emirates (UAE), Bahrain, Saudi Arabia, Oman, Qatar and Kuwait. The GCC countries are facing the most severe water shortages in the world (ACSAD, 2000) (for details, see Table 1.1).

Water is a scarce resource in the Gulf region, and supplies are already severely limited. Maintenance and improvement of water services are challenges which must be urgently addressed. Fortunately, the region has the financial resources and the ability to turn these challenges into opportunities for economic growth and expansion.

For many years the GCC countries have responded to increase in demand for water increase by increasing water supplies. Unfortunately, this approach has been unable to cope with the continuous increase in water demand as a result of the sharp increase in the socio-economic situation of the region in the last few decades since the available renewable water resources are limited.

The average annual renewable water availability per capita in the GCC countries is about 1200 $m^3$. There are, however, huge differences of endowment in the wider region, ranging from less than 50 $m^3$ in Kuwait up to 5000 $m^3$ in Iraq (Bakir, 2003). Water shortage occurs when a country has 1000 $m^3$ or less of per capita per year in renewable resources (ESCWA, 2005, cited in Rosegrant, 1997), and becomes even worse when combined with high population growth.

**Table 1.1:** Water stress levels in some countries in the Arab Region

| Level of Water Stress ($m^3$/ Capita) | Stress level |
|---|---|
| 1,700 – 3,000 | Iraq |
| 1,000 - 1,700 | **Mild Water Stress Situation**<br>Syria |
| 500 – 1,000 | **Severe Water Shortage**<br>Lebanon, Egypt, Oman |
| 200 – 500 | **Critical Water Shortage**<br>Saudi Arabia, Yemen, Palestine |
| <200 | **Acute Shortage**<br>Bahrain, Jordan, UAE, Qatar, Kuwait |

Source: adapted from ESCWA, (2005)

The increase in population is putting much pressure on the water resources in GCC countries in the absence of measures to minimise consumption, forcing them to expand existing desalination plants and set up new desalination units (Al Sharhan and Wood, 2003). Es'haqi and Al-Khaddar (2008) reported that GCC countries are already consuming more than 100% of their renewable resources.

In order to address water problems, Bahrain followed the same approach of other GCC countries by developing more technologies in desalination of sea water that aim at increasing the volume of available water resources. Also, Bahrain increased substantially the abstraction from groundwater resources to meet the ever-increasing agricultural demands. Also, treated wastewater was used as an option for irrigation. However, it was realised later by the Electricity and Water Authority (EWA) that this approach led to many problems (explained later in this Chapter) and an imminent need for integrated water resources management in order to solve Bahrain's water resources problems, was brought to attention.

This Chapter sets out the background of the thesis and introduces the general subject domain. It then leads on to the research aim and develops research questions and a summary of the methodology adopted. Finally, a summary of the chapters is provided in order to illustrate the content, logic and structure of the thesis.

## 1.2 Status of water resources and demand

The challenge of water management the world over is enormous and growing more daunting with each passing year. Arlosoroff (1998) stated that population growth is generally occurring in developing countries and the increase is mainly in the urban centres of these countries, especially the Asian urban centres. In 1995, twenty-nine countries with populations totalling 436 million experienced water stress/scarcity (Abdel-Dayem, 2000). The World Bank estimates that by 2025 about forty-eight countries will experience water stress, and the population affected will rise to 1.4 billion. Furthermore, an estimated three (3) billion people will be living in water-stressed countries by 2035 (Abdel-Dayem, 2000).

As explained in section 1.1, the six countries (including Bahrain) of the GCC are now suffering from a water gap between renewable water resources and current water demand, which is estimated to approach fifteen billion cubic metres a year in total. The demand is normally met through supplies from costly desalination plants and other resources (Al-Mugrin, 2004). The gap is a result of the rapid increase in the population, along with social, agricultural and industrial development, and has thus resulted in a substantial increase in water demand, and has put great pressure on the region's limited water resources.

Demands in GCC countries are being satisfied by the development of groundwater, (91%), construction and expansion of desalination plants (7%), expansion in wastewater treatment and reuse (2%), in addition to the construction of dams to collect, store and utilise run-off (Zubari, 2004a; Abdul Rahman 2005). However, groundwater resources are being over-exploited to meet mainly agricultural water demand, with continuous deterioration in quantity and quality (Abdul Rahman 2005). In most of the countries, unplanned groundwater mining continues without a clear 'exit' strategy to limit groundwater abstraction. To meet domestic water supply requirements, GCC countries have turned to desalination and have become collectively the world leaders in desalination, with more than 50% of the world production capacity (Abdul Rahman 2005). Desalination remains, however, capital-intensive and costly. In terms of wastewater recycling, available treated wastewaters are still not being reused to their full potential; planning for full utilisation of treated effluent is in the early

stages (Zubari, 2004a). Table 1.2 summarises the used water resources, water consumption, and groundwater dependency in the GCC countries.

**Table 1.2:** Summary of Water Resources used, Water Consumption, and Groundwater Dependency in the GCC Countries (in $Mm^3$/year)

| Country | Sustainable Conventional Water Resources | | Non-Conventional Water Resources | | Total Renewable and non conventional | Water Consumption | | | | | Utilisation (%) | Groundwater dependency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface Water | Natural Groundwater recharge | Desalinated water | Wastewater and Drainage reuse | | Surface water | Natural Groundwater use | Desalinated water | Wastewater and Drainage reuse | Total Renewable and non convention | | |
| Bahrain | 0 | 127 | 119 | 15.2 | 261.2 | 0 | 258 | 119 | 15.2 | 392.2 | 150.15 | 65.78 |
| Kuwait | 0.1 | 160 | 345 | 52 | 557.1 | 0.1 | 405 | 345 | 52 | 802.1 | 143.98 | 50.49 |
| Oman | 918 | 550 | 86 | 23 | 1577 | 918 | 1644 | 86 | 23 | 2671 | 169.37 | 61.55 |
| Qatar | 1.4 | 85 | 131 | 0 | 217.4 | 1.4 | 185 | 131 | 0 | 317.4 | 146.00 | 58.29 |
| Saudi Arabia | 5000 | 3000 | 1050 | 400 | 9450 | 5000 | 14430 | 1050 | 400 | 20880 | 220.95 | 69.11 |
| United Arab Emirates | 190 | 129 | 1008 | 234.5 | 1561.5 | 190 | 900 | 1008 | 234.5 | 2332.5 | 149.38 | 38.59 |
| Total | 6109.5 | 4051 | 2739 | 724.7 | 13624.2 | 6109.5 | 17822 | 2739 | 724.7 | 27395.2 | 201.08 | 65.06 |

Source: Adopted from ESCWA, (2005)

It can be seen that Bahrain suffers from an unsustainable water situation. Bahrain consumes from groundwater resources 258 $Mm^3$/year, more than twice the amount of water recharge to aquifers (127 $Mm^3$/year). This means that there is an urgent need to develop water demand management through a holistic manner.

## 1.3 Research background

### *1.3.1 Problem statement*

Supply and demand estimates for water resources in Bahrain indicated a deficit of 110 $Mm^3$ in the year 2000. Consequently, it is important that proper management and vital action is taken to help balance the supply-demand equilibrium and control water quality deterioration. The Kingdom of Bahrain comprises an archipelago of forty islands and shoals located in the Arabian Gulf, with a total area (in year 2010) of about 760 $km^2$ distributed over the forty

islands. Bahrain does not have land boundaries with other countries and has about 161 kilometres of coastline. Bahrain is generally flat comprising a low desert plain rising gently to a low central escarpment with the highest point at Jabal Al-Dukhan at 122 meters in height. The soils are shallow to moderate in depth (CIO, 2007; Al-Masri, 2010).

Bahrain's overall climate is arid, with hot summers and relatively warm winters. The average rainfall is less than 100 mm per year with high evaporation rates, with peaks of over 10 mm/day (Al-Masri, 2010; Al Ansari, 2004). The combination of low rainfall and high evaporation creates impossible conditions for perennial surface water to exist.

The total population of Bahrain was 1.234 million people in the year 2010, with a relatively high population density of about 1,388 inhabitants per square kilometre; it is one of the world's most densely populated countries (Al-Masri, 2010). Bahrain has experienced high rates of population growth and urbanization since the early 1960s following the sudden increase in the country's oil revenues, thus leading to a rapid increase in its economic base and an improvement in the standards of living (Al-Masri, 2010; CIO, 2008). This has exerted immense pressure on its limited natural resources, including the country's freshwater resources. Owing to its small size, the kingdom experiences mixed development with industrial areas being located close to residential areas. In 2002 the total area of the islands of Bahrain increased to 720 $km^2$, after land reclamation, and there has been a decrease of 42 $km^2$ of agricultural land owing to residential development in the central part of the country (Abdul Ghaffar, 2004). However, in the year 2008 the total area of the island increased to 757.5 $km^2$ (CIO, 2008)

Desalinated water has become a major component of the supplied water in Bahrain. The country's water requirements, amounting to about 392.2 $Mm^3/y$ (refer to Table 1.2), are met mainly through groundwater abstraction (65.8%) and desalination plants (30.3%), and to a lesser extent by treated wastewater (3.9%) (ESCWA, 2005). Inefficient water resource management is another important factor that adds to water shortages and it limits available supplies.

For the Kingdom of Bahrain, the case study country for this research, the present range of problems related to water is extensive and the disparity between water supply and demand is growing with time. The overall water problems can be attributed to the following difficulties:

1. Bahrain is characterised by a harsh desert environment with no rivers or lakes. Its fresh water resources consist of limited quantities of groundwater. It also relies on non-conventional water resources (desalination and reclaimed wastewater) (Al-Masri, 2010; Al Ansari and Al Hammadi, 2005). Therefore, Bahrain suffers from scarcity of water resources.
2. It receives an average rainfall of less than 100 mm per year (Al Ansari, 2004).
3. The imbalance between water demand and the limited water resources is increasing in the municipal sector. Measures need to be taken in order to limit and minimise groundwater abstraction (MEW, 2005) as Bahrain is already consuming twice the amount of the annual recharge to the aquifers. The available water resources are deteriorating in quality (Al-Masri, 2010). Bahrain is an island; it means, when groundwater is abstracted in volumes greater than the sustainable yield of aquifers, saltwater will invade the aquifers as a result of considerable decline in the groundwater levels. Bahrain used to enjoy a number of freshwater springs but they are now completely dry. This means that Bahrain has developed its water resources to meet the increasing demand at the expense of protecting these water resources from salinity and pollution problems.
4. Water demand management has been completely absent from the development plans. The per capita consumption in Bahrain increased to 500 litres per day as a result of the economic growth, high leakage in the water supply systems and a weak tariff system. Limited consideration has been given to controlling the demand. The level of awareness about the value of water is another reason for high consumption rates. The agricultural sector consumes most of the available water resources and there are no policies to control agricultural water use despite the fact that Bahrain is not considered an agricultural country. Many scientists (Al-Masri, 2008b) have reported that there is no sustainable future for agriculture in Bahrain. In some cases agricultural wells were drilled with the financial support of the government.

5. There is a lack of awareness in the public sector, of the need for the rational use and management of water resources. Water shortages are further compounded because water is often used wastefully, unwisely and inefficiently (A-lNoami, 2004; Al-Masri, 2010). Efficient water use was also not observed in the development plans.
6. Existing water legislation is not enforced effectively (Al-Alawi and Abdulrazzak, 1994; Al-Masri, 2010).
7. Fragmented water institution policies have encouraged the development of one economic sector without regard to the consequent effect on other sectors (Al-Masri, 2010; Es'haqi and Al-Khaddar, 2008; Al-Noami, 2004; Al-Mansoor, 1999). There are a number of governmental bodies in charge of water resources development and management. These bodies lack coordination among themselves and it is not clear who does what.
8. Non-Revenue Water (NRW) in Bahrain is relatively high compared with other countries, currently at 45.03 $Mm^3$/ year 367.08 $m^3$/connection/ annum, 1005.7 l/connection/hr, 28.87% (Al-Maskati, 2005).

In summary, *the development and management of Bahrain's water resources is not sustainable, as it does not take into consideration, the environmental, social and economic impacts. Bahrain is increasingly dependent on water extracted from the groundwater aquifer, leading to a raising deficit between abstraction and recharge rates.* This situation is environmentally unstainable.

## 1.4 Aim, and research questions

### *1.4.1 Aim*

The subject of this study is Water Demand Management (WDM) in Bahrain. As explained earlier and in order to overcome the sharp increase in water demand and high level of non-revenue water (NRW), and further enhance demand control measures and users' responsiveness, WDM strategies should be a management option for the imbalance between water demand and available water resources in Bahrain. The overall aim of this research is to "**evaluate the effect of Water Demand Management (WDM) measures in**

**achieving a sustainable water supply for Bahrain.”**. This aim is further translated to research questions to be answered as explained in the following section.

### *1.4.2 Research questions*

In order to achieve the above mentioned aim, the following research questions are represented as the core of the work in this thesis:

1. How can WDM measures taken at the **utility level** contribute in providing a sustainable water supply for Bahrain?
2. How can WDM measures taken at the **household level** contribute in providing a sustainable water supply for Bahrain?
3. How can WDM measures taken at the **non-domestic consumers level** contribute in providing a sustainable water supply for Bahrain?
4. How can WDM measures taken at the **government policy level** contribute in providing a sustainable water supply for Bahrain?

In order to answer the research questions, the following issues are further investigated:

1. Current practices of water resources management in Bahrain.
2. Reviewing international experience in the field of WDM, in order to identify what WDM measures can be applied in Bahrain.
3. Identification of WDM activities and associated problems in Bahrain.
4. Evaluation of the public awareness at household and industrial levels with regard to usage of water saving devices, and the need for water tariff reform and on water conservation, through surveys.
5. Investigating the willingness of corporations to use recycling water in industry.

## *1.5* Justification for the research

The researcher has reviewed recent literature that discusses Water Demand Management (WDM) application in Bahrain and found that, to date, there has been no discussion or proper application in relation to WDM that takes into consideration economic, institutional

and technical aspects. Also, the researcher found that WDM measures were not included properly in the national strategies of Bahrain. This current research includes the following original aspects:

- Assessment of public opinions, on water supply issues in Bahrain, using a questionnaire. It is believed that this has not been adequately addressed in the past.
- Assessment of industry owners on water supply issues in Bahrain, using questionnaires which has not been addressed before.
- This study places an emphasis on important items such as low water tariff, high per capita consumption, limited fresh water resources in Bahrain, and high Non Revenue Water (NRW).

The researcher believes that this research is justified in order to fill the gaps since no combination of WDM measures at different levels has been considered in Bahrain. Also, Bahrain has limited freshwater resources and the country needs every drop of water. In combining WDM measures the researcher will try to assess the contribution of these for sustainable management of the available water resources in Bahrain. In addition, using Bahrain as a case study provides a strong example because the kingdom does not share resources with other countries in the GCC i.e. there are no cross-border aquifers. Finally, the results of this research will be made available to the Bahraini water utilities, in order to consider incorporating these findings into the WDM strategies in Bahrain.

## 1.6 Brief summary of research strategy and methods

In order to achieve the research questions outlined in section 1.4, the research strategy adopted was a single case study. A suitable research methodology was developed and utilised as follows:

(1) At first literature review was conducted. This review included relevant official and non-official documents, reports and publications. This review helped to identify water demand management problems in Bahrain as reported by different officials and researchers in this field. An understanding of the population of Bahrain and important aspects that have both direct and indirect influences on the attitudes, habits and lifestyle of the population were studied and described. This understanding was

essential in order to adequately study the country's water resource demand trends and the consumption patterns of urban areas. An overview of Bahrain's water resources and consumption patterns was also provided in this literature review.

(2) Interviews and questionnaires: 18 in-depth semi-structured interviews with key staff from relevant units and departments of the Electricity and Water Authority (EWA) of Bahrain were conducted. The chosen staff members are involved in WDM-related activities. Standardised questionnaire surveys of householders and industries were then designed and distributed and the feedback was collected and analysed. Specifically, six hundred (600) householder questionnaires and thirty four (34) industrial questionnaires were issued and the feedback was analysed. The response rates were ninety percent (90%) and one hundred percent (100%) for the householders and industries respectively.

(3) Pilot tests were also carried out related to water saving measures. These included the use of Low Flow Control (LFC) devices in assessing meter under-registration at low flow rates. Also leakage assessment was carried out by using Infrastructure Leakage Index (ILI) and Linear Leakage (LLI) performance indicators.

(4) The above steps then led to a careful analytical study of the water supply system in Bahrain taking into consideration the limited available water resources to meet increases in water demand, and the current high percentage of non revenue water (NRW). This further enhanced demand control measures and user responsiveness. In this study WDM measures were evaluated to study how they could contribute to reducing water demand and achieving full cost recovery. The analysis of this study covered a variety of options for each research question mentioned in section 1.4.2.

(5) The results of the research findings and conclusions were validated using questionnaires distributed to water experts.

Finally, significant findings were identified regarding the various aspects of this research, including the overall conclusions, limitations, recommendations and implications for future research. Figure 1.1 provides a summary of the thesis structure.

The detailed research strategy, methods and design are further elaborated in chapter 4.

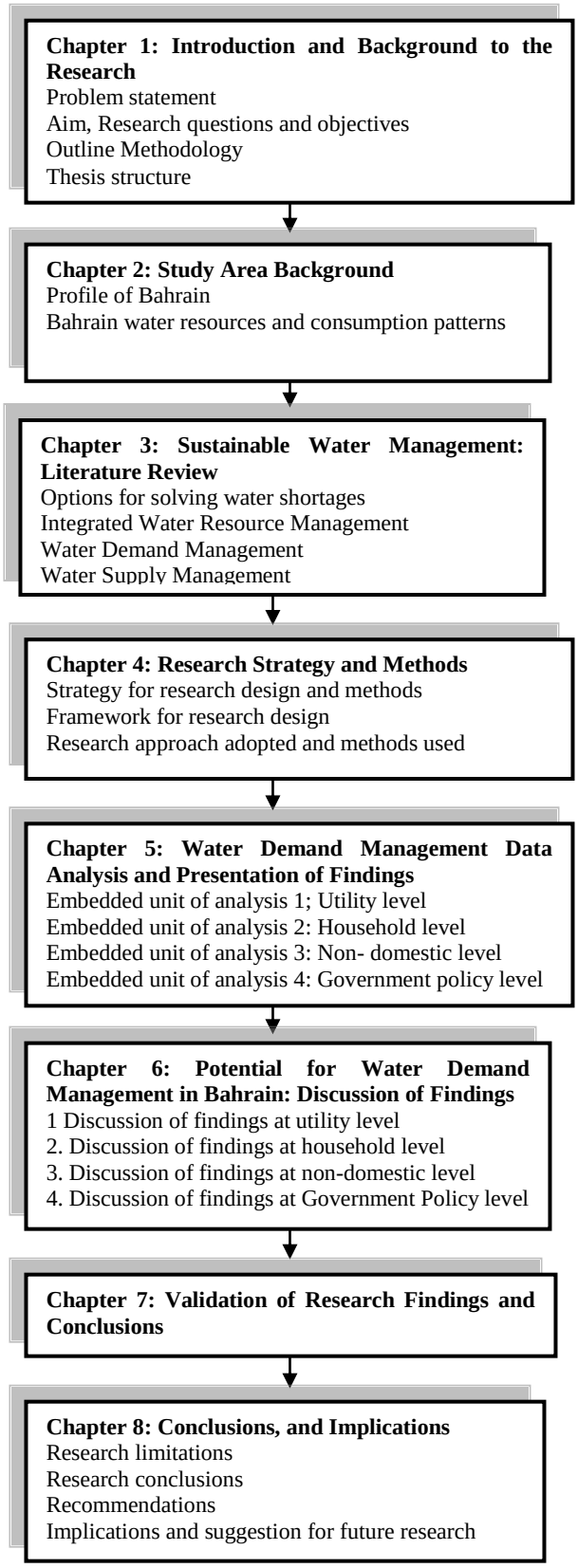


**Figure 1.1** Thesis Structure

## 1.7 Key contributions to knowledge, policy and practice

The research has succeeded in achieving the aims and research questions set out in Section 1.4. The main research contributions to knowledge and policy are as follows:

- This is one of the few studies that empirically examined the use of Low Flow Control (LFC) devices in assessing meter under-registration at low flow rates in water supply systems.
- This research employed a top down methodology that looked at both service providers as well as end-users.
- Using Bahrain as a case study provides a unique example because the kingdom does not share resources with other countries in the GCC and has no surface water sources. For example, there are no cross-border aquifers. The findings add to the existing knowledge by extending generalisations from the Kingdom of Bahrain to other GCC countries.
- The research extends the knowledge on the application of the use of Infrastructure Leakage Index (ILI) performance indicators in prioritising zones for leakage detection exercises to control leakage in the distribution network.
- It is important for countries with limited water resources, high per capita consumption, and highly subsidized water supply to reform their water tariff to recover operation and maintenance cost. For the water to work effectively as an economic measure for WDM, it should be designed so that it is water conserving.
- This study demonstrated the use of grey water from mosques and health centre pools as additional source of water to irrigate surrounding areas and to save potable water for other uses.

## 1.8 Delimitations of the scope of research

The scope of this study focused solely on water from a municipal water supply supplied by Electricity and Water Authority (EWA) in Bahrain. EWA is the only water utility in the country that supplies blended water to end-users both domestic and non-domestic and it maintains an updated billing and customer register and sends regular bills to its customers. Consequently, it was easier to compile a sampling frame for urban utility customers who are

being served by EWA. Furthermore, more valid responses were expected from EWA staff and customers and more data could be gathered easily such as staff interviews and limited access to customers database.

In limiting the organisational scope, it was assumed that EWA customers will provide a representative sample of urban water utility consumers. Since data for the research was collected in Bahrain only-an island country, as such the research findings may not be applicable to other countries than GCC countries. This achievement would have had more significance if the analysis had an international outlook. However, due to the limitations associated with costs and time available for this research, the focus was limited to a single country, Bahrain.

Although there is a wide range of WDM measures in coordination with WSM that the urban utilities could be investigated in providing sustainable water, this study focused on some WDM measures excluding rainwater harvesting and desalination plant. In particular this study has focused on water conservation, water tariff, public awareness and education.

## 1.9 Key definitions

For completion purposes, Box 1.1 shows definitions of Integrated Water Resource Management (IWRM), Water Demand Management (WDM), Water Supply Management (WSM) and Integrated Resource Planning (IRP). Box 1.2 shows definitions of Water Demand Management terms.

## Box 1.1 Basic Definitions of IWRM, WDM, WSM, and IRP, IUWRM, WC

**Box 1.1**
**Basic Definitions of IWRM, WDM, WSM, and IRP, IUWRM, WC**

**Integrated Water Resource Management (IWRM):** IWRM has been defined by the Global Water Partnership (GWP) Technical Advisory Committee as a "*Process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem".* (TAC, 2000).

**Water Demand Management (WDM):** One definition of Water Demand Management (WDM) is "*Development and implementation of strategies that achieve effective sustainable use of available limited water supply*". (Savenije and Van der Zaag, 2002).

**Water Supply management (WSM**): Supply management aims to increase supply, to make more water available to domestic, industrial, agricultural, commercial and other consumers through exploitation of water resources (Gregersen et al, 2000) such as by:

1. Effective legislation and water use regulations especially for groundwater withdrawal
2. Optimal utilisation and development of existing water resources
3. Groundwater exploration and recharge
4. Desalination technology
5. Recycling of waste-water

**Integrated Resource Planning (IRP**): Integration of the various components of urban water supply is to achieve integration, relationships between each of the major components.
IRP is a continuous process that results in the development of a comprehensive water resource management plan. It identifies and gives balanced consideration to supply and demand management planning alternatives. It includes analyses of engineering, economic, societal, and environmental costs and considerations while balancing the needs of competing users and multiple objectives of the use of the resource. It is an open and participatory process involving all stakeholders and striving for consensus, while encompassing least-cost analyses of short-and long term planning options, and satisfying utility and regulatory policy goals. Finally, IRP explicitly seeks to identify and manage risk and uncertainty and provides for co-ordination of planning between water and wastewater utilities in specific regions (American Water Works Association Research Foundation AWWARF, 1997).

**Integrated Urban Water Resource Management (IUWRM):** The Integrated Urban Water Management (IUWM) refers to the practice of managing freshwater, wastewater, and storm water as links within the resource management structure, using an urban area as the unit of management (UNEP - DTIE – IETC).

**Water Conservation (WC):** The minimization of loss or waste, care and protection of water resources and the efficient and effective use of water

**Box 1.2 Water Demand Management terms**

**Box 1.2**

The existing literature suggests many definitions for water demand management terminology; the most suitable ones are as defined below:

**Water Demand Management Measures (WDMM):** WDM measures are categorised into two: technical changes and behavioural changes. The aim of the measures is to increase water efficiency which usually results in using less water. WDM measures may also include source substitution or a combination of reduction and source substitution. Measures may be optional but some may be imposed. Individual measures may include elements of behavioural and technical changes. Technical change measures are those resulting in greater efficiency of water use through more efficient design, while behavioural changes lead to reduction in water use or more efficient water use through changes in actions and practices.

**Water Demand Management Instruments (WDMI):** are drivers that assist in achieving the adoption of a measure (how to do it). These instruments are categorised into three: regulatory, economic and communicative. One measure can be driven by a combination of more than one instrument. **Regulatory** instruments deal with the use of local regulations authorising the installation of water-efficient fixtures or minimum appliance efficiency standards at point of sale. **Economic** incentives may include rebates and retrofits for efficient fixtures and fittings or cost-reflective pricing that makes (consumers) customers consider how they can reduce their water use to reduce their water bills. The measures could also be combined with a **communicative** instrument in the form of education for behavioural changes. An Instrument is a driver applied by the government and/or other institutional body.

**Water Demand Management strategies:** require the selection of appropriate instruments and measures that can be used to achieve maximum water conservation.

**Water Demand Management Programme:** A water demand management programme consists of a selected socially appropriate and acceptable group of strategies.

## 1.10 Summary

This chapter has laid the foundation for conducting the research in this thesis. The background to the research was outlined and the problems of water resources in Bahrain were introduced. Then the research aim and questions were described. Thereafter, the research was justified and the research strategy and methods were outlined. The next chapter details the case study background with respect to the status of water resources.

# Chapter 2: Study Area Background

## 2.1 Introduction

Chapter 1 introduced the research problem, and then a justification for the research was made. This research aims to make a contribution and demonstrate how WDM measures at different levels can contribute to a sustainable water supply in Bahrain, and therefore the background of the study area is provided here as related to this aim.

This Chapter provides an overview of the important aspects that have direct and indirect influences on the attitudes, habits and lifestyle of the people, which are essential for the study of Bahrain's water resources, demand trends and water supply and consumption patterns. Included in this Chapter are description of the study area followed by a review of the water problems, existing water resources and their qualities, municipal water supply and consumption trends, institutional arrangements for water supply in Bahrain, and water production costs and tariffs. Finally, the Chapter addresses the water policy and legislative environments.

## 2.2 Geographic location and climate of the country

The Kingdom of Bahrain is an island nation located in the Arabian Gulf between latitude 26° 14" North and longitude 50° 34" East as shown in Figure 2.1. The island is generally flat and low lying, with a maximum elevation of 134 metres above sea level. The highest mountain is Jabal Al-Dukhan at 122 meters above sea level. The soils of the Kingdom of Bahrain are shallow to moderate in depth; the landscape of the kingdom being generally rocky and bare. The limestone bedrock is covered with varying depths of sand which supports little vegetation other than a few hardy desert plants (CIO, 2002). Figure 2.2 shows the location of Bahrain in the region of MENA.

A small percentage of urban areas are as high as about 55 m above sea level while substantial areas are flat and at 3–5 m above sea level. The Kingdom has a total land area of 760.46 $km^2$ (in 2010). Bahrain comprises several islands; however Bahrain Island is the largest in surface area. Bahrain Island represents about 81% of the total area of the country (CIO, 2008). Bahrain does not have land boundaries with other countries, and it does not have surface water resources.

Bahrain's coastline is approximately 161 km long. It is one of the world's most densely populated countries with a total population of 1.106 million (based on 2008 estimation) (Al-Masri, 2010). According to 2010 census the total population has increased to 1.234 million (CIO, 2010).


**Figure 2.1:** Bahrain location, Source: CIA, (2011)

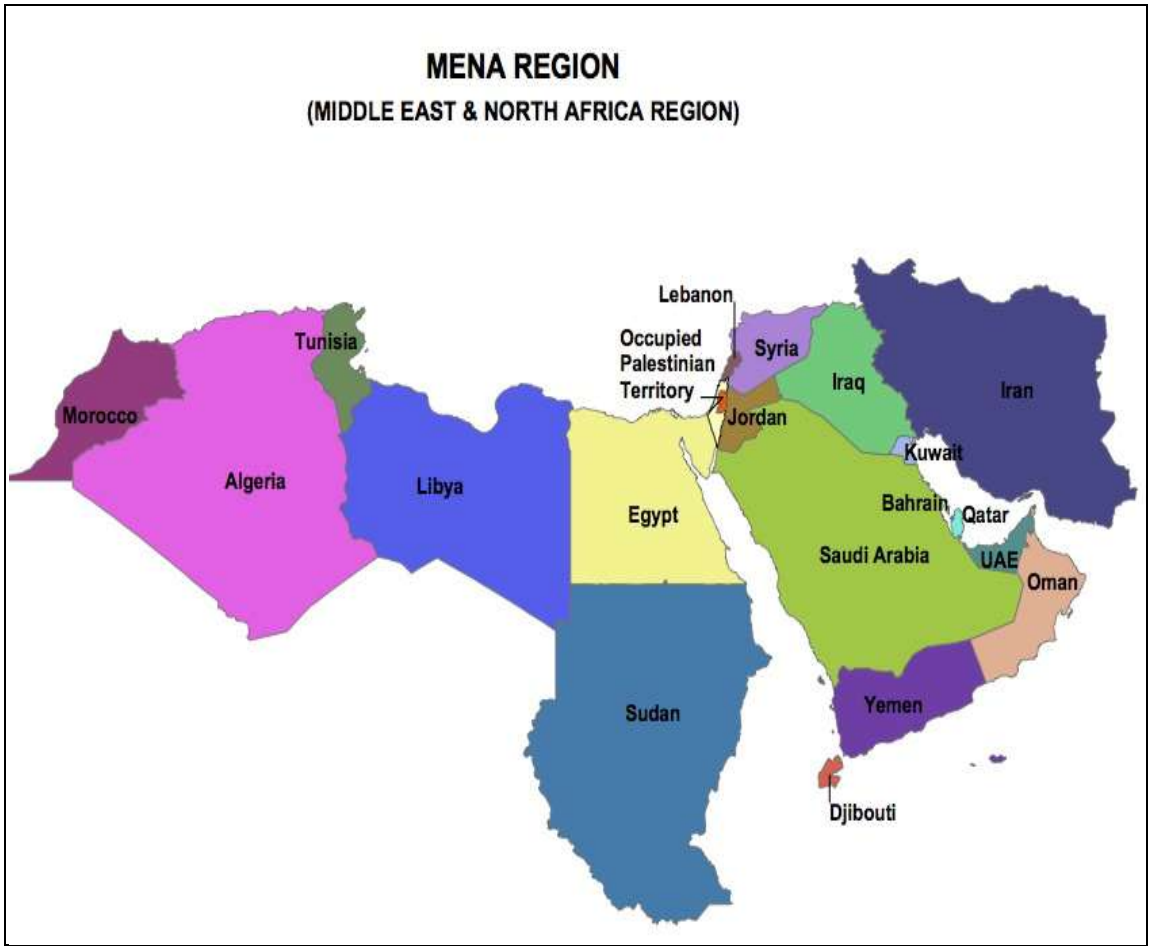


**Figure 2.2:** Location of Bahrain in the region of MENA, Source: skydancingblog, (2011)

The climate of Bahrain is arid to hyper-arid; with warm winters and sparse rainfall, hot summers, high evapo-transpiration rates (greater than 2,600mm/ year) and high humidity levels due to the surrounding Arabian Gulf water. Average rainfall reaches less than 100 mm/year and the mean annual relative humidity exceeds 67% (Al-Masri, 2010; Al-Ansari, 2004). There are significant seasonal variations in the average monthly temperature. The hottest months are July and August with mean daily maximum temperatures greater than $40^0$C, while December and January are the coldest and most humid with average monthly temperatures of about $17^0$C, and a mean monthly humidity of 73%. The mean daily maximum humidity is about 90% throughout the year, while the mean daily minimum humidity drops to about 15% in May, June and July (Nader, 2006). Table 2.1 summarises climate data for the period 1960–2005, while Table 2.2 shows some climate indicators for the Kingdom of Bahrain for the year 2008.

**Table 2.1:** Summaries of Climate Data for Bahrain during the period 1960 – 2005

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Air Temperature (°C)** | | | | | | | | | | | | |
| Mean monthly | 17.1 | 18 | 20.9 | 25.2 | 30.1 | 32.7 | 34.1 | 34.1 | 32.4 | 29.1 | 24.2 | 19.3 |
| Mean daily maximum | 24.1 | 26.7 | 31.3 | 36.2 | 39.9 | 41.1 | 42.1 | 41.2 | 39.5 | 36.7 | 31.8 | 26.4 |
| Mean daily minimum | 11 | 11.9 | 14.5 | 18.3 | 23.2 | 26.7 | 28.6 | 28.9 | 26.6 | 22.7 | 16.9 | 12.5 |
| **Relative Humidity (%)** | | | | | | | | | | | | |
| Mean monthly | 73.4 | 71.4 | 66.4 | 60.9 | 56.1 | 55.3 | 58.5 | 62.8 | 65.1 | 66.9 | 68.4 | 73.2 |
| Mean daily maximum | 97.8 | 97.7 | 96.3 | 93.9 | 91.4 | 91.9 | 92.3 | 92.7 | 94.4 | 95.6 | 95.6 | 97.5 |
| Mean daily minimum | 33.8 | 27.8 | 22.3 | 17.6 | 15.5 | 15.7 | 15.8 | 20.5 | 19.1 | 20.5 | 27.8 | 32.1 |
| **Rainfall (mm)** | | | | | | | | | | | | |
| Total monthly | 17.6 | 13.6 | 19.7 | 3.7 | 0.61 | 0 | 0 | 0.02 | 0.23 | 1.17 | 7.94 | 14.1 |
| **Evaporation (mm)** | | | | | | | | | | | | |
| Mean daily | 1.57 | 1.85 | 2.42 | 3.21 | 4.36 | 5.11 | 4.75 | 4.32 | 3.73 | 2.83 | 2.22 | 1.54 |

Source: Nader, Bahrain Civil Aviation, (2006)

**Table 2.2:** Some climate Indicators for the Kingdom of Bahrain for the year 2008

| Indicator | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature (°C)** | | | | | | | | | | | | |
| **Mean** | 15.3 | 16.6 | 22.9 | 26.3 | 31.5 | 34.1 | 35.4 | 35.1 | 33.8 | 29.6 | 24.1 | 18.1 |
| High mean | 18.4 | 21.1 | 28.8 | 31.5 | 37.1 | 39.8 | 40.5 | 39.9 | 38.7 | 33.8 | 27.6 | 22.4 |
| Low mean | 12.4 | 12.9 | 18.6 | 22.0 | 27.4 | 30.2 | 31.4 | 31.5 | 30.1 | 25.9 | 21.1 | 14.6 |
| **Sun rise (hr)** | | | | | | | | | | | | |
| Daily mean | 5.6 | 8.9 | 9.2 | 8.5 | 9.9 | 9.6 | 9.8 | 9.4 | 9.0 | 9.0 | 7.4 | 8.6 |
| **Humidity (%)** | | | | | | | | | | | | |
| Mean daily | 68 | 65 | 54 | 53 | 50 | 41 | 50 | 62 | 59 | 66 | 66 | 65 |
| High mean | 82 | 81 | 77 | 74 | 70 | 59 | 69 | 79 | 78 | 81 | 79 | 80 |
| Low mean | 52 | 45 | 29 | 30 | 26 | 27 | 31 | 39 | 37 | 45 | 49 | 47 |
| **Rainfall (mm/month)** | 14.9 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| **Evaporation rate (mm/day)** | 3.5 | 5.8 | 8.0 | 10.0 | 11.6 | 15.6 | 13.0 | 10.1 | 10.8 | 7.6 | 6.4 | 4.4 |
| **Winds** | | | | | | | | | | | | |
| Wind direction (degree) | 340 | 340 | 320 | 310 | 320 | 320 | 330 | 100 | 330 | 330 | 330 | 290 |
| Wind speed (knots) | 39 | 39 | 30 | 30 | 30 | 32 | 26 | 30 | 27 | 27 | 35 | 27 |

Source: CIO report, (2008)

## 2.3 Demographic and socio-cultural characteristics

As calculations and estimates of current and future water requirements are based on population and demand, these have an important effect on the social and economic system.

Population growth in the Kingdom of Bahrain is a major issue affecting all sustainable socio-economic development. The significant turning point in Bahrain's economy was due to the discovery of oil in 1932 and the investment of its revenues in development projects as well as diversification of the national economic base. This has encouraged the growth of the Bahraini population since 1932.

The source of population statistics in the Kingdom of Bahrain is the Central Information Organisation (CIO), formerly known as Central Statistics Organisation (CSO). A census is normally conducted at intervals of approximately 10 years. The latest census was conducted in April 2010.

The first population census in Bahrain was carried out in 1941. Since then eight more have been conducted in 1950, 1959, 1965, 1971, 1981, 1991, 2001 and 2010 (CIO, 2010). Table 2.3 summarises the population growth rate during the period 1941–2010 (CIO, 2008; CIO, 2010).

Based on historic census data, the population of Bahrain for 2010 was 1,234,571, of which 54% were non-Bahraini origin; 62% male and 38% female. The average estimated annual growth rate was 6.47% (CIO, 2010). Life expectancy was 74.2 years (CIO, 2008). The population density of 1461 per sq km exerts immense pressures on its limited natural resources, including the country's freshwater resources. Of the populated area, 92% is urbanised (CIO, 2008), and water is supplied through a distribution network.

**Table 2.3:** Bahrain population and population growth 1941–2010

| Year | Population | Population growth (%) | Annual population growth (%) |
|---|---|---|---|
| 1941 (Census) | 89,970 | | |
| 1950 (Census) | 109,650 | 21.78 | 2.42 |
| 1959 (Census) | 143,135 | 30.54 | 3.39 |
| 1965 (Census) | 182,303 | 27.36 | 4.56 |
| 1971 (Census) | 216,078 | 18.53 | 3.09 |
| 1981 (Census) | 350,798 | 62.35 | 6.23 |
| 1991 (Census) | 508,037 | 44.82 | 4.48 |
| 2001 (Census) | 661,317 | 30.17 | 3.02 |
| 2002 (Estimate) | 710,554 | 7.44 | 7.44 |
| 2003 (Estimate) | 764,519 | 7.59 | 7.59 |
| 2004 (Estimate) | 823,744 | 7.75 | 7.75 |
| 2005 (Estimate) | 888,824 | 7.90 | 7.9 |
| 2006 (Estimate) | 960,425 | 8.06 | 8.06 |
| 2007 (Estimate) | 1,039,297 | 8.21 | 8.21 |
| 2008 (Estimate) | 1,106,509 | 6.47 | 6.47 |
| 2009 (Estimate) | 1,170,540 | 5.79 | 5.79 |
| 2010 (Census) | 1,234,571 | 5.47 | 5.47 |

Source: CIO reports, (2008 and 2010)

The population growth rate was 21.78% from 1941 to 1950, and increased to 30.54% between 1950 and 1959, and to 27.36% from 1959 to 1965. This increasing trend reversed between 1965 and 1971; a period in which a population growth rate of 18.53% was reported. During the period 1971–1981, the population in Bahrain increased by an average of 62.35%. From year 2001-2005, the growth rate was greater than 7%. This was due to increased immigration to Bahrain as a result of the construction boom. Once again the estimated growth rate dropped to 6.47% during 2007-2008, while in 2009-2010 it was 5.47% and population reached to 1,234,571 with an increase of 64,031 from 2009.

Other demographic characteristics of the population are the increase in life expectancy from 51 years during the period 1950–1955, to 64 years during 1970–1975 and 74.2 years in 2008 (CIO report, 2008). The death rate has decreased from 3.7/1000 to 3.02/1000. Birth rate has also decreased, from 34.6/1000 in 1971 to 20.57/1000 in 2005 (CIO, 2006; Al-Masri, 2009) – an excellent indicator of achievements in health services. The population of Bahrain is relatively young. The 2001 census results show that 35.3% of the population were in the age group 0–14 while 61.4% of the population were in the age group 15–65 and only 3.3% were above 65 years. With regard to education, 89.1% of people over 15 can read and write

(91.9% of men, 85% of women); this means that the levels of education and healthcare in Bahrain are high (CIO report, 2005).

## 2.4 Land use and economic status

### *2.4.1 Land use*

Land and freshwater resources in Bahrain, like many other small island nations, are subject to the competing demands of urban development, agriculture, housing, industry and tourism, and other uses. These two resources are vital for meeting basic human needs, economic growth and improved access to goods and services.

Planning of land use is influenced by three main factors – geographical, human and international. Geographically, Bahrain is located between India and Europe, giving it its strategic trading position and bringing cultural benefits. Being an island-nation, its proximity to the sea helps in the harvest of fish and pearls which provide both traditional livelihoods. The human factor is represented by the development of agriculture in northern areas due to the availability of fresh groundwater and fertile soil for agriculture. Following the discovery of oil, some workers in the fishing and agriculture sectors moved to work in the oil industry in search of an improved work environment (Al-Masri, 2008a). This resulted in changes in land-use plans. An international factor was the impact of wars in the region, especially the civil war in Lebanon (1974- 1986) which led to the shift of the financial sector centre from Lebanon to Bahrain (Al-Masri, 2008a).

Table 2.4 shows the development of land use in Bahrain and the percentage increase for different sectors. Domestic and commercial/industrial sectors have increased continuously, rising by 49% and 25% respectively during the period 1988–2007 (Al-Masri, 2008a). The total land use increased by 21% during the same period; this percentage is more than the fall in land not in use, which is 6% for the same period (around 0.32 % annually). This indicates that increases in domestic, commercial and industrial land use happened, partially because of an increase in total area, due to a reclamation program in parts of the Gulf, and due to the development of agricultural land. This was offset by the creation of new agricultural land. However, the quality of such land is not as good as that which was used previously and this

has had a negative effect on agricultural production. It is expected that land use area will increase in future and this means there will be more effort required in order to provide water resources of suitable quantity and quality for all future water uses.

**Table 2.4:** Development in land use in Kingdom of Bahrain for the period 1956–2007

| Type of use | Usage per year in km$^2$ | | | | | % change | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1956 | 1969 | 1982 | 1988 | 2007 | 1956 - 1969 | 1969 - 1982 | 1982 - 1988 | 1988 - 2007 |
| **Domestic** | 12.35 | 32.2 | 68.16 | 91.95 | 136.71 | 161 | 112 | 35 | 49 |
| **Agricultural** | 64.6 | 64.6 | 37.48 | 40.7 | 41.87 | 0 | -42 | 9 | 3 |
| **Commercial/ industrial** | 31.45 | 33.71 | 84.65 | 137.63 | 172.52 | 7 | 151 | 63 | 25 |
| **Oil and Gas wells** | 140 | 140 | 114 | 114 | 114 | 0 | -19 | 0 | 0 |
| **Total used** | 248.4 | 270.51 | 304.29 | 384.28 | 465.1 | 9 | 12 | 26 | 21 |
| **Total not used** | 424.05 | 402.94 | 380.35 | 306.95 | 288.84 | -5 | -6 | -19 | -6 |
| **Total area** | 672.45 | 673.45 | 684.64 | 691.23 | 753.94 | 0.15 | 1.66 | 0.96 | 9.07 |

Source: Al-Masri, (2008a)

### *2.4.2 Economic status*

Other information that can be useful in the analysis of water use and predicting water demand includes socio-economic statistics, data on levels of economic growth, Gross Domestic Product (GDP), and value added to economy by the various economic sectors.

Bahrain has adopted a market-based economy. All sectors of the Bahrain economy contribute to the country's growth. According to the CIA's 2007 estimates, more than 90% of Bahrain's GDP is dependent on industry and services. Bahrain's estimated GDP for 2007 stood at $24.01 billion. The GDP real growth rate was estimated to be 6.7% and GDP per capita at $33,900. Bahrain's oil and gas production accounted for less than 20% of its GDP in 2007. A rise in labour productivity has been a major reason for Bahrain's economic growth (CIA Factbook 2007).

Petroleum production and refining in Bahrain constitutes about 30% of GDP, 60% of government revenues and 60% of export revenue. With its highly developed communication and transport facilities, Bahrain is home to numerous multinational firms with business in the Gulf. Construction proceeds on several major industrial projects. Unemployment,

especially among the young, and the depletion of both oil and groundwater resources, are major long-term economic problems (CIA Factbook 2007, Economic Overview, Kingdom of Bahrain, 2008).

## 2.5 Bahrain's water resources problems – quality and quantity

Due to its location in an arid region, rain does not significantly contribute to water resources in Bahrain. Annual rainfall is less than 100 mm/year and is concentrated in certain months (December, January, February and March) of the year. Bahrain also experiences scattered rain in May and November. However, due to the high evaporation rates that range from 3 mm/day in December to 11.4 mm/day in July, the effective rainfall is less than 1 $Mm^3$/year, which makes the economic benefit of using rainfall highly limited at present (Al-Masri, 2010).

For several years, Bahrain attempted to meet its steadily rising water demand through the supply-side approach alone. While augmentation of supply-side capacity was initially a necessity, the ever-increasing financial outlays involved in boosting production, coupled with the serious water resources problems and the inordinately high water consumption patterns in Bahrain, necessitated a more rigorous 'policy re-think' for meeting water demand (Al-Noami, 2004). Greater emphasis began to be laid down by the Electricity and Water Authority (EWA) on controlling demand through the encouragement of water conservation and implementation of water demand-management measures (Al-Maskati, 2005; Al-Masri, 2010, Zubari, 2010).

The researcher believes that there are four elements to Bahrain's water problem: The first is the geographical location and the dry climate, the second is its technology and the high cost of developing alternatives; the third is of human creation, brought about by adopting the wrong attitude to consumption and finally, the fourth is that WDM is still not given top priority by both the government and people.

**1. Shortage of conventional water resources**

Bahrain, like other countries in the region, faces a shortage of renewable fresh water. The only source is groundwater, for which it uses the Dammam aquifer. Studies estimate its renewable annual yield is limited to 112 $Mm^3$ (Al-Mansoor, 1999). Annual per capita allocation from this source is in continuous decline due to population increase and limited water resources: in 1995 it was 193 $m^3$/capita/year and it is expected to reach 89 $m^3$/capita/year in 2025 (Al-Maskati and Ismail, 2002). This figure is well below the water stress figure which is estimated internationally to be 1000 l/c/d (365 $m^3$/capita/year) (Al-Masri, 2009). The Kingdom of Bahrain has been tabulated as a water scarce country since the 1950s by the United Nations, and it is the seventh most water-stressed country in the world (Al-Mansoor, 1999). All policies and laws issued for the last four decades were unsuccessful in terms of controlling water abstraction rates and thus controlling groundwater level from deterioration (Mahmood and Tiwig, 1995, cited in Es'haqi and Al-Khaddar, 2008, Zubari, 2010)

**2. Alternative resource cost**

Alternative water resources, such as desalinated water for drinking, can reduce the level of groundwater consumption. In 2009 desalinated water accounted for around 25% of overall blended water in the network as indicated in Table 2.10 (Hajjaj, 2010). Desalination can also improve the quality of distributed water, which in some cases has reached a high degree of salinity that is not acceptable internationally (Al-Mansoor, 1999).

Adding extra quantities of desalinated water to the groundwater supplies is technically possible, although some environmental precautions are necessary, but ultimately production depends on economics. The introduction of more desalination plants within the country's financial budget would seem a wise option. This was applicable until the mid 1980s when Sitra and Ras Abu Jarjur desalination plants were constructed. Unfortunately, this option was not available afterwards because of the reduction in oil prices and the major impact this had on the country's income.

## 3. Water consumption patterns

The general attitude to water usage indicates that people are not fully aware that this precious natural resource is limited. The absence of legislation, awareness, enforcement of bylaws, penal actions and economic factors ultimately lead to high levels of consumption, especially for agriculture/horticulture. This contributes to the imbalance between water abstractions and natural water recharge quantities.

***Water resources***

Water resources can be divided into conventional and non-conventional water resources. Conventional water resources include rainfall and groundwater while non-conventional water resources include desalinated water, treated sewage effluent, and agricultural drainage water.

At present, water is supplied from the following principal sources in Bahrain:

1. Permeate from a brackish water reverse osmosis (RO) plant at Ras Abu Jarjur and a seawater RO plant at Ad Dur;
2. Distillate derived from multistage flash (MSF) seawater desalination plants at Sitra, Alba and Hidd;
3. Groundwater for blending with desalinated product water (mainly from wells in the west and north of Bahrain and in Muharraq);
4. Treated sewage effluent (TSE) for irrigation purposes.

In 2007 the total Kingdom water resources requirements amounted to 371.9 $Mm^3$. The island's groundwater resources contributed about 54.6% (203.3 $Mm^3$) of the total water demand (the agricultural sector was the main groundwater consumer as it consumed about 63% of the total abstractions, followed by domestic and industrial consumptions), while desalinated water and treated wastewater contributed 36.6% (132.3 $Mm^3$ ) and 9.7% (36.1 $Mm^3$) respectively. Other water resources' contributions were less than 0.1% (Al-Noami, 2008).

It is worth mentioning that water resources doubled in 55 years (1924-1979) from 83.0 $Mm^3$ to 162.1 $Mm^3$ per year and doubled again in only 15 years to reach 331.2 $Mm^3$ in 1994 due

to governmental efforts to develop non-conventional water resources. According to the Electricity and Water Authority and the Ministry of Works plans, based on current projections, it is expected that water resources will reach 617 $Mm^3$ in 2025. All data are actual except for the projected data of year 2025 (Al-Noami, 2008), as indicated in Table 2.5. Considering the minor contribution of rainfall and drainage water to the water budget, only groundwater, desalinated water and TSE are discussed.

**Table 2.5:** Quantities contributed from different water resources (in $Mm^3/y$) in Bahrain, 1924–2025

| Year | Ground water | Natural spring | Desalinated water | Treated water | Agricultural water | Total |
|---|---|---|---|---|---|---|
| 1924 | 0.0 | 83.0 | | | | 83.0 |
| 1952 | 65.2 | 51.6 | | | | 116.8 |
| 1966 | 115.7 | 37.6 | | | | 153.3 |
| 1971 | 127.1 | 29.0 | | | | 156.1 |
| 1979 | 147.4 | 14.7 | | | | 162.1 |
| 1980 | 153.7 | 13.9 | 3.3 | | | 170.9 |
| 1981 | 159.9 | 13.1 | 4.0 | | | 177.0 |
| 1982 | 166.2 | 12.3 | 5.4 | | | 183.9 |
| 1983 | 172.5 | 11.5 | 6.2 | | | 190.2 |
| 1984 | 178.7 | 10.7 | 13.1 | | | 202.5 |
| 1985 | 185.0 | 9.9 | 42.9 | | | 237.8 |
| 1986 | 191.9 | 8.9 | 49.6 | | | 250.4 |
| 1987 | 198.8 | 7.9 | 44.1 | | | 250.8 |
| 1988 | 205.7 | 6.9 | 49.2 | 1.5 | 0.2 | 263.5 |
| 1989 | 212.6 | 6.0 | 48.6 | 2.3 | 0.2 | 269.7 |
| 1990 | 219.5 | 5.0 | 54.2 | 4.4 | 0.2 | 283.3 |
| 1991 | 214.8 | 4.6 | 56.0 | 5.9 | 0.2 | 281.5 |
| 1992 | 231.1 | 4.2 | 61.3 | 7.5 | 0.2 | 304.3 |
| 1993 | 243.0 | 3.8 | 58.3 | 8.3 | 0.2 | 313.6 |
| 1994 | 256.3 | 3.4 | 59.8 | 11.5 | 0.2 | 331.2 |
| 1995 | 266.9 | 2.8 | 52.7 | 11.7 | 0.2 | 334.3 |
| 1996 | 274.6 | 2.4 | 60.6 | 13.2 | 0.2 | 351.0 |
| 1997 | 287.9 | 2.0 | 58.9 | 12.8 | 0.2 | 361.8 |
| 1998 | 293.4 | 1.6 | 61.4 | 12.2 | 0.2 | 368.8 |
| 1999 | 272.3 | 1.3 | 62.7 | 14.0 | 0.2 | 350.5 |
| 2000 | 262.8 | 1.2 | 89.2 | 14.6 | 0.2 | 368.0 |
| 2001 | 231.9 | 1.0 | 93.9 | 15.3 | 0.2 | 342.3 |
| 2002 | 244.9 | 0.8 | 93.7 | 15.6 | 0.2 | 355.2 |
| 2003 | 239.5 | 0.6 | 102.4 | 18.8 | 0.2 | 361.5 |
| 2004 | 231.6 | 0.4 | 109.3 | 18.6 | 0.2 | 360.1 |
| 2005 | 211.7 | 0.2 | 113.1 | 20.9 | 0.2 | 346.1 |
| 2006 | 218.2 | 0.0 | 122.6 | 33.1 | 0.2 | 374.1 |
| 2007 | 203.3 | 0.0 | 132.3 | 36.1 | 0.2 | 371.9 |
| 2025 | 155.0 | 0.0 | 306.8 | 148.2 | 7.0 | 617.0 |

Source: Al-Noami, (2008); Al-Masri, (2008a)

### *Groundwater resources*

Groundwater, namely, the Dammam aquifer, was traditionally the main source of water supply in Bahrain prior to the adoption of desalination and wastewater treatment plants. The Dammam Aquifer forms only a small part of the extensive regional aquifer system, termed the Eastern Arabian Aquifer, that extends from central Saudi Arabia, where the aquifer rocks outcrop and its main recharge area is located, to the Arabian Gulf water, including Bahrain, Kuwait, and southern Qatar. The Dammam aquifer in Bahrain receives its water mainly by under-flow from this regional aquifer, with additional, insignificant amount by rainfall recharge, averaging about 0.5 $Mm^3/y$ (GDC, 1980).

The system which provides the groundwater in Bahrain is composed of three main aquifers: the Alat, Khobar and The Rus-Umm Er Radhuma Formation. These are termed A, B and C aquifer zones respectively. Alat and Khobar aquifers are termed collectively as the Dammam aquifer system. The system extends beneath the Gulf from Saudi Arabia, and the general hydrogeological picture of Bahrain is as a major discharge area of the Eastern Arabian aquifer complex. A schematic illustration of the aquifer system is shown in Figure 2.3, with the three aquifer systems (A, B and C) indicated on the left hand side of the figure

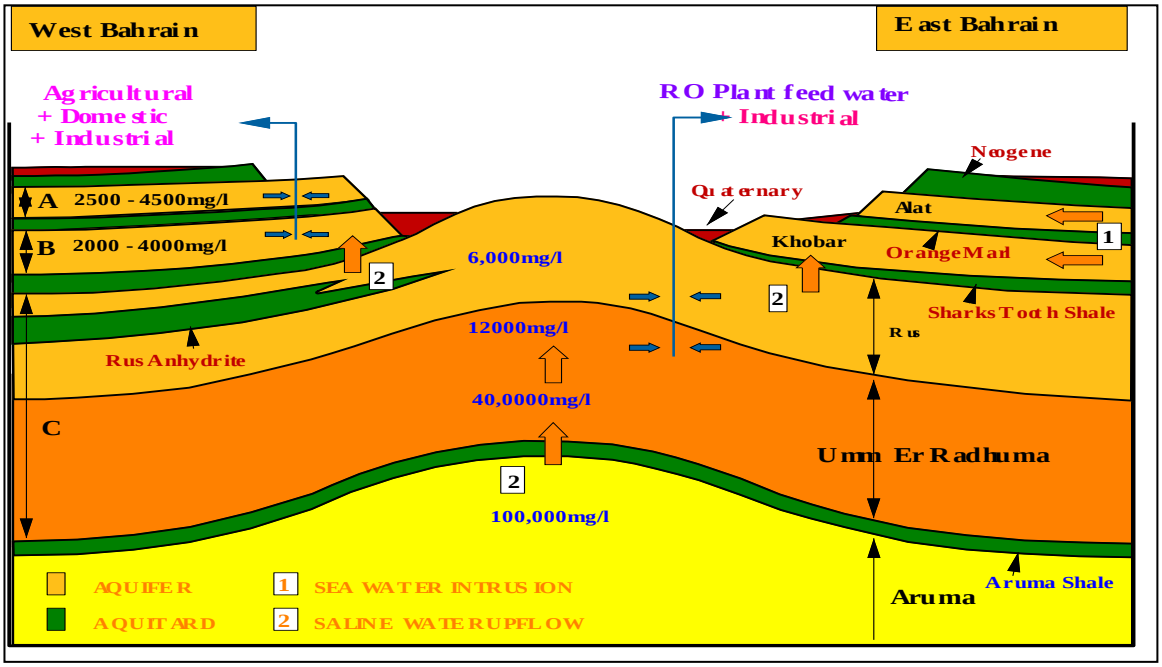


**Figure 2.3:** The composition of different aquifers and their water quality (TDS), Source: Al-Zubari (2005)

The material about aquifers in the next three paragraphs is based on Al Zubari (2005).
The upper two aquifers (A & B) yield relatively fresh water whereas the lower C aquifer is brackish. The B zone is the main aquifer for domestic and agricultural use and provides most of the water used by Electricity and Water Authority (EWA) for blending whilst brackish Dammam and Rus-Umm Er Radhuma water is confined to limited industrial use. The C zone is used for Ras Abu Jarjur RO plant and many industrial supplies.

The Alat formation is a white finely crystalline limestone, 15–25 m thick, with distinctive basal orange-coloured marl. It forms the upper Dammam, and counts as a secondary aquifer. The salinity ranges between 2500–4500 mg/l. It is used for irrigation in north-eastern areas. It has a fairly low hydraulic conductivity in the range of 2–6 $m^3$/day. Khobar is 20–45 m thick and forms the lower Dammam. It consists of white, buff and brown limestone, dolomite limestone and dolomite. It provides high-yielding wells from which most of the groundwater is extracted. Hydraulic conductivity varies between 15 and 200 m/day, and it contains the best quality groundwater. Total Dissolved Solid (TDS) varies from 2,000 to over 4,000 mg/l. The Rus-Umm Er Radhuma Formation consists mainly of grey, chalky, detrital and calcarenitic limestone. The thickness varies from 175 to 450 m. The carbonate sequence is normally porous and permeable, particularly in its middle part. The salinity of the groundwater is in the range of 6000–40,000 mg/l with a reasonable amount of malodorous hydrogen sulphide ($H_2S$), which makes it unsuitable for conventional use.

According to many researchers (Al-Mansoor, 1999, Al-Noaimi, 1993; Zubari, 1987; GDC, 1980; Wright, 1967), the steady state rate of under-flow from eastern Saudi Arabia to Bahrain ranges from 100 to 112 $Mm^3$/y. Till 1975, groundwater resources alone supplied all water demand through natural springs and abstraction wells. As water demand increased, however people were forced to increase their abstraction rates beyond the safe yield in order to satisfy the growing demand. As a result, potentiometric levels dropped and water quality deteriorated due to seawater intrusion in eastern and south-eastern areas, upward flow of brackish water from Rus aquifer to Dammam aquifer in the north central area, and percolation of agricultural water in the western areas.

**Abstraction rate:** abstraction rates from the Dammam aquifer increased steadily from 63.2 $Mm^3$ in 1952 to reach 254 $Mm^3$ in 1998; the rate decreased to reach 182.5 $Mm^3$ in 2004 due to quality deterioration and development of other water resources. It is estimated that the abstraction rate in 2007 was about 147.6 $Mm^3$. Conversely, abstraction rates from Rus-Umm Er Radhuma increased from 2 $Mm^3$ in 1952 to 49.1 $Mm^3$ in 2004. It is estimated that the abstraction rate was about 55.71 $Mm^3$ in 2007 (Al-Noami, 2008).

**Water quality:** water quality is generally declining; the deterioration of quality varies from one location to another according to the pollution sources. It has been observed that the worst impact was in the areas that suffered from seawater intrusion. The increase in groundwater salinity in these areas was, on average, about 6,000 mg/l with extremes hitting 15,000 mg/l. Areas that suffered from upward flow from Rus aquifer to Khobar, experienced an increase in salinity of about 4,000 mg/l. Groundwater salinity in the western areas increased in a similar fashion due to percolation of brackish water from sabkha (areas of coastal flats subject to periodic floating from the sea) and agricultural drainage water. Groundwater salinity in the North West areas increased by 2500 mg/l; however, it has the best water quality (Al-Masri, 2008a).

**Groundwater users:** The agricultural sector, drinking water supply sector and industrial sector depend on groundwater for their water needs. The agricultural sector is always the main user of the Dammam aquifer; it used 69.5 % (102.57 $Mm^3/y$) of water abstracted in 2007. The municipal sector came second with 27.4% (40.4 $Mm^3/y$), followed by the industrial sector, which used 3.1% (4.6 $Mm^3/y$). The municipal sector is the main user of Rus-Umm Er Radhuma as it used, about 66.8% (37.2 $Mm^3/y$) of water abstracted to feed the Ras Abu Jarjour RO desalination plant. The industrial sector came second (17%; 9.5 $Mm^3/y$), followed by the agricultural sector with 16.2% (9.01 $Mm^3/y$). Table 2.6 illustrates groundwater usage from Rus-Umm Er Radhuma and Dammam aquifers by different sectors and their quantities (Al-Noami, 2008).

**Table 2.6**: Groundwater usage by sector ($Mm^3/y$) from Dammam and Rus-Umm Er Radhuma aquifer, 1952–2007

| Groundwater abstraction for different usage during 1952-2007 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Dammam** | | | | **Rus-Umm Er Radhuma** | | | | **Total** |
| | **Agricultural** | **Municipal** | **Industrial** | **Total** | **Agricultural** | **Municipal** | **Industrial** | **Total** | |
| 1952 | 48 | 5.1 | 10.1 | 63.2 | 0 | 0 | 2 | 2 | 65.2 |
| 1966 | 89 | 16.5 | 8.2 | 113.7 | 0 | 0 | 2 | 2 | 115.7 |
| 1971 | 96 | 20.89 | 8.2 | 125.09 | 0 | 0 | 2 | 2 | 127.09 |
| 1979 | 90 | 41.1 | 7 | 138.1 | 1.3 | 0 | 8 | 9.3 | 147.4 |
| 1985 | 99.9 | 47.4 | 4.9 | 152.2 | 2.5 | 25.7 | 4.6 | 32.8 | 185 |
| 1990 | 124.7 | 56.8 | 5.9 | 187.4 | 5 | 23.1 | 4 | 32.1 | 219.5 |
| 1991 | 121.3 | 53.1 | 5.3 | 179.7 | 4.9 | 26.6 | 3.6 | 35.1 | 214.8 |
| 1992 | 136.1 | 52.5 | 5.6 | 194.2 | 6.1 | 27.3 | 3.5 | 36.9 | 231.1 |
| 1993 | 139 | 61.1 | 6 | 206.1 | 6.1 | 27.3 | 3.5 | 36.9 | 243 |
| 1994 | 150.8 | 61.2 | 6.3 | 218.3 | 6.2 | 28.3 | 3.5 | 38 | 256.3 |
| 1995 | 159 | 64.6 | 6.7 | 230.3 | 6.5 | 26.9 | 3.2 | 36.6 | 266.9 |
| 1996 | 169 | 61.8 | 7.1 | 237.9 | 6.8 | 26.6 | 3.3 | 36.7 | 274.6 |
| 1997 | 178.3 | 65.2 | 7.4 | 250.9 | 6.4 | 26.9 | 3.7 | 37 | 287.9 |
| 1998 | 180.5 | 66 | 7.5 | 254 | 7.3 | 29 | 3.1 | 39.4 | 293.4 |
| 1999 | 170.3 | 52.8 | 6.2 | 229.3 | 7.6 | 30.5 | 4.9 | 43 | 272.3 |
| 2000 | 159.9 | 52.7 | 6.2 | 218.8 | 7.3 | 31 | 5.7 | 44 | 262.8 |
| 2001 | 137.4 | 45.2 | 5.1 | 187.7 | 7.5 | 30.5 | 6.2 | 44.2 | 231.9 |
| 2002 | 141.9 | 53.9 | 5.3 | 201.1 | 7.8 | 29.2 | 6.8 | 43.8 | 244.9 |
| 2003 | 135.9 | 54.4 | 5.1 | 195.4 | 7.8 | 29.2 | 7.1 | 44.1 | 239.5 |
| 2004 | 123.2 | 54.7 | 4.6 | 182.5 | 8.4 | 31.2 | 9.5 | 49.1 | 231.6 |
| 2005 | 117.55 | 49.8 | 4.6 | 171.95 | 8.51 | 31.7 | 9.5 | 49.71 | 221.66 |
| 2006 | 110.06 | 48.1 | 4.6 | 162.76 | 8.76 | 37.2 | 9.5 | 55.46 | 218.22 |
| 2007 | 102.57 | 40.4 | 4.6 | 147.57 | 9.01 | 37.2 | 9.5 | 55.71 | 203.28 |

Source: Al-Noami (2008)

### *Non- conventional water resources*

Additional large water sources have become necessary in order to meet the present and projected future water requirements in Bahrain. Non-conventional water resources including desalination and reclaimed sewage wastewater are the only logical viable options. These two options are currently being used worldwide to supplement limited natural water resources to satisfy domestic water demand.

### *Desalinated sea water*

As it is neither economic nor practical to consider replacement of the Khobar as a major source of water for agriculture, it is necessary to obtain considerable reductions from the municipal and industrial quota. Additional supplies must inevitably come from desalination plants, fed either by seawater or saline water from Rus-Umm Er Radhuma aquifer. Seawater desalination is an expensive operation that requires a large amount of capital funding to

construct, operate, and maintain. In addition, the Total Dissolved Solid (TDS) level in the Gulf (which varies between 40,000 and 60,000 mg/l) is much higher than that of other seas and oceans (Abderrahman, 2007). For this reason, water desalination in Gulf Cooperation Council (GCC) countries is more expensive than in other countries using the same methods of desalination. However, new desalination plants are required in order to keep pace with potable water demand and to minimise the need to draw water from the aquifer.

The Electricity and Water Authority (EWA), previously the Ministry of Electricity and Water (MEW) (it became an authority on 11th December 2007), is the authority in charge of desalination. Desalination started in Bahrain in 1975 with the production of about 8 $Mm^3$/year to cover part of the municipal demand and to reduce groundwater abstraction. At present EWA operates three desalination plants, with a total production of around 69.26 $Mm^3$/year. This processed water for municipal water supply is then blended with lower-quality groundwater for distribution throughout the state. The other two plants (Alba and Hidd Private Company) are owned by the private sector and produce 66% of the total desalinated water (2009); the ratio is expected to increase for 2010 (EWA, 2009; Al-Masri, 2008b). Because the amount of desalinated water is less than municipal demand, groundwater is also used (Al-Masri, 2008b). Table 2.7 shows desalination plants and their existing conditions. As can be seen, all of the desalination plants had a reserve capacity in 2007.

**Table 2.7:** The desalination plants and their existing conditions

| Plant | Commissioning Date | Production Capacity $Mm^3$/Year | Actual capacity Year 2007 $Mm^3$/Year | Efficiency* % | Feeding Source | Technology |
|---|---|---|---|---|---|---|
| Sitra | 1975 | 41 | 36 | 86.10 | Seawater | MSF |
| Ras Abu Jarjur | 1984 | 27 | 26 | 94.87 | Rus-UmmEr-Radhuma | RO |
| Addur** | 1990 | 17 | 7 | 42.49 | Seawater | RO |
| Alba | 2003 | 12 | 8 | 70.43 | Seawater | MSF |
| Hidd*** | 2007 | 149 | 55 | 37.07 | Seawater | MSF-MED |
| Groundwater | | | 40 | | | |
| Total | | 246 | 173 | | | |

Source: Al-Ka'abi (2008)

* Efficiency = Actual capacity/ Production capacity

** This desalination plant is facing operational problems

*** Only stage 1 & 2 in operation while stage 3 under construction

### *Treated Sewage Effluent (TSE)*

The need to reduce groundwater abstraction has prompted the government to consider the use of treated sewage effluent (TSE) as an additional source of water for agricultural purposes. Accordingly, Tubli Water Pollution Control Centre (WPCC) was constructed in 1983 with an initial supply of 22 $Mm^3$/year. Presently, the Tubli treated outflow is around 70 $Mm^3$/year (2010). Though recycling of wastewater will expand in the future, only 20% of the present treated outflow is being utilised and the rest is discharged into the sea (Al-Masri, 2010; Zubari, 2010). Usage of TSE on a wider scale has not been accepted socially based on religious and psychological grounds. There are also concerns against widespread usage for health reasons. Therefore, efforts are needed to promote the use of treated sewage effluent in the agricultural sector. The Tubli WPCC applies extended aeration activated sludge process for secondary treatment, followed by dual media filtration and disinfection by chlorination or ozonation for tertiary treatment. Tertiary treated wastewater is reused in unrestricted agricultural and landscape irrigation while secondary treated wastewater is discharged to Tubli Bay. The Tubli facilities were designed and constructed, and are now operated, with the objective of recycling both the treated effluent and the stabilised sewage sludge.

In addition to the Tubli WPCC, there are other minor treatment plants in Bahrain; some of them are privately owned, while the rest are owned and operated by the government. They are operated under the control of Tubli WPCC administration and management (Al-Masri, 2010).

**TSE capacity:** The TSE capacity increased from 1.5 $Mm^3$ in 1988 to 14.6 $Mm^3$ and 33.1 $Mm^3$ in the years 2000 and 2006 respectively. The current TSE capacity is 36.1 $Mm^3$.

**TSE quality**: quality of TSE has declined due to excessive hydraulic and organic loads, which led to serious deterioration of the final effluent quality that affected unrestricted use plans and posed a potential risk to public health.

**TSE uses:** The government is currently implementing a programme in order to improve the current situation and to extend the capacity of Tubli WPCC. The major objectives are attaining a full and sustainable utilisation of the final treated sewage effluent for agricultural purposes and avoiding the daily carry-over at the final clarifiers to protect Tubli Bay.

## 2.6 EWA municipal water

**EWA water supply production and groundwater abstraction trends**

EWA owns and operates boreholes in all populated areas of Bahrain. A total number of 77 boreholes were used for abstracting groundwater for blending with desalinated water or for direct supply to consumers; 45 boreholes are effectively in use and 32 are out of production due to high salinity. The groundwater is blended with desalinated water before it is supplied to consumers. The principal sources are located in the agricultural areas to the north and west of the island at Central area (79.3% of the total abstraction) and Northern area (14.5%). There is a minor abstraction from boreholes in Manama (4.2%), Muharraq (1.5%) and Sitra (0.5%). The average TDS is 5388 mg/l. The Northern area has the best TDS at 4340 mg/l (with exception to Hoora with 3110 mg/l), followed by the central area with TDS 4956 mg/l. Table 2.8 shows the monthly abstraction of groundwater and its quality for drinking purposes for 2010 distributed by area while Figure 2.4 shows the location of boreholes (Hajjaj, 2011).

The quantity of groundwater used in blending by EWA during the period 1980–2010 was in the range of 41–55 $Mm^3$/year. At the same time, blended water quantity increased from 44.29 $Mm^3$ to 236.63 $Mm^3$, which reduced the dependence on groundwater for drinking water from 93% to 8% (Hajjaj, 2011), which shows the success of EWA efforts in limiting consumption of groundwater for drinking purposes. This percentage is expected to continue to reduce as the desalination project continues to operate efficiently – refer to Table 2.10.

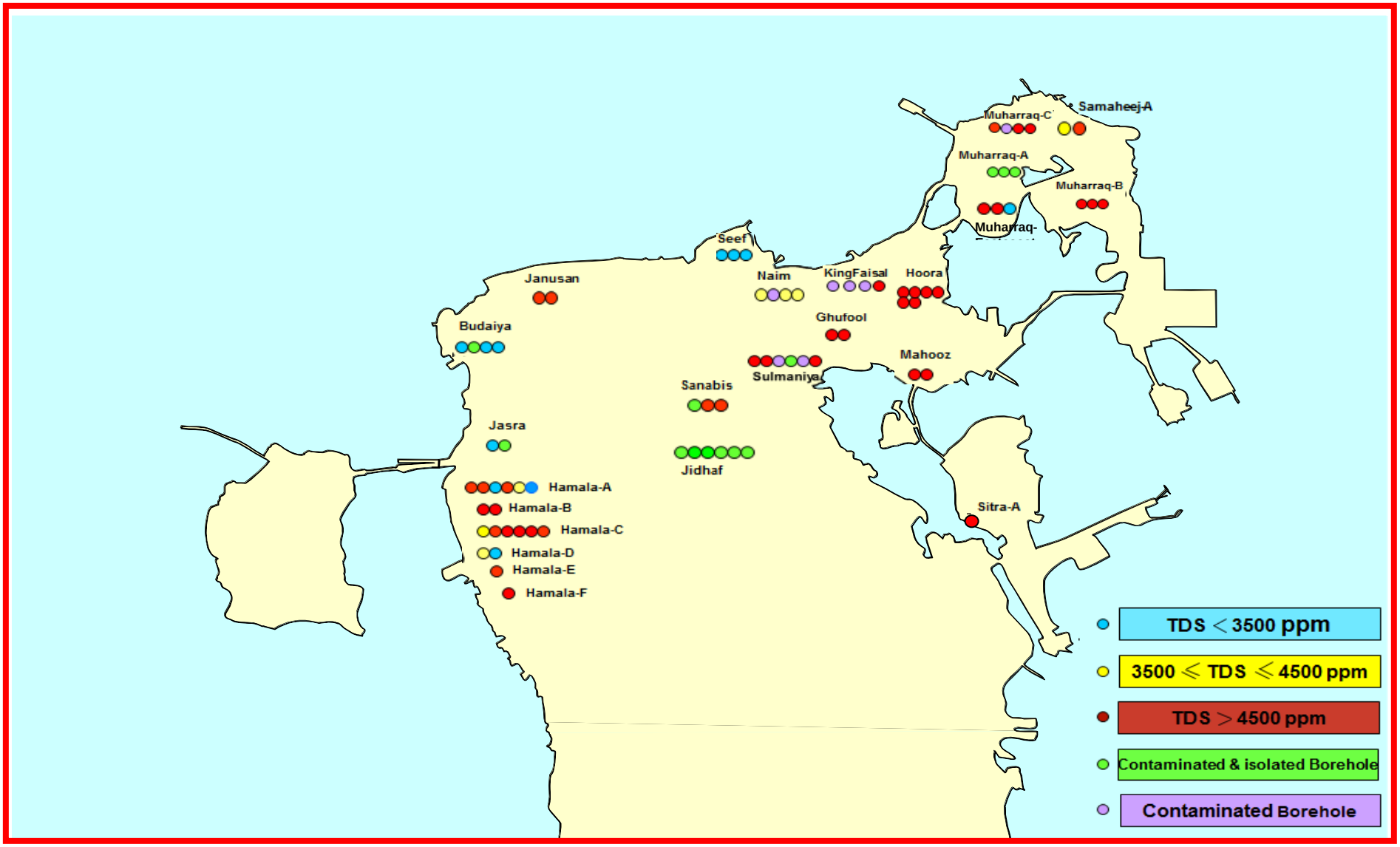


**Figure 2.4:** Groundwater Boreholes location with Total Dissolved solids (TDS) in year 2010, Source: WTD (2011)

**Table 2.8:** Monthly abstraction of groundwater used by EWA for drinking purposed for 2010, Source: Hajjaj, (2011)

| Area | Boreholes in use | Boreholes abandoned | Month | | | | | | | | | | | | Total (MG/y) | TDS mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | | |
| Central Area | 19 | 1 | 319.52 | 234.94 | 315.49 | 325.46 | 293.25 | 360.00 | 348.80 | 322.54 | 296.11 | 355.51 | 316.05 | 290.50 | 3778.17 | 4956 |
| Hamala (A) | 6 | 0 | 117.95 | 89.17 | 115.95 | 120.95 | 116.26 | 128.95 | 123.35 | 122.11 | 117.79 | 128.50 | 113.28 | 101.04 | 1395.31 | 4199 |
| Hamala (B+D+E+F) | 6 | 0 | 89.37 | 74.44 | 93.85 | 91.63 | 81.3 | 90.24 | 91.49 | 80.87 | 65.3 | 91.88 | 84.31 | 81.62 | 1016.30 | 5132 |
| Hamala (C) | 6 | 0 | 90.32 | 60.15 | 87.51 | 93.46 | 77.4 | 116.8 | 109.5 | 98.81 | 95.38 | 110.7 | 99.45 | 90.61 | 113.00 | 5728 |
| Jasra | 1 | 1 | 21.88 | 11.18 | 18.18 | 19.42 | 18.29 | 24.04 | 24.42 | 20.75 | 17.64 | 24.4 | 19.01 | 17.23 | 236.44 | 3890 |
| Sitra | 1 | 0 | 1.78 | 0.00 | 1.89 | 0.00 | 0.06 | 0 | 1.8 | 6.05 | 4.95 | 1.89 | 2.87 | 1.05 | 22.34 | 9875 |
| Manama Area | 9 | 20 | 5.67 | 1.34 | 0 | 0 | 0 | 0 | 0 | 6.5 | 38.36 | 62.68 | 30.58 | 52.62 | 197.75 | 6121 |
| Salmanya | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A |
| Hoora | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20.84 | 20.84 | 3110 |
| Mahooz | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A |
| Manama | 7 | 3 | 5.67 | 1.34 | 0 | 0 | 0 | 0 | 0 | 6.5 | 38.36 | 62.68 | 30.58 | 31.78 | 176.91 | 6353 |
| Jidd Hafs | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A |
| Muharraq Area | 8 | 7 | 7.82 | 4.02 | 0 | 0.37 | 0 | 3.62 | 3.46 | 4.98 | 21.1 | 18.38 | 0 | 0 | 73.44 | 5580 |
| Muharraq ( C) | 2 | 2 | 5.78 | 0.22 | 0 | 0.2 | 7.32 | 0 | 1.69 | 3.58 | 15.45 | 14.98 | 0 | 0 | 49.22 | 5800 |
| Muharraq Minor | 4 | 5 | 2.04 | 3.8 | 0 | 0.17 | 2.37 | 3.62 | 1.77 | 1.4 | 5.65 | 3.4 | 0 | 0 | 24.22 | 13471 |
| Muharraq | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8915 |
| Northern Area | 8 | 4 | 103.8 | 26.44 | 41.32 | 54.73 | 84.16 | 62.03 | 63.34 | 68.39 | 48.55 | 89.4 | 14.99 | 34.24 | 691.39 | 4340 |
| Sanabis | 2 | 1 | 20.26 | 2.79 | 12.44 | 14.04 | 18.73 | 12.64 | 10.04 | 11.13 | 8.65 | 16.34 | 0 | 0 | 127.06 | 5200 |
| Budaiya | 3 | 1 | 42.64 | 0.7 | 0 | 11.91 | 31.69 | 3.74 | 0 | 16.68 | 0 | 22.3 | 0 | 0 | 129.66 | 3312 |
| Janusan | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.06 | 0 | 0 | 10.06 | 5903 |
| AlSeef | 3 | 0 | 40.9 | 22.95 | 28.88 | 28.78 | 33.74 | 45.65 | 53.3 | 40.58 | 39.9 | 40.7 | 14.99 | 34.24 | 424.61 | 3460 |
| Total | 45 | 32 | 438.6 | 266.7 | 358.7 | 380.6 | 377.5 | 425.7 | 417.4 | 408.5 | 409.1 | 527.9 | 364.5 | 378.4 | 4753.4 | 5388 |

***Blended water supply quantity***

**Water quality:** Table 2.8 shows that the concentration of Total Dissolved Solids (TDS) in all boreholes is higher than the GCC and Bahraini standard, which is 1000 mg/l. It was reported that the average TDS was 1565 mg/l in 2005 and decreased to 1425 and 1209 mg/l in 2006 and 2007 respectively due to the decrease in the amount of groundwater used for blending purposes (WTD, 2007).

**Blended water users**: Blended water is used not only in the domestic sector, but also in the industrial, commercial, institutional and agricultural sectors. The non revenue water (NRW) was estimated 38% in 2010 (WDD, 2010).

With the efforts of EWA, drinking water supply increased more than threefold, from 53.55 $Mm^3$ to 200.80 $Mm^3$ during 1981–2008 (an average increase of 2.7% annually). The population increased from 350,798 to 1,106,509 in the same period (average increase 2.5% annually). Table 2.9 shows development of annual drinking water production, population and per capita consumption. Drinking water production refers to the blended water that is distributed to consumers. This consists of a blend of groundwater and desalinated water.

**Table 2.9:** Development of Annual drinking water production, population and gross per capita consumption

| Year | Population | | Total drinking water production | | Gross Per Capita Consumption (PCC) | |
|---|---|---|---|---|---|---|
| | | % increase | $Mm^3/y$ | % increase | l/c/d | % increase |
| 1981 | 350798 | | 53.55 | | 418.22 | |
| 1991 | 508037 | 3.1 | 100.32 | 4.7 | 541.00 | 22.7 |
| 2001 | 661317 | 2.3 | 135.28 | 2.6 | 560.44 | 3.5 |
| 2002 | 710554 | 0.7 | 138.11 | 0.2 | 532.52 | -5.2 |
| 2003 | 764519 | 0.7 | 145.95 | 0.5 | 523.03 | -1.8 |
| 2004 | 823744 | 0.7 | 153.97 | 0.5 | 512.10 | -2.1 |
| 2005 | 888824 | 0.7 | 159.33 | 0.3 | 491.12 | -4.3 |
| 2006 | 960425 | 0.7 | 170.67 | 0.7 | 486.86 | -0.9 |
| 2007 | 1039297 | 0.8 | 172.70 | 0.1 | 455.26 | -6.9 |
| 2008 | 1106509 | 0.6 | 200.80 | 1.4 | 497.18 | 8.4 |
| 2009 | 1170540 | 0.5 | 220.68 | 0.9 | 516.52 | 3.7 |
| 2010 | 1234571 | 0.5 | 236.65 | 0.7 | 525.17 | 1.6 |

Source: CSO, (2001); CIO, (2008); Hajjaj, (2010); CIO, (2011)

One factor that may contribute to the rapid increase in water demand is that the drinking water sector is highly subsidised by the government through the construction of desalination plants, transmission networks and distribution networks to cover the population's requirements. Total drinking water production and groundwater withdrawal capacity in 2010 was 236.65 $Mm^3$/ y (Hajjaj, 2011).

Other factors that affect water demand and production include improvements in the economic situation, increase in percentage of water connections and sewage connections, and water losses including non-revenue water.

Table 2.10 shows the total water production from the desalination plants, potable water from Alba and Hidd Private Company and groundwater withdrawal put into the public supply system for municipal uses during 1980–2010. In 2010 a total of 236.63 $Mm^3$ was distributed through the public network, out of which groundwater accounted for 17.84 $Mm^3$ (8%). About 56.95 $Mm^3$ (25%) was desalinated water and potable water from Alba and Hidd Private Company was 145.89 $Mm^3$ (66%).

Municipal water use is met by metered and billed blended water and brackish groundwater pumped into the public supply distribution network, and by metered but unbilled self-supplied groundwater or desalinated groundwater.

**Table 2.10**: Total EWA water production and groundwater withdrawal (1980–2010)

| Year | Groundwater | | RO Water (RAJ & Addur) | | Desalinated water (Sitra PWS) | | Potable Water (ALBA & HPC) | | TOTAL | Daily average |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Mm^3/y$ | % | $Mm^3/y$ | % | $Mm^3/y$ | % | $Mm^3/y$ | % | $Mm^3/y$ | Mld |
| 1980 | 41.01 | 93 | 0.00 | 0 | 3.28 | 7 | 0.00 | 0 | 44.29 | 121.34 |
| 1981 | 49.55 | 93 | 0.00 | 0 | 3.99 | 7 | 0.00 | 0 | 53.54 | 146.68 |
| 1982 | 55.22 | 91 | 0.00 | 0 | 5.42 | 9 | 0.00 | 0 | 60.64 | 166.14 |
| 1983 | 56.11 | 90 | 0.00 | 0 | 6.24 | 10 | 0.00 | 0 | 62.35 | 170.82 |
| 1984 | 57.82 | 82 | 3.60 | 5 | 9.45 | 13 | 0.00 | 0 | 70.87 | 194.16 |
| 1985 | 37.15 | 46 | 15.38 | 19 | 27.52 | 34 | 0.00 | 0 | 80.05 | 219.32 |
| 1986 | 35.37 | 42 | 15.62 | 18 | 33.98 | 40 | 0.00 | 0 | 84.97 | 232.80 |
| 1987 | 45.83 | 51 | 14.29 | 16 | 29.84 | 33 | 0.00 | 0 | 89.96 | 246.47 |
| 1988 | 45.30 | 48 | 13.36 | 14 | 35.84 | 38 | 0.00 | 0 | 94.50 | 258.90 |
| 1989 | 51.27 | 51 | 12.04 | 12 | 36.51 | 37 | 0.00 | 0 | 99.82 | 273.48 |
| 1990 | 48.19 | 47 | 14.63 | 14 | 39.53 | 39 | 0.00 | 0 | 102.35 | 280.41 |
| 1991 | 44.31 | 44 | 17.85 | 18 | 38.16 | 38 | 0.00 | 0 | 100.32 | 274.86 |
| 1992 | 43.30 | 41 | 24.11 | 23 | 37.80 | 36 | 0.00 | 0 | 105.21 | 288.26 |
| 1993 | 53.35 | 48 | 19.57 | 18 | 38.79 | 35 | 0.00 | 0 | 111.71 | 306.05 |
| 1994 | 50.88 | 46 | 20.04 | 18 | 39.74 | 36 | 0.00 | 0 | 110.66 | 303.18 |
| 1995 | 54.64 | 51 | 17.77 | 17 | 34.73 | 32 | 0.00 | 0 | 107.14 | 293.53 |
| 1996 | 50.34 | 46 | 22.95 | 21 | 36.37 | 33 | 0.00 | 0 | 109.66 | 300.44 |
| 1997 | 53.93 | 48 | 20.25 | 18 | 37.52 | 34 | 0.00 | 0 | 111.70 | 306.03 |
| 1998 | 54.52 | 48 | 21.40 | 19 | 38.63 | 34 | 0.00 | 0 | 114.55 | 313.84 |
| 1999 | 55.37 | 47 | 22.95 | 20 | 38.32 | 33 | 0.00 | 0 | 116.64 | 319.56 |
| 2000 | 45.67 | 36 | 22.64 | 18 | 35.36 | 28 | 23.27 | 18 | 126.94 | 347.78 |
| 2001 | 45.18 | 33 | 22.66 | 17 | 30.49 | 23 | 36.74 | 27 | 135.07 | 370.05 |
| 2002 | 46.72 | 34 | 22.75 | 16 | 27.39 | 20 | 41.25 | 30 | 138.11 | 378.38 |
| 2003 | 47.38 | 32 | 21.84 | 15 | 36.57 | 25 | 40.15 | 28 | 145.94 | 399.84 |
| 2004 | 48.28 | 31 | 21.44 | 14 | 36.43 | 24 | 47.82 | 31 | 153.97 | 421.84 |
| 2005 | 49.83 | 31 | 18.49 | 12 | 38.90 | 24 | 52.10 | 33 | 159.32 | 436.49 |
| 2006 | 48.03 | 28 | 32.35 | 19 | 36.72 | 22 | 53.57 | 31 | 170.67 | 467.59 |
| 2007 | 40.43 | 23 | 33.02 | 19 | 35.71 | 21 | 63.54 | 37 | 172.70 | 473.15 |
| 2008 | 28.51 | 14 | 33.64 | 17 | 27.47 | 14 | 111.18 | 55 | 200.80 | 550.14 |
| 2009 | 17.84 | 8 | 31.77 | 14 | 25.18 | 11 | 145.69 | 66 | 220.48 | 604.05 |
| 2010 | 21.65 | 9 | 34.25 | 14 | 26.49 | 11 | 154.24 | 65 | 236.63 | 648.30 |

Source: WTD, (2006); Hajjaj, (2011)

**Non Revenue Water (NRW)**

NRW is the difference between the volume of water that enters the water system and the amount of water that gives revenue to the utility. NRW includes not only real losses (physical losses) and apparent losses (commercial losses), but also unbilled authorised consumption. Unbilled authorised consumption is that volume of water that is supplied to

group of people but they do not pay back, because they are considered as Very Important Customers (VICs).

The components of NRW can be determined by conducting a water balance analysis. McKenzie and Seago, (2005) state that a clearly defined standardised water balance is the first essential step in the assessment of non-revenue water and the management of water losses in potable water distribution systems. In July 2000, the IWA Task Forces (Alegre *et al*., 2000) on Performance Indicators and Water Losses published a standard international "best practice" water balance, based on measurements or estimations of (i) water produced, (ii) water imported or exported, (iii) water consumed, and (iv) water lost. The IWA water balance provides a Water Balance Calculation that gives guidance to estimate how much water is lost as leakage from the network (physical losses) and how much is apparent losses. This calculation helps the practitioner answer the question 'how much water is lost?' Table 2.11 shows Water Balance calculated for EWA year 2010. The water balance is calculated over a 12 month period (year 2010).

**Table 2.11:** IWA Standard Water Balance (EWA, year 2010 Quantities in $m^3$/year)

| | | | | | |
|---|---|---|---|---|---|
| System Input Volume ($m^3$) **229,612,636 [100%]** | Authorized consumption **[68%]** | Billed authorized consumption | Billed metered Consumption | | Revenue Water **142,107,517 [62%]** |
| | | | Billed un-metered Consumption | | |
| | | unbilled authorized consumption | Unbilled Metered/ unmetered consumption | 13,776,758 **[6%]** | Non Revenue Water [**NRW**] **87,505,119 [38%]** |
| | Water Losses **73,728,361 [32%]** | Apparent Losses | Unauthorized Consumption | 2,296,126 **[1%]** | |
| | | | Customer Meter Inaccuracies [6%] | 8,526,452 **[4%]** | |
| | | Real Losses | Leakage from Distribution mains | 62,905,784 **[27%]** | |

Source: Researcher's calculation, (2011)

Definitions of principal components of the IWA water balance are as follows:

- System Input Volume: is the annual volume input to the particular part of the water supply system. It was measured (229.6$Mm^3$/year)

- Authorised Consumption is the annual volume of water taken by registered customers,
- Non-Revenue Water (NRW) is the difference between the volume of water that enters the water system and the amount of water that gives revenue to the utility. NRW consists of :
- Unbilled Authorised Consumption (usually a minor component of water balance); it was estimated 6% of total input volume.
- Water Losses: Water Losses is the difference between System Input Volume and Authorised Consumption; consisting of Apparent Losses and Real Losses.
- Apparent Losses consist of unauthorised consumption and all types of metering inaccuracies. It is quoted as 5% of system input volume (1% for unauthorised consumption and 4% for customer meter inaccuracies).
- Real Losses are annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering. It was estimated as 27% of input volume.

Official data for annual variation in the Non Revenue Water (NRW) from 1994–2010 is shown in Table 2.12. NRW varies from about 18.52% in 1998 to 38.10% in 2010. In 1994, the level of NRW was estimated at 32.32%; it was substantially reduced to 22.78% in 2002, accounting for 32.1 $Mm^3$ of the total piped water used in that year. In 2004 it had increased to 25.88% and in 2006 NRW was 24.3%, accounting for 39.8 $Mm^3$, while in 2010 it was 38.1%. Leakage from the distribution network alone represents 27.3% of the total unaccounted-for water, or almost 62.9 $Mm^3$; the remainder is from illegal connections and other miscellaneous unbilled consumption (WDD Annual report, 2010).

**Table 2.12**: NRW and leakage %, 1994–2010

| Year | 1994 | 1996 | 1998 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 |
|---|---|---|---|---|---|---|---|---|---|
| NRW % of input water to system | 32.32 | 35.74 | 18.52 | 22.88 | 22.78 | 25.88 | 24.30 | 33.90 | 38.10 |
| Leakage % of input water to system | 25.81 | 20.90 | 15.92 | 18.14 | 18.74 | 18.88 | 17.3 | 23.03 | 27.39 |

Source: WDD, (2010)
Note: %NRW = (input water to system – Revenue water)/ (input water to system) × 100
% Leakage = % NRW - % unbilled consumption - % apparent losses.

The NRW was calculated as the difference between System Input Volume and Billed Authorised Consumption for each year, while leakage was calculated as the difference between system input volume and authorised consumption plus apparent losses.

***Blended water supply quality***

With regard to blended water quality, due to increases in groundwater salinity, the salinity of blended water that is pumped into the distribution network was high and exceeded the national and international standards during period 1985-2006, especially in Hoora, Salmanya and Hamad Town, while it is generally within the national standard in Sitra. Bahrain follows Gulf standard No. 149/1993. Table 2.13 shows Total Dissolved Solid (TDS) levels in blended water (mixing desalinated water with abstracted water saline groundwater) for the period 1991 – 2010. It can be seen that water quality of saline groundwater was improved after mixing with desalinated water during period 2008-2010 for all the stations. In 2010 the TDS level of blended water was between 169 mg/l – 801 mg/l, for most stations except WR1, WR2 and Hamad Town where TDS level was 1060 mg/l, 1003 mg/l, and 1838 mg/l respectively.

**Table 2.13:** Yearly Average Blended Water TDS (1991-2010)

| Station | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hidd BS | 1220 | 1210 | 1750 | 1985 | 2180 | 1900 | 1830 | 1980 | 2303 | 1140 | 1165 | 1265 | 1387 | 1284 | 1340 | 1377 | 910 | 281 | 189 | 266 |
| Muharraq C | 1270 | 1210 | 1710 | 1654 | 1850 | 1910 | 2210 | 2290 | 2501 | 1280 | 1170 | 1365 | 1430 | 1504 | 1600 | 1692 | 916 | 577 | 202 | 338 |
| Hoora | 1320 | 1230 | 1650 | 1460 | 1960 | 1720 | 1575 | 1790 | 2214 | 1117 | 1190 | 1413 | 1495 | 1610 | 1797 | 1872 | 1588 | 749 | 290 | 300 |
| Sanabis | | 2200 | 2610 | 2525 | 1780 | 2620 | 2800 | 2565 | 2747 | 1674 | 1110 | 1205 | 1185 | 1450 | 1342 | 1061 | 559 | 389 | 323 | 583 |
| Seef | Commissioned in 2000 | | | | | | | | | 646 | 1080 | 1146 | 1236 | 1138 | 1069 | 1065 | 713 | 481 | 317 | 701 |
| Budaiya | Started receiving blended water from seef in 2001 | | | | | | | | | | 1500 | 1407 | 1447 | 1292 | 1263 | 1657 | 1054 | 683 | 298 | 801 |
| Sulmaniya | 1360 | 1280 | 1655 | 1440 | 2130 | 1835 | 1660 | 1925 | 2064 | 1417 | 1375 | 1512 | 1762 | 1799 | 1758 | 1701 | 1503 | 699 | 237 | 358 |
| Mahooz | 1185 | 1325 | 1515 | 1320 | 1640 | 1895 | 1375 | 1260 | 1057 | 1000 | 1150 | 1292 | 1326 | 1501 | 1895 | 1593 | 786 | 256 | 199 | 226 |
| Mussalla | 1225 | 1170 | 1535 | 1440 | 1720 | 2030 | 1620 | 1960 | 2122 | 1372 | 1135 | 1405 | 1584 | 1666 | 1400 | 1257 | 569 | 375 | 278 | 256 |
| Sitra C | 850 | 790 | 830 | 875 | 1120 | 1095 | 945 | 935 | 945 | 933 | 935 | 1158 | 1165 | 358 | 516 | 594 | 142 | 161 | 162 | 169 |
| WR1 | 980 | 830 | 1010 | 1075 | 1260 | 1185 | 1180 | 1080 | 1202 | 1217 | 1300 | 1394 | 1390 | 1497 | 1775 | 1416 | 1500 | 1349 | 794 | 1060 |
| WR2 | Commissioned in 2001 | | | | | | | | | | 1220 | 1415 | 1332 | 1414 | 1609 | 1328 | 1500 | 1434 | 816 | 1003 |
| Hamad Town | 970 | 875 | 1080 | 1075 | 1520 | 1075 | 1280 | 1200 | 1262 | 1356 | 1145 | 1439 | 1362 | 1568 | 1812 | 1642 | 1631 | 1467 | 1521 | 1838 |
| Average | 1153 | 1212 | 1535 | 1485 | 1716 | 1627 | 1519 | 1699 | 1906 | 1196 | 1190 | 1340 | 1392 | 1391 | 1475 | 1404 | 1029 | 685 | 433 | 608 |

Source: WTD annual report, (2010)

Note TDS in drinking water should be less than 1000 mg/l as per GCC standard 149/1993

## 2.7 EWA water consumption trends

Demand for blended water covers three areas: domestic needs; industrial, commercial and tourism need; and to a limited extent, agricultural needs. Demand for desalinated water is continuously increasing due to population growth, improved standards of living and economic growth which have fuelled development in other sectors. The volume of water supplied through the public water network in 2010 was 236.63 $Mm^3$.

Table 2.14 represents data on water sales from 1993 to 2010. Data is classified into domestic and non-domestic categories, and the table also shows annual total water sales. Non-domestic categories primarily include commercial and industrial water uses. The data shows that domestic consumers are always the major users of municipal water, accounting for 81.6–92.6% of the total municipal water use. Non-domestic users account for 7.4-18.4% of the total billed consumption, though this has been increasing in recent years. For example 7.4% or 5.7 $Mm^3$ of the total publicly was supplied to non domestic sector in 1993; this had increased to about 10.23 $Mm^3$ in 2000, a percentage share of 10.6%. The drop in the non-domestic share to about 10.3% in 2001 is most probably due to the abandonment of the supply restriction policy from August 2000, which primarily benefited domestic users.

**Table 2.14:** Annual total water sales of municipal water 1993–2010

| Year | Water sales in million cubic metres ($Mm^3$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Domestic | % | Commercial | Industrial | Non-domestic | % | Total sales |
| **1993** | 71.63 | 92.6 | - | - | 5.72 | 7.4 | 77.35 |
| **1994** | 73.26 | 92.0 | - | - | 6.39 | 8.0 | 79.65 |
| **1995** | 72.14 | 91.9 | - | - | 6.40 | 8.1 | 78.54 |
| **1996** | 72.14 | 91.7 | 6.49 | 0.06 | 6.55 | 8.3 | 78.69 |
| **1997** | 71.26 | 89.8 | 7.69 | 0.42 | 8.11 | 10.2 | 79.37 |
| **1998** | 80.55 | 89.7 | 7.82 | 1.40 | 9.22 | 10.3 | 89.77 |
| **1999** | 81.47 | 88.5 | 9.13 | 1.43 | 10.56 | 11.5 | 92.03 |
| **2000** | 86.52 | 89.4 | 8.77 | 1.46 | 10.23 | 10.6 | 96.75 |
| **2001** | 86.22 | 89.7 | 8.32 | 1.55 | 9.87 | 10.3 | 96.09 |
| **2002** | 86.52 | 89.4 | 8.77 | 1.46 | 10.23 | 10.6 | 96.75 |
| **2003** | 91.42 | 89.3 | 9.42 | 1.51 | 10.93 | 10.7 | 102.35 |
| **2004** | 91.60 | 86.6 | 11.61 | 2.51 | 14.12 | 13.4 | 105.72 |
| **2005** | 98.03 | 88.4 | 11.39 | 1.51 | 12.90 | 11.6 | 110.93 |
| **2006** | 102.88 | 88.2 | 12.06 | 1.64 | 13.70 | 11.8 | 116.58 |
| **2007** | 105.47 | 87.8 | - | - | 14.60 | 12.2 | 120.07 |
| **2008** | 112.94 | 89.8 | - | - | 12.78 | 10.2 | 125.72 |
| **2009** | 100.80 | 85.1 | 15.69 | 2 | 17.69 | 14.9 | 118.49 |
| **2010** | 115.94 | 81.6 | 24.54 | 1.62 | 26.16 | 18.4 | 142.11 |

Source: EWA Customer Services Directorate Annual reports, adapted by author, (2009); Al Jamri, (2010); Milur, (2011)

## 2.8 Water policy and legislative environment and institutional arrangement for water supply in Bahrain

Bahrain does not have a clear policy on water use and management. The overall management of water resources is on an ad-hoc basis through several uncoordinated pieces of legislation spread amongst several Ministries and other non-governmental institutions. It is aimed at solving specific issues without consideration to harmonisation (Al-Mansoor, 1999; Al-Noami, 2004; Al-Masri, 2010; Zubari, 2010).

According to Es'haqi's (2009) study, the absence of a water-related institutional framework; the deficiency of stakeholder's awareness; the weak public involvement and participation, as well as ineffective water related policies strategies in Bahrain have contributed towards creating unsustainable attitudes towards water conservation actions. The problem had been operational and behavioural.

The majority of the policies and legislation address the problem of water supply and distribution, and do not make explicit attempts to address the issue of water demand

management (Zubari, 2010). This is to be expected, as the concept of water demand management is new for Bahrain.

The enabling environment basically comprises the national policies and the legislation that constitutes the "rules of the game" and enables all stakeholders to play their respective roles in the development and management of water resources; including information and capacity building to facilitate and exercise stakeholder participation.

The Water Resources System (WRS) in the Kingdom of Bahrain is managed by three different institutions:

(i) The Electricity and Water Authority (EWA), which is responsible for the provision and management of potable water supply services for the whole country. It is in charge of water supply in the water distribution network, and is responsible for providing potable water of good quality to customers. EWA has three directorates whose responsibilities are as follows:

- The Water Production Directorate, which is responsible for producing desalinated water, and operation and maintenance of production plants;
- The Water Transmission Directorate, which is responsible for transmitting distillate and groundwater from desalination plants and boreholes and is also responsible for blending distillate water with groundwater, then treating and storing it in tanks before distribution; and
- The Water Distribution Directorate, which supplies water from storage tanks through the distribution network, directly to customers' storage tanks.

(ii) The Ministry of Municipalities and Agriculture Affairs (MAA), which is responsible for managing groundwater abstraction for agriculture; and

(iii) The Ministry of Works (MOW), which is responsible for water supply to public gardens and streets and is responsible for collecting and treating Sewage Effluent (TSE) to be used in landscaping. The mandate institutions of these are to formulate policies to face current and future challenges.

The current structure has inter-ministerial linkage or communication. However, there are gaps in this integration mainly due to poor coordination of activities. The poor coordination results in conflicts in the way departments implement their activities. Having three different

agencies (two ministries and one authority) dealing with water supply issues creates problems because of the different policies followed by each. Es'haqi, (2009) in her study states that the weak relationship and sometimes the absence of coherent integration between water authorities had created many conflicts among them. Additionally, the insufficient integration between the water-related authorities and Ministry of Education had resulted in creating unsustainable water knowledge among students jeopardizing future sustainability. Hence there should be integration between all the responsible agencies related to water; ideally it should be managed by just one agency or ministry. Thus, formulated policies cannot be considered as national water policies but rather as sectoral water policies (Al-Mansoor, 1999; Al-Noami, 2004; Al-Masri, 2010; Zubari, 2010).

Legislation provides the basis for government intervention and establishes the context and framework for action by non-governmental entities; hence it is an important element within an enabling environment. The kingdom of Bahrain developed its first water-related law (48/135) in the year 1933 providing a basis for issuing licences for drilling groundwater wells. Many laws have been developed since that time, and can be classified according to their objective into: (i) control of groundwater abstraction, such as laws 2/1971, 12/1980, 23/1980, 10/1982 and 4/1983; (ii) protecting the environment and managing treated wastewater, such as laws 7/1980, 4/1985, 11/1991, 21/1996, and 33/2006; (iii) setting water tariffs, such as law 3/1985, which was modified three times due to social reasons; and (iv) institutional reform, such as law 9/1982 which provided the basis for establishing the Water Resources Council (WRC). Table 2.15 shows some selected Water Governances and orders in the Kingdom of Bahrain.

Despite the technical and legal efforts that were exerted during formulation of these laws, most of these laws faced major difficulties during implementation due to a lack of institutional capacity and insufficient awareness. Consequently, these laws need more enforcement in order to effectively control the WRS and to provide a sound basis for IWRM implementation.

In the case of institutional roles, these comprise identification of water-management institutions and a clear definition of their roles. They also comprise a coordination

mechanism among institutions in addition to capacity building. As was mentioned earlier, the coordination among the three main institutions managing WRS in the Kingdom of Bahrain is inadequate. The participation of each institute, and other stakeholders in the developed policies of other ministries, is minor.

The government has realized this situation and in the year 2009 modified the law no 7/1982, that was initially developed to establish the Water Resources Council (WRC). WRC main tasks are developing National Water Policy and enhancing cooperation and coordination among all stakeholders. Unfortunately, the WRC has not been effective due to a number of reasons. Modification of the law No. 36/2009, includes adding more members to the council and identifying periodic meetings to enforce the role of WRC (Akhbar AlKhaleej, 2009). The main purpose of the decree is the implementing of general water strategies to protect and preserve the water resources, to provide support and necessary guidelines to ensure the implementation of the required strategies, to advise on the needed regulations and laws, to ensure proper usage of the water resources, to operate and maintain all water supply sources, and finally to ensure the citizens' awareness.

**Table 2.15:** Some selected Water Governances and orders in the Kingdom of Bahrain

| No | Law, Legislations and Governances | Year of issue |
|---|---|---|
| 1 | Governmental order for controlling wells drilling by charging fees especially if used for agriculture. | 1933 |
| 2 | Governmental order for fixing good quality valves to reduce water wasting from artesian wells | 1941 |
| 3 | Governmental order for formation of "Water Resources Board" to combat the deterioration of natural water resources condition | 1970 |
| 4 | Governmental order No. 2 for monitoring and managing water control | 1971 |
| 5 | Governmental order No. 12 for monitoring groundwater utilisation. | |
| 6 | Governmental order No. 7 for establishing Water Council | 1982 |
| | Prime Minister order No. 10 for formulation of Water Council | |
| 7 | Governmental order No. 6 water tariff for consuming groundwater from Dammam aquifer | 1997 |
| 8 | Governmental order No. 3 modifying water tariff for consuming groundwater from Dammam aquifer in 1997 | 2000 |
| 9 | Governmental order No. 36 for modifying "establishing Water Council" | 2009 |

Source: Al-Noami, (2004); Es'haqi, and Al-Khaddar, (2008); Al-Masri, (2010); Zubari, (2010) Compiled by researcher, (2010)

## 2.9 Drinking Water costs and water tariff

### *Production cost*

The drinking water cost in Bahrain is expensive as Bahrain depends on desalinating water. This cost covers (a) production cost, (b) purchasing from Alba and Hidd companies, (c) transmission cost, and (d) distribution cost. The production cost of water varies from plant to plant depending on the desalination process used, capacity of plant, efficiency of plant and degree of salinity of the feed water used for desalination. The total drinking water cost increased from BD 24.6 Million in 1985 to BD 53.8 million in 2007. This is because of an increase in drinking water quantity produced and consumed. The unit cost also rose to BD 0.312/ $m^3$ in 2007 and continued to increase where it reached BD 0.380 in 2010, due to an increase in the cost of chemicals and spare parts when inflation has been factored these costs as shown in Table 2.16.

**Table: 2.16:** Production and consumption cost per $m^3$ for the period 1985 - 2007

| Year | Cost (Million BD) | | | | | | Unit cost BD/$m^3$ | Unit price BD/$m^3$ |
|---|---|---|---|---|---|---|---|---|
| | Production | Transmission | Distribution | Purchase from Hidd | Purchase from ALBA | Total | | |
| 1985 | 17,524 | | 7,084 | | | 24,608 | 0.307 | 0.019 |
| 1986 | 21,613 | | 7,430 | | | 29,043 | 0.342 | 0.019 |
| 1987 | 19,392 | | 7,821 | | | 27,213 | 0.302 | 0.032 |
| 1988 | 19,921 | | 7,851 | | | 27,772 | 0.294 | 0.041 |
| 1989 | 20,240 | | 9,019 | | | 29,259 | 0.293 | 0.042 |
| 1990 | 19,256 | | 8,819 | | | 28,075 | 0.274 | 0.560 |
| 1991 | 19,957 | | 8,819 | | | 28,776 | 0.290 | 0.600 |
| 1992 | 18,668 | | 9,224 | | | 27,892 | 0.265 | 0.052 |
| 1993 | 15,841 | 5,971 | 9,437 | | | 31,249 | 0.280 | 0.049 |
| 1994 | 15,973 | 6,856 | 9,095 | | | 31,924 | 0.288 | 0.056 |
| 1995 | 15,654 | 6,813 | 8,937 | | | 31,404 | 0.293 | 0.054 |
| 1996 | 15,565 | 6,422 | 8,808 | | | 30,795 | 0.281 | 0.052 |
| 1997 | 15,076 | 6,625 | 8,891 | | | 30,592 | 0.274 | 0.058 |
| 1998 | 14,704 | 6,628 | 9,035 | | | 30,367 | 0.265 | 0.065 |
| 1999 | 13,468 | 6,086 | 8,839 | | | 28,393 | 0.243 | 0.065 |
| 2000 | 16,448 | 7,070 | 8,774 | | | 32,292 | 0.254 | 0.060 |
| 2001 | 17,580 | 7,120 | 8,600 | | | 33,300 | 0.246 | 0.055 |
| 2002 | 19,590 | 7,450 | 7,290 | | | 34,330 | 0.249 | 0.065 |
| 2003 | 21,140 | 8,140 | 9,640 | | | 38,920 | 0.267 | 0.057 |
| 2004 | 20,860 | 8,720 | 1,021 | | 1,430 | 32,031 | 0.268 | 0.066 |
| 2005 | 29,510 | 7,956 | 9,919 | | 1,911 | 49,296 | 0.309 | 0.060 |
| 2006 | 20,455 | 8,078 | 10,691 | 988 | 2,468 | 42,680 | 0.309 | 0.061 |
| 2007 | 18,797 | 9,906 | 11,885 | 11,353 | 1,862 | 53,803 | 0.312 | |

Note: 1 US $ = 0.378 BD
Source: Al-Masri, (2009)

### *Water tariff*

Metered water users obtaining water from the public supply system are charged according to an increasing block pricing structure imposed in 1990. For Bahrain, the water tariff is substantially lower than the actual production costs. The government heavily subsidises both the domestic, and to a certain extent, the industrial supply.

Water tariffs differ between the various sectors within the country based on consumption. These tariffs are largely imposed as a means of partial cost recovery and limited revenue generation rather than a means of managing demand or recovering costs.

In Bahrain the tariff system includes a very low block rate for small water consumers, incrementally increasing to a high rate for large consumers, using a tariff system referred to as an Increasing Block Tariff (IBT).

The current municipal water tariff for domestic users consists of three blocks, 0.025 BD for consumption less than 60 $m^3$, 0.08 BD for consumption from 60 $m^3$ to less than 100 $m^3$, and 0.2 BD for consumption higher than 100 $m^3$. The current water tariff is not effective as it does not send a signal indicating water scarcity nor does it achieve cost recovery (Al-Masri, 2010). The first 60 $m^3$ of domestic consumption has a low, subsidised tariff; and higher consumption within different ranges is charged at an increasingly high tariff. Similarly, for non-domestic consumption, the first 450 $m^3$ has a tariff of BD 0.300; for more than 450 $m^3$, the tariff is BD 0.400. Table 2.17 shows details of the increasing block tariff system, for domestic and non-domestic water tariffs in Bahrain.

**Table 2.17**: Current water tariff for domestic and non-domestic water use in Bahrain

| Water use and type | Water usage ($m^3$ /month) | Tariff (BD/$m^3$) |
|---|---|---|
| **Domestic water use** | | |
| Blended water | 1–60 | 0.025 |
| | 61–100 | 0.080 |
| | 101 and above | 0.200 |
| **Non-domestic water uses** | | |
| Blended water | 1–450 | 0.300 |
| | 451 and above | 0.400 |

Note: 1 US $ = 0.378 BD
Source: Al Jamri, (2007)

The largest block water tariff for the domestic sector (101 $m^3$ and above) is only charged at 0.200 BD, which is well below the total cost of 0.312 BD/$m^3$ (EWA, 2008). In other words, in the case of the highest consumption block for domestic supplies, the charges do not cover water production and distribution costs. That means the country is not only subsidising the lower block (1–60 $m^3$/month) consumers who are economical in their use of water – but the current tariff also subsidises the large block of consumers who use much larger volumes of water.

For example a domestic customer using 115 $m^3$/ month will pay BD. 7.900

60 × 0.025= BD. 1.500

\+ 40 × 0.080= BD. 3.200

\+ 15× 0.2= BD. 3.000

Total = BD. 7.900 ($ 20)

Analysis of the above facts clearly shows that there is a huge gap between the cost of production and tariffs. Only 20% of what is actually spent on producing water is received as revenue while the balance (approximately 80%) is borne by the government.

## 2.10 Conclusions

This chapter provides an overview of water supply issues in Bahrain, the case study area. At the beginning of the chapter, geographic location and climate, demographic and socio-cultural characteristics were discussed. Water resource problems, quality and quantities were then presented, followed by water consumption trends and institutional management for water supply to Bahrain. Finally, water production costs and water tariffs were discussed.

This chapter revealed the following issues that built up the background to the research focus:

- Water resources in Bahrain are limited to desalinated water and groundwater, and, to some extent, treated sewage effluent.
- Water tariffs are highly subsidised by the government, which encourages wasteful and unnecessary water uses.
- Water quality is poor due to high salinity.

- The absence of integrated private and/ or governmental bodies to be responsible for protecting water resources and issuing water legislation worsens the water situation in Bahrain. Bahrain does not have a clear policy on water use and management.

There is, therefore, a need to carry out research on how water demand management at different levels can contribute to a sustainable water supply for Bahrain. The next chapter reviews the literature on research carried out in sustainable water management, on water demand management measures, instruments, and strategies implemented internationally.

# Chapter 3: Sustainable Water Management: Literature Review

## 3.1 Introduction

Chapter 2 provided the background to the research area and its water problems. This Chapter is a Literature Review about sustainable water management with an emphasis on water demand management (WDM). The objectives of the literature review were to:

- Explore important variables relevant to sustainable water management.
- Explore means of adapting principles of water demand management measures at different levels to sustain water supply.
- Identify the main research methodologies in water demand management.
- Identify gaps in previous research on water demand management.

The data for review were mainly sources arising from a comprehensive literature search. The majority of information was obtained from Pilkington Library (Loughborough University) and through the inter-Library loan facilities available there. It was obtained through the identification and use of key journals, which have published materials on water demand management categories, water demand management measures such as water tariff reform, leakage management, wastewater reuse, and water regulation and bylaws identification of websites.

This literature review includes relevant text books, journal articles, the internet etc. Additionally, a number of seminars, conferences and workshops were attended in order to investigate the various issues related to the field of research and to obtain knowledge on which the researcher's own work could be built. The literature review involved gathering the core international literature that reviewed various aspects of water demand management measures, water supply augmentation, integrated resource planning, and case studies about water demand management.

The keywords used for the search were: water demand management, water saving device, water tariff, leakage detection, wastewater reuse, water meter management, water regulation, Non revenue water and water supply management.

It was difficult to obtain material about water demand management related to the situation in Bahrain, which is an arid region with limited water resources, with a highly subsidised water tariff, and is largely dependent on desalination plants to provide water for its consumers. Most of the literature deals with water demand management for the irrigation sector, groundwater, or one or two water demand measures within one level. Although there are many publications and papers available on the topic of WDM, especially through the WDM initiative of the Canadian International Development Research Centre (IDRC, 1994), a summary paper for the Middle East and North Africa (MENA) region was last prepared in 1997 by Ghezawi (in Brooks et al., 1997). It was thus interesting to obtain an update on the picture Ghezawi drew thirteen years ago. Also, the author made a comprehensive search for literature on water conservation public awareness activities in the Eastern Mediterranean Region (EMR) but few references were retrieved due to the unavailability of material regarding the WDM in the Arab region.

This Chapter reviews options for solving water shortages and provides an overview of integrated water resource management, water supply augmentation, water demand management (with international experience in this subject) and identifies gaps in knowledge about WDM.

## 3.2 Development of options for solving water shortages

Historically, water resources management, especially in urban areas, has passed through several phases, because of the growth in population and water demand. The initial phase, named ‘water abundance’, is characterised by low population numbers and thus low water demand relative to the quantity of water naturally available. As soon as the water demand exceeds the naturally available water supply, the situation becomes one of ‘water scarcity’ where the water resource becomes increasingly inadequate (Xenon et.al., 2002). This focuses attention on increasing water supply via engineering solutions for water resource

development. The strategy includes construction of dams and transportation of water from other locations. This situation has been called the 'supply phase' and results in the so-called 'structurally-induced water abundance' (Xenon et.al., 2002). When the water demand continues to increase, the amount of water that can be obtained by conventional engineering solutions is soon exceeded; a situation of 'water deficit' ensues and any further growth in water demand worsens the degree of water deficit. Arlosoroff (1998, 1999) states, however, that because the water supply management approach considers water needs as **requirements** that **must** be met, and not as **demands** that are variable and changeable, this water supply management strategy may lead to over-use of the resource, over-capitalisation and resource wastage, and may not be a cost-effective solution. Jalil and Njiru (2006) also documented that, along with scarcity of suitable water sources, the costs of developing new approaches to obtaining raw water are steadily rising. In this situation, a new approach for water management, namely Water Demand Management (WDM), is essential to shift the water policy in integrated, and therefore more sustainable, directions.

The current traditional urban water management concepts which were developed in the nineteenth century cannot adequately respond to the change in water demand as the concepts were designed for the urban water infrastructure services, and were mainly driven by public health considerations rather than environmental sustainability (Kayaga et al., 2007; Kayaga and Smout, 2008). This did not take into consideration the rapid population growth rate, high level of urbanisation, industrial growth and the climate changes which the world is currently experiencing.

Kayaga and Smout (2008) documented that current urban water management concepts have the following limitations:

1. High-quality drinking water is not necessary for all domestic purposes. Where there are substantial differences in water quality demanded for different uses in the household, drinking and cooking account for only a small portion of the total volume of high quality treated water.
2. Large volumes of treated water are lost during its long distance transmission.
3. The conventional water management over-emphasises managing supply at the expense of considering demand options. The traditional response to increasing water

demand is development of new water resources. Such supply management is neither environmentally sustainable nor economically viable, as it leads to higher rates of depletion of the finite water resources at higher marginal costs.

4. The institutional set-up causes a highly fragmented division of responsibilities and tasks for water supply and management.

In this situation, efforts to control and manage water demand through water conservation measures and strategies were taken into consideration in order to improve the efficiency of water use (Xenon et al., 2002). This transition is reflected in changes in the general social consciousness around water resources, and driven by a growing understanding of the issues of ecological or environmental sustainability. The management focuses on the shifts from infrastructure management to water resource management, and from limited planning and management to full commitment and participation of the civil society (Xenon et al., 2002). This effort is based on effective water demand management strategies and techniques rather than structural supply solutions. This new approach is referred to as Water Demand Management (WDM), and is seen by researchers (Abu Qdis, 2004; Nkhuwa and Mtine, 2007; Abdel Khaleq, 2008; Al-Masri, 2010; Egbars, 2010) as the preferred alternative to meeting increasing water demand.

Water Demand Management is defined by Schuringa (2000) as a strategy to improve efficiency and sustainable use of water resources, taking into account economic, social and environmental considerations. It relies much more on socio-economic techniques such as economic analysis, establishment of incentives and disincentives, water conservation technologies, reduction of non-revenue water (NRW), reuse of treated wastewater, and public education. Where they have been introduced, these approaches have proved to be very cost-effective in modifying water demand patterns (Arlsoroff, 1998; Abdel Khaleq, 2008).

Due to the constraints in the current urban water management concepts it is clear that application of the urban water management concept will not ensure sustainability (Kayaga and Smout (2008). Such supply management is neither environmentally sustainable nor economically viable, as it leads to higher rates of depletion of the finite water resources at higher marginal costs. Thus there is a need for the application of sustainable development to

developing, as well as developed, nations of the earth, in order to avoid the environmental and social impacts of dominating the water market and thereby depriving the poorest people from having an equitable share of limited available water resources. Efforts by each country are needed in order to develop and manage water resources using an integrated approach (TAC; 2000; UNEP, 2003; Kayaga et al., 2007, Abdel Khaleq, 2008).

Currently, many countries, international donors, and aid organisations have started revising their water policies in order to achieve sustainability of water resources. These efforts gained momentum after the Dublin 1992 International Conference on Water and the Environment.
The recommendations of the Dublin Conference and the 1992 United Nations Conference on Environment and Development (in Rio de Janeiro), emphasised the urgent need to move beyond the traditional management (supply management) practices of water resources, which are typically wasteful, inefficient, and fragmented, to a new paradigm that takes a holistic view of water availability and demand. WDM is a basic tenet of this concept, which integrates quality and quantity concerns, links management of land and water, recognises freshwater, coastal and marine environments as parts of a comprehensive management system, encourages public-private partnership, incorporates institutional incentives that promote efficient and improved sector performance, and focuses on services that users want and are willing to pay for.

Additionally, the 2002 World Summit on Sustainable Development (WSSD) recognised the need to adopt integrated water resources management (IWRM) for the promotion of more sustainable approaches to water development and management (WSSD, 2002).

The World Bank (1993) cited in Lonergan and Brooks (1995:7) reported that ‘responding to water shortage by increasing supplies through different measures has reached its financial, legal and environmental limits. Attention must now shift from development to management’.

At present, calls for integrating WDM strategies into water resources planning come from countries, international communities and non-governmental organisations (NGOs) alike. Demand management is used to reduce the consumption of water, and it is applied in order

to meet water shortages or to improve water use efficiency (Abu Qdais, 2003; Abdel Khaleq, 2008).

Broadly, there are three ways for public water utilities to solve the water shortage problem in any location:

- Finding and developing new sources to increase supply (Griffin, 2006 as cited in Child and Karmer 2008);
- Decreasing demand using existing sources of water (Griffin, 2006 as cited in Child and Karmer 2008); and
- Combining supply and demand side planning in what is referred to as an integrated resource planning process (Beecher, 1995; Abdel Khaleq, 2008).

## 3.3 Overview of Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is an approach that 'Promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (GWP-TAC, 2000:22).

The IWRM principles are in line with the first Dublin principle (ICWE, 1992 as cited in Savenije and Van der Zaag, 2002):

1. Fresh water is finite and vulnerable, essential to sustaining life.
2. Water development and management should be based on a participatory approach involving users, planners, and policymakers together.
3. Women play a major part in the provision, management and safeguarding of water.
4. Water has an economic value in all its competing uses and should be recognised as an economic good.

**The Evolution of IWRM**

There have been serious attempts to implement IWRM in different regions of the world over several decades. Many trace the roots of IWRM to the 1940s (Tortajada, 2005). However, the roots of IWRM go far beyond that as in many countries water management has been

institutionalized in an advanced and integrated way over centuries. This can be traced back to historic times and the various stages as documented by (Majdalani, 2005) are:

1. **The Sectoral Approach (Historic to 1950s)**

Each sector involved in water and wastewater issues did its own planning and implementation except when the various sectors had overlapping responsibilities.

2. **The Co-operative Approach (1960s and 1970s)**

It became clear that a more cooperative approach between the many agencies involved in planning and activities in the water sector would be more efficient. Some joint planning and activities between two or more stakeholders started to occur.

3. **IWRM – Management-oriented (1980s)**

Early efforts at IWRM were based on an extension of eco-system science to the broader problems of managing water supplies. The goals of such efforts were to improve the techniques, models and data sources for such integration efforts and were presented as 'an integrative approach to water resource or watershed management'.

4. **IWRM – Goal-oriented (1990s to today)**

Majdalani, (2005) identifies the goals as:

- To develop a consensus-based vision of ideal water resources conditions.
- To develop and apply tools for water resource decision-making, such as computer simulation models, conflict resolution tools, data management system.
- To take management actions to resolve identified problems.
- To assign responsibility for actions and costs for remedial measures.
- To monitor the degree of implementation of management actions and progress toward water resources objectives.

IWRM principles cannot be applied wholesale to the urban context, mainly because management boundaries in IWRM are catchment-based, while water supply and wastewater systems in urban areas are usually demarcated along political boundaries. Integrated Urban Water Resources Management (IUWRM) is therefore different from IWRM, mainly because it is operated on a much more local scale. The main components of IUWRM are supply optimisation; demand management; participatory approaches to ensure equitable distribution; improved policy, regulatory and institutional framework; and an inter-sectoral approach to decision-making (UNEP, 2003).

Integrated Urban Water Resources Management (IUWRM) is a concept that covers the entire urban water cycle, including desalination, rainwater, ground and surface water, etc., as well as distribution, treatment, recycling and the protection, conservation and exploitation of water resources at their origin. It also permits authorised local communities to decide on the level of access to safe water, the need to produce more food, the need to create more sustainable livelihoods per unit of water, and the need to manage human water use in order to conserve the quantity and quality of freshwater. Water Demand Management (WDM) and Water Supply Management (WSM) are both components of IUWRM. WDM options and WSM options can be combined to formulate water resource strategies. Box 3.1 shows the principal components of IUWRM as adopted from UNEP (2003).

**Box 3.1- Principal components of IUWRM as adopted from UNEP (2003)**

**Box 3.1- Principal Components of IUWRM as adopted from UNEP (2003)**

Integrated urban water resources management (IUWRM) is a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits.
The principal components of an IUWRM system include:
**Supply optimisation**, including assessment of surface and groundwater supplies, water balances, wastewater reuse, and environmental impacts of distribution and use options.
**Demand management**, including cost-recovery policies, water use efficiency technologies, and decentralised water management authority.
**Equitable access** to water resources through participatory and transparent management, including support for effective water users associations, involvement of marginalised groups, and consideration of gender issues.
**Improved policy**, regulatory and institutional frameworks, such as the implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.
**Intersectoral approach** to decision-making, combining authority with responsibility for managing water resources.

## 3.4 Water Supply Management (WSM)

In the past, efforts to satisfy increasing demand have often been expended principally on increasing the supply of the resource by seeking out new sources of water and expanding infrastructure capacity, as long as they are available abundantly and at a relatively low cost. Thus the water planning paradigm until the last two decades of the twentieth century was mainly characterised by a focus on supply management as identified by Gleick, (2000) and Abdel Khaleq (2008).

Supply management aims to increase supply, and to make more water available to domestic, industrial, agricultural, commercial and other consumers through the exploitation of water resources as highlighted by Al-Jayyousi and Kofahi, (2001):

1. Effective legislation and water use extractions;
2. Optimal utilisation protection and development of existing water resources;
3. Groundwater exploration and recharge;
4. Desalination technology;
5. Recycling of wastewater.

For this reason innovations in the water sector in terms of demand management are rather limited and water conservation measures are perceived only as drought relief mechanisms that result in reduced service levels as discussed by Vairavamoorthy and Mansoor, (2006).
In the past, water supply problems were met by the expansion of water supply facilities or occasionally by conveying water, sometimes over, long distances from where it was available to where it was required. These options are becoming increasingly less viable because the best supply opportunities have been exploited and the 'marginal' opportunities are much more expensive economically and environmentally. It seems that the best opportunities in the future for 'increasing' water availability will be to learn how to manage demand more effectively. This approach is based on the principles of least-cost planning and demand management (Chanan et al., 2004).

## 3.5 Water Demand Management (WDM)

Water Demand Management (WDM) is a relatively new concept in the area of integrated water resources management. Water Demand Management is one of the IUWRM components (Smout et al. 2009). It places much emphasis on the socio-economic characteristics of water use (Arlosoroff, 1998).

The demand management approach differs from the supply-oriented approach by placing more emphasis on social and economic uses of water. Demand management views water use as a demand that can be altered through various policy and technical means, while the traditional view of water use sees water as a requirement that must be met (Tsinde

Development Consultants, 2001; Abu Qdais, 2004; Biswas et al., 2008; Abdel Khaleq 2008). When used together with current water supply management approaches, Water Demand Management offers the prospect of greatly improved water management in comparison with its present status (Abdel Khaleq and Dziegielewski, 2006).

The WDM approach aims at initially assessing the efficiency of water use at both the utility and consumer levels and achieving a more efficient and equitable water use that results in reducing water demand (Kayaga and Smout, 2007; Nkhuwa and Mtine 2007; Al-Masri, 2010; Khatri and Thapa, 2011). WDM also aims to promote the adoption of water demand management tools and policies as essential components in the search to achieve sustainable water management.

Water Demand Management (WDM) can be defined as the development and implementation of strategies that achieve effective sustainable use of available limited water supply as identified by Savenije and Van der Zaag, (2002:99). In other words, demand management is any action that modifies the level and/or timing of demand for a particular resource (White and Fane 2001). WDM is a policy for the water sector that stresses making better use of existing supplies, rather than developing new ones as Winpenny (1997); Biswas et al., (2008) state. The concept of WDM is gaining popularity globally, as it has the potential to increase water availability through more efficient allocation and use (Jalil and Njiru, 2006; Nkhuwa and Mtine, 2007). Water demand is usually affected by certain factors, such as socio-economic characteristics, water resource reliability to meet the needed amount with the required quality at all times, and consumer opinion on the policies followed in managing the water resources (Abu Qdais, 2003).

**WDM, a critical component of the Integrated Resource Planning (IRP)**

WDM is a key component of the integrated resource planning (IRP) approach that was first developed in the energy sector in the 1980s (Beecher, 1995). IRP may be defined as a comprehensive form of planning that uses an open and participatory decision-making process to evaluate least-cost analysis of demand-side and supply-side options as identified by Beecher (1995). Howe and White (1999) suggest that IRP is a process in which water utilities determine the least-cost options that they can use to provide their customers with water-related services that they demand, rather than the water itself The guiding philosophy

of IRP is that demand for a resource such as water is not a demand for that source itself but rather for the services that the resource provides, often called end uses. As such, consumers are seen as generating demand for the end uses, such as clothes washing or toilet flushing, rather than a demand for litres of water (White and Fane, 2001). As a result, increasing the efficiency of resource use is one way to fulfil the demand, as it is assumed that providing the same services with fewer resources makes no difference to the consumer.

Maddaus and Maddaus (2001) state that IRP is a systematic planning process that identifies the most efficient means of achieving the goals, while considering the costs of the project impacts on other social objectives and environmental management goals.

IRP is a long-term iterative process that involves a cycle of evaluating and assessing options, investing in selected options, assessing the conservation results and demand forecasts, and then re-evaluating options.

According to Maddaus and Maddaus, (2001) the key steps in a model IRP process include:

1. Water demand forecasting;
2. Assessment of existing conservation programmes;
3. Demand forecasts for normal, dry and wet and critical year conditions;
4. Supply-side planning to identify water resources with safe yields for all or part of future demand; demand-side planning to identify additional conservation methods to reduce demand, quantified in terms of cost and saving;
5. Supply reliability evaluation, that compares the probability of a supply shortage with short-term demand reductions which could be used to balance supply and demand during droughts;
6. Resource strategies, that combine new supply development and demand reductions into a manageable number of options;
7. How the utility goals/policies inform evaluation of supply reliability and resource strategies;
8. Financial planning for funding the IRP projects, which could include tariff-setting for WDM;
9. Public input throughout the project cycle; and
10. Evaluation of the results, to keep the IRP plan updated.

Figure 3.1 shows the process of IRP while Table 3.1 shows a comparison of traditional urban planning with IRP (adapted from Beecher 1995; Maddaus and Maddaus, 2001; and Turner et al., 2006).

These IRP concepts have been applied in various contexts by water utilities around the world, with significant work done in America and Australia.

The supply measures to increase the supply of water in Bahrain include desalination and development of non-renewable groundwater resources. This research assumes that most of the supply measures have been exhausted, and will require lengthy procedures, or massive investment. Thus, the focus is on demand-oriented measures. The next section describes water demand management strategies.

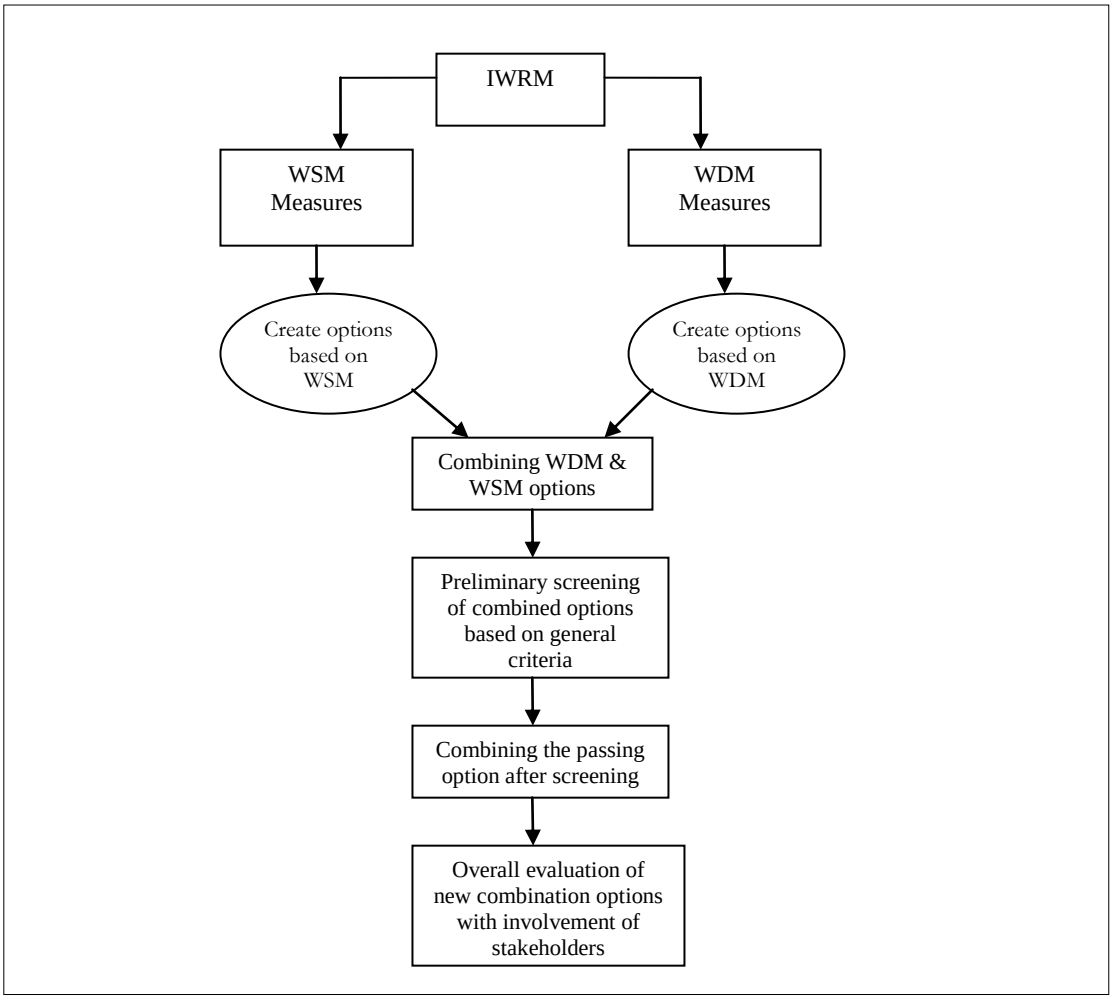


**Figure 3.1:** Integrated Resource Planning Process**.** Source: Author (2006)

**Table 3.1**: Comparison of traditional urban planning with IRP, adapted from Beecher, (1995); Maddaus and Maddaus, (2001) and Turner et al., (2006)

| Criteria | Traditional Planning | IRP |
|---|---|---|
| **Planning Orientation** | | |
| Resource option | Supply options with little diversity | Supply and demand management options; efficiency and diversity are encouraged |
| Resource ownership and control | Utility-owned and centralised | Some resources owned by other utilities, other producers, customers |
| Scope of planning | Single objective, usually to add to supply capacity | Multiple objectives determined in the planning process |
| Assessment criteria | Maximise reliability and minimise costs | Multiple criteria, including cost control, risk management, environmental protection, economic development |
| Resource selection | Based on a communication to a specific option | Based on developing a mix of options |
| **Planning Process** | | |
| Nature of the process | Closed, inflexible, internally-oriented | Open, flexible, externally-oriented |
| Judgement and preferences | Implicit | Explicit |
| Conflict management | Conventional dispute resolution | Consensus-building |
| Stakeholders | Utility staff and its rate-payers | Multiple interests |
| Role of stakeholders | Disputants | Participants |
| **Planning Issues** | | |
| Supply reliability | Constraint and high priority | A decision variable |
| Environmental quality | A planning constraint, complying with regulations | A planning objective |
| Cost considerations | Direct utility system costs | Direct and indirect costs, including environmental & social externalities |
| Role of pricing | A mechanism to recover costs | An economic signal to guide consumption, and a way of sharing costs and benefits between different stakeholders |
| Risk and uncertainty | Should be avoided or reduced | Should be analysed and managed |

### Water demand management (WDM) strategy for urban water supplies

White (1998:7) states, 'A demand management strategy is a key component of overall strategic planning process for a water utility that is facing the need for increased supply capacity, or wishing to improve the level of reliability of its water supply'. Meanwhile, Nkhuwa and Mtine (2007) state that implementing WDM measures will ensure the

economic value of water is recognised in all policy and sector activities. Thus, wise and efficient use of water resource is initiated and promoted in urban centres.

Water demand can be managed through a wide range of demand management measures such as economic (e.g. cost-effective pricing, tariffs, incentives), legal and institutional (e.g. regulations, building code, capacity building, setting a legal framework), technical (e.g. leakage detection and repair programmes, metering, pressure control, water conservation campaigns), and behaviour modification and educational (e.g. public awareness campaigns, seminars, media campaigns) (White, 1998; White and Howe, 1999; Brooks, 2000; Green, 2003; Abu Qdais 2004; Abu-Zeid. et al., 2004; Stacey, 2004; Biswas et al., 2008; Al-Masri, 2010; Khatri and Thapa, 2011; Kayaga, 2011a).

Dziegielewsk, (2003) suggests that in practice, water demand management requires a combination of measures to motivate people and their activities to regulate the quantity, manner and price by which they access, use and dispose of water, thus alleviating pressure on freshwater supplies and protecting quality.

Therefore, the starting-point for a comprehensive WDM programme is setting out a clear strategy which is acceptable to water utilities, customers and politicians. This strategy should be planned and implemented at both the utility (supply) level and the customer (domestic and non-domestic) level. WDM measures related primarily to actions by the water utility, and which are designed to be implemented by it, include pricing reform, metering, control of non-revenue water, including leakage detection and repair, authority water use and reuse. WDM measures should also be applied at the customer end of the water industry, since it is the customer who must ultimately manage his or her water demand and use water efficiently. Box 3.2 shows measures commonly applied in WDM strategy for urban water supplies as identified by Jalil and Njiru (2006).

The listed measures fall into broad categories: those that promote structural/technical changes and those that promote behavioural changes (Turner and White, 2006; Biswas et al., 2008). As defined in Box 1.2, Chapter 1, the WDM strategy is a combination of measures and instruments.

**Box 3.2**: WDM measures commonly applied. Adapted from Jalil and Njiru, (2006).

**At policy (government) level**

- Policymaking for WDM
- Supportive tariffs that promote water demand management
- Implementation of bye-laws yielding better water demand management

**At the utility (service provider) level**

- Reduction in system losses
- Minimising operational wastages for flushing and reservoir cleaning
- Proper metering and billing reforms, e.g. use of universal metering, volume-based pricing
- Disconnecting illegal connections and preventing illegal connections
- Control of overflowing water tanks
- Ensuring that meters fitted in the system are relatively accurate
- Imposing heavy penalties on illegal water users
- Controlling or abolishing street water points
- Institutional capacity building on WDM measures
- Ensuring accountability of tariff of the water utility
- Introducing efficient and customer-friendly billing system
- Rationing water when necessary
- Detailed feedback system for customers
- Training and advisory services to customers
- Detailed water use analysis (audits) among consumers in the various sectors
- Minimum performance standards for efficiency of equipment and appliances
- Subsidy on cost of purchase for water-efficient equipment

**At the customer (domestic and non-domestic) level**

- Using water-efficient processes in industries (process modification)
- Adapting clean technology in the manufacturing processes of industries
- Installing low water use appliances (e.g. low flush/double flush cisterns for toilets, water-efficient washing machines, low-flow shower heads, push water taps, manual flushing of urinals)
- Awareness of need for conservation of water
- In-house/ industrial recycling of wastewater
- Prevention of overflowing tanks
- Timely repair of leaks in the service line
- Timely repair or replacement of faulty taps and plumbing fixtures
- Practising water-efficient gardening
- Use of alternative water sources (e.g. rainwater or storm water) for some household uses

Vairavamoorthy and Mansoor (2006) state in order to achieve the objectives of WDM, a number of instruments have to be developed. These instruments are interdependent and reinforced and the most optimal way they are applied will depend on the current local conditions. Instruments used in a WDM programme include: water loss reduction (including leak detection and repair); changes in water-pricing concepts, comprehensive metering; wastewater reuse; installation of water-saving devices (retro-fittings); institutional

development; and public awareness and educational campaigns. Johnson (2011) stated that management of apparent loss component of NRW must take into account the various type of meter measured error and their effect on the water balance.
There are other instruments such as intermittent water supply and rainwater harvesting but these are not considered in this study.

Vairavamoorthy and Mansoor (2006) documented that the use of intermitted supplies is one of the most common methods of controlling water demand. This is done by cutting off the supply of water for most of the day and limiting the consumer ability to collect water. They also argue that this method results in serious problems with the supply, including insufficient pressure, inequitable distribution of available water and short duration of supply. Thus water quality deterioration is envisaged. Fewkes, (2006) states the concept of rain water harvesting is simple, consisting of the process of collecting, storing and using rainwater as a primary or supplementary water source. It is applied in both developing countries and developed countries and is used to supply non-potable water to buildings.

**Economic Measures at Utility Level**

Realistic water-pricing is one of the most fundamental keys to water demand management and is central to many of its options. Charging for water on a per unit basis with payment tied to volumetric use is one of the most powerful methods to encourage WDM (Arlosoroff, 1999; Biswas et al., 2008; Kayaga, 2011a).

Simply stated, prices promote better water-use practices in the sense of moving toward increasing conservation and sustainability in the use of water resources and send a signal to both consumers and producers about the economic value of the resource use as identified by Tate (1990). A study by Olmstead and Stavins (2008) indicated that water demand management through non-price techniques is a devastatingly dominant paradigm in cities around the world. It states that ‘Raising prices, particularly for what people perceive to be a ‘public service’, can be politically difficult. Non-price programs are more expensive to society than water price increases, once the real costs of programs and associated welfare losses are taken into consideration’, Olmstead and Stavins (2008:18). It also indicates that raising water price (like elimination of any subsidy) is politically difficult, but there may be

political capital to be earned by elected officials who can demonstrate the cost effectiveness advantages of the price-based approach. Foster et al., (2000) state that there is new concept called 'Direct Subsidy' which means that the subsidy is directed towards a certain portion of the society i.e. the poor.

Tariff and pricing are conservation strategies because they involve understanding the true value of water and conveying information about that value, through prices, to water customers. The change in the customer use of water is often considered a necessary (but not always sufficient) part of water conservation strategy. Utilities should conduct a cost analysis to understand what types of usage drive up system costs (Al Senafy et al., 2008). Mayer et al., (2007) documented that the water tariff rate structure offers the promise of more stable revenue generation. It improves customer acceptance to conserve water, and increases water use efficiency. It also offers potential benefits to water utilities and their customers in terms of coping with increasing water scarcity. Kayaga (2011a) reported choosing an appropriate pricing strategy is difficult. Ideally the tariff should be based on full-cost pricing, to include all costs of construction, operation, maintenance and replacement of infrastructure. However, not only is it difficult, but in many cases policy makers are reluctant to recover full costs from customers.

There are also socio-religious factors to consider when establishing water pricing strategies: Faruqui et al., (2001) clearly states that recovering costs for providing water is allowable in Islam. But what is a fair tariff? According to Islam, a fair tariff will lead to greater equity across society.

Water-conservation tariff structures include flat tariff structures and increasing tariff structures. Increasing slab tariff structures have varying water rates for step-wise increases in water use. Kayaga (2011a) states for the tariff to work effectively as an economic measure for WDM, customers' premises should be fitted with meters that record consumption accurately, and the tariff structure should be designed so that it is water conserving. Kenny et al. (2008) point to literature which indicates that the simple existence of an increasing rate structure has been proven to decrease residential water demand. Flat rate structures result in a constant price for any volume of water use. These structures are included because they are

a conservative alternative to a third type of rate structure: the declining block rate structure. This price structure charges a decreasing rate for water as volumetric use increases.

Conservation-oriented pricing requires planners to make certain assumptions (based on the available empirical evidence) about the elasticity of water demand, or the responsiveness of water usage to a change in price. Elasticity of water demand is a common indicator of pricing effects on demand because it measures empirically the amount by which customers will change their demand for water for a given change in price. Elasticity is measured by the ratio of a percentage change in quantity demanded to a percentage change in price. The formula for the coefficient of price elasticity of demand for a good is

$$\mathbf{E_D = \%\ change\ in\ quantity\ demanded / \%\ change\ in\ price = (\Delta Q_d / Q_d) / (\Delta P / P)}$$

The price elasticity of demand for water is normally discussed in terms of values between zero and one and values greater than one. An elasticity value $E_D < 1$, means that demand is inelastic, in the sense that an increase in price leads to a less-than-proportional increase in demand. Elasticity values greater than one $E_D > 1$ implies that the changes in demand are more than proportional to the causative change in price. In actual fact, elasticity values are always negative in value. By convention, however, the values are discussed in absolute terms. This shows that demand for water is inelastic over the initial quantity of water used, which means that price change affecting this range of water use will not be very effective in inducing a decrease in water demand. This equation is not appropriate to apply for the water sector as a whole, but for certain sub-sectors (e.g. urban water use, industrial water use, and irrigation). It may serve the purpose of analysing the impacts of tariff changes on water consumption. The problem with the equation is that $E_D$ is not constant; it depends on the price and water use, and it varies over time as identified by Klaiber et. al, (2010). Other than tariffs, a water supply providers could apply subsidies to encourage water conservation by end-users economic instruments include incentives to reduce consumption, as has been undertaken in Zaragoza (Kayaga, 2011b).

**Structural and Operational Measures at Utility Level**

Structural measures are those that alter existing structures in order to achieve better control over water demand. These measures could be taken at the utility level to reduce water losses.

Examples of structural measures include metering, retro-fitting, controlling flow, and recycling (Shawky, 2001; Biswas et al., 2008; Kayaga, 2011a). Operational measures are actions by water suppliers and customers to modify existing water use procedures in order to control demand patterns more effectively. They include network leakage detection and repair and water use restrictions during periods of water shortages at utility level, while using water-saving devices, behavioural practices at the users' end that conserve water, and use of renovated wastewater for irrigation and other non-potable purposes.

**Water metering management at utility level**

Water metering is not a direct conservation measure, but it is essential for a successful WDM programme as it is the link between consumption and price. Without metering, any attempt at demand-based pricing and demand management will be ineffective (Tate, 1990; Shawky, 2001; Biswas et al., 2008). It has been widely demonstrated that "if you cannot measure, you cannot manage". Moreover, "if a job is worth doing, it is worth doing well". These statements hold true in water-metering as well. Full metering helps with assessing non-revenue water. The water bill based on the meter reading is the principal communication between the customer and the water authority. Thus all meters should be in good working condition (White, 1998; G2C, 2006; Biswas et al., 2008; Kayaga, 2011a).

Several studies have found that metering alone can substantially reduce water use by 20 to 40 percent and allow easier detection of system leaks. This is achieved by introducing meters where they have not previously been used (Ruthann, 1991).

There are several types of customer meters in common use. Positive displacement meters are the most common, in addition to multiple jet inferential meters.

A positive displacement meter operates on a piston or other arrangement so that it is difficult for water to pass without moving the metering parts. While the jet type inferential meter relies on the impulse applied to turn an impeller and register the volume of water passing, positive displacement meters are better able to record low flows, such as those from a dripping tap (White, 1998).

Positive-displacement meters are mainly used for domestic purposes due to excellent sensitivity to low flow rates and high accuracy across a wide range of flow rates. A known volume of liquid in an enclosed compartment moves with the flow of water and the flow rate is calculated based on the number of times the compartment is filled and emptied. A reduction in the actual volume of each compartment is impossible, for this the meter will stop. Therefore, over-registration will not occur and the error curve will become more negative (under-registration) (Figure 3.2). Consequently, these meters tend to under register actual water usage when they become older and excessively worn.

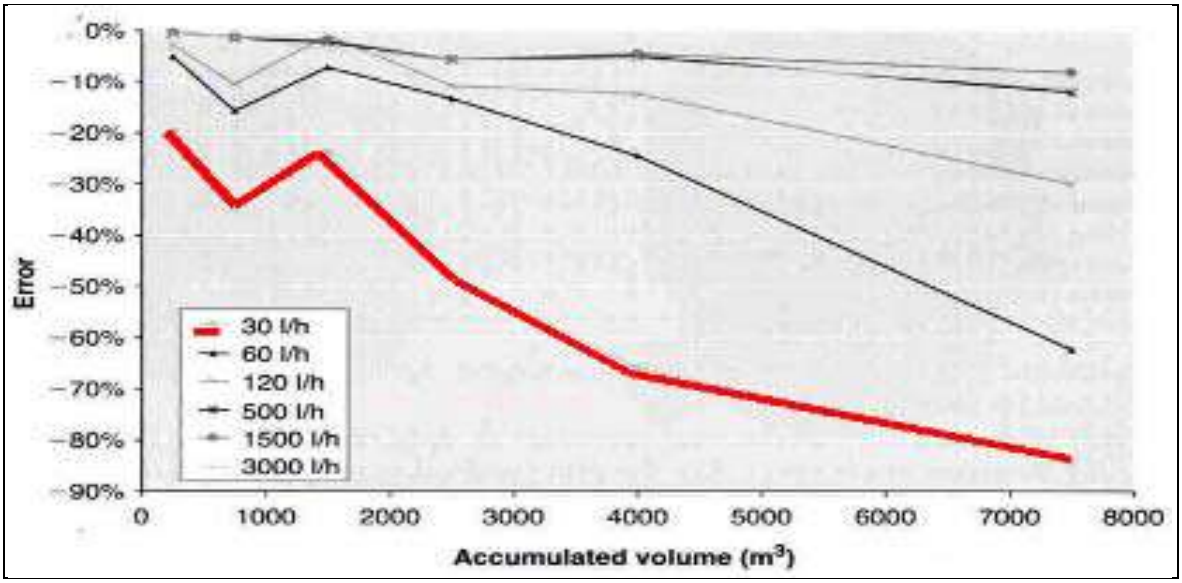


**Figure 3.2:** Evolution of the metering Error obtained from a sample of volumetric meters (1/2") (Arregui el. 2006, p.28) as cited in Yaniv, (2009)

Egbars (2010) states that the accuracy of mechanical meter is affected by the type, age and flow profile of meter, natural wear and water impurities. Thus replacement decisions have been decided by age or when a predetermined limit for usage is reached. Egbar (2010) looks at the use of modelling to determine an optimum replacement strategy for aging meters.

Al Senafy et al., (2008) documented and called for a comprehensive review of metering policy with regard to meter selection and sizing, installation details, allowable pump arrangements, meter replacement programmes and multiple occupancy situations in order to resolve the issues related to metering and arrive at a reliable estimation of water utilisation and network leakage.

Since drinking water bills are based on the quantity consumed, as indicated by meters, all meters must be of good quality and should be replaced regularly within 15 years (depending on the condition of meter and accuracy). The large users of water should be accurately metered, and the meters used might be replaced every two to three years. The accuracy of any assessment of non-revenue water (NRW) is important, especially when the result is to be used for monitoring improvement in performance (Rathberger, 2011; Jonson, 2011). In Australia and New Zealand, metering consumer connections has recently been deemed necessary in reducing water use (G2C, 2006).

Many problems have been reported, mainly related to mis-measurement resulting from poor meter quality, poor water quality, incorrect sizing and incorrect installation (Farley and Trow 2003; Vairavamoorthy and Mansoor, 2006).
Meter inaccuracies can be caused by a number of factors, including the age of the meter and low flows through the supply pipes.

It is noted that accuracy of meters deteriorates with usage; it mainly affects the low flow range, mostly in domestic meters, as most of the flow in domestic meters is less than 1,000 l/hr (White, 1998). The cumulative potential error from under-registration of customer water meters may be up to 10% of all water delivered, although this will depend on the type and age of meters, the water quality and other factors.

Existing residential water meters have been found to be unreliable for low flows and for water that contains sediment. The meters also have a limited life and generally need replacement every ten years, or depending on the results of monitoring and manufacture's specifications (White, 1998; Bird, 2011). In addition to a meter-testing program, a water supplier should develop a meter replacement program to replace or repair defective meters. Customer meters may need to be replaced at least once every 10 years, if not earlier. In accordance with AWWA Manual M6, a planned meter replacement program can be implemented over a given number of years, e.g., 10 percent of the meters each year over 10 years or 20 percent per year over five years, so that all replaced meters in the system will be the more-efficient, modern design (White 1998; EPD, 2007).

As documented by Yaniv (2009) and Fantozzi et.al (2011), a solution to this problem has been developed by ARI- the unmeasured flow reducer (UFR), it is also known as Low Flow Control Valve (LFC) which is installed before or after the meter and creates a batch flow through the meter as the pressure drops on one side of the UFR and pulls a plunger back from a membrane to let water through (refer to Figures 3.4 & 3.5). The meter can then pick up the water used which would have otherwise passed slowly through the meter undetected. Several studies have been carried out during the last three years to address the problem of meter-under registration, and to evaluate the use of unmeasured flow reducer (UFR) in several countries such as Israel, Cyprus, Palestine Italy and Malta (Davidesko, 2007; Christodoulides, 2008; Fantozzi et.al, 2011).


**Figure 3.3:** UFR - Unmeasured-Flow Reducer, Source: Yaniv (2009)

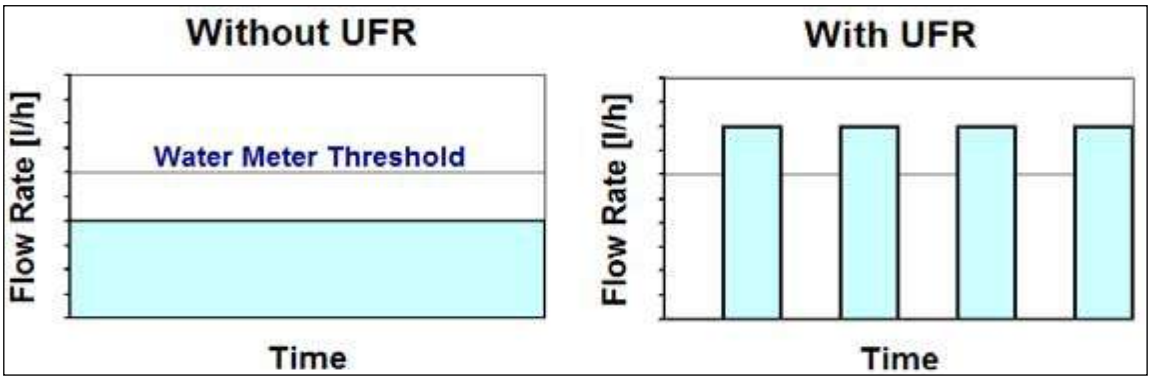


**Figure 3.4:** UFR – Principle of Operation, Source: Yaniv (2009)

**Water loss management at utility level**

There is increasing global awareness that water resources are limited and that careful management must be applied when dealing with a scarce resource, particularly water lost from potable water distribution systems (Seago et al., 2005).

Water loss can be determined by conducting a water balance using the IWA water Balance standard as shown in Table 3.2. It is expressed as: the difference between system input

volume and authorised consumption, and consists of apparent losses and real losses. While non-revenue water is expressed as: the difference between water input volume and water billed or consumed. It provides a good measure of the efficiency of a water supply system as it includes all water which is delivered in bulk but is not registered on a meter as having been used. Water losses occur in all distribution systems; only the volume of loss varies depending on pipe network age, water utility operational practice and level of technology and experience applied in controlling it (Farley and Trow, 2003). NRW is influenced by an error in calculating apparent loss (Jonson, 2011).

**Table 3.2:** IWA Standard Water Balance, Source: McKenzie et al., (2007)

| | | | | |
|---|---|---|---|---|
| System Input Volume | Authorized consumption | Billed authorized consumption | Billed metered Consumption | Revenue Water |
| | | | Billed un-metered Consumption | |
| | | unbilled authorized consumption | Unbilled Metered/ unmetered consumption | Non Revenue Water [**NRW**] |
| | Water Losses | Apparent Losses | Unauthorized Consumption | |
| | | | Customer Meter Inaccuracies | |
| | | Real Losses | Leakage from Distribution mains | |

Water losses are grouped into two types– real losses and apparent losses. Real losses, which are also referred to as physical losses, include leakage from pipes, fillings, and joints. The volume will depend on pipe network and leak detection and repair policy practised; leakage in a water system occurs from a few large leaks and a large number of small leaks. The smaller leaks can be difficult to locate, and consequently it is impracticable and uneconomic to eliminate leakage completely (White, 1998).

Apparent losses are caused by revenue meter under-registration, water theft, illegal metering errors and billing errors. Real losses are an expense owing to lost water; apparent losses are not so much of an expense to the water utility as a loss of potential revenue.

Water loss can be determined by conducting water balance, while leakage is assessed through a comprehensive and intensive leak detection programme. This programme involves

visual inspection for leaks along transmission and distribution pipeline routes, and conducting leak detection night tests for distribution mains.

It is important to differentiate between water loss and leakage. The International Water Association (IWA) defines water loss as:

Water loss = 'real' losses + 'apparent' losses.

Real losses comprise leakage from pipes, joints and fittings, from leakage through service reservoir floor and walls, and from reservoir overflows.

Water losses are often expressed as a percentage of the water into supply, or water into the distribution system. Trow, (2007) documented that it is generally accepted that percentages are not good technical measures because they are affected by other factors such as customer demand, and their use must take into account actual customer use, and also level of intermittency of service. Owing to the disadvantage of relying on water balance for assessment of real losses as percentage of water input to the system, they should be assessed by additional methods. The International Water Association's (IWA) sub-task force has introduced a methodology for determining and comparing leakage in water distribution systems, which is now accepted as best practice in many countries worldwide. It is a performance indicator; the Infrastructure Leakage Index (ILI) is the dimensionless ratio of the Current Annual Losses (CARL) to the Unavoidable Annual Real Losses (UARL). UARL is calculated using an empirical formula (based on an auditable component analysis of real losses) which varies in terms of mains length, number of service connections and average distance from property line (or curb stop).

$$ILI = CARL/UARL \qquad \text{[Equation 1, Lambert 2005]}$$

$$UARL = [18 \times L_m + 0.8 \times N_c + 25 \times L_p] \times P \qquad \text{[Equation 2, Lambert 2005]}$$

Where, CARL: current annual real losses (L/day)

UARL : unavoidable annual real losses (L/day)

ILI : Infrastructure Leakage Index (dimensionless)

$L_m$ : length of mains (km)

$N_c$ : number of service connections (connections)

$L_p$ : total length of pipe between property line and customer (km)

P : average operating pressure (m)

ILI is a main indicator for comparing levels of leakage amongst water utilities and between zones within the same supply organisation (Trow, 2007). It is dimensionless, it measures how effectively the infrastructure activities (speed and quality of repairs, active leakage control and pipeline material) are being managed at current operating pressure. However, once the ILI is calculated, the next step for water utility is to ask 'how low can we go?' as documented by Preston and Sturm (2007).

Leak detection programmes are reported to reduce levels of unaccounted-for water loss by 50-75% in small systems (Tate, 1990).

Although experienced practitioners consider the ILI as the most appropriate performance indicator for real losses, in terms of physical losses, they questioned the initial applicability limitations for the ILI in areas with usually high pressure or unusually low pressure that may make comparison between different networks difficult (Liemberger and McKenzie, 2005):

- The unavoidable annual real loss (UARL) equation is based on length of main, number of service connections, length of underground pipe from the mains to the point of metering and average system pressure. This data is difficult to provide for utilities with a poor Management Information System (MIS).
- The use of ILI is not valid in cases when a water utility operates under either abnormally high or unusually low pressure. The ILI calculation equation is only valid in cases where the average system pressure is in the range 25-90 m.
- The use of ILI is not valid for systems with < 3000 connections.
- The system should have no less than 20 connections/km of mains.

A lower limit of 25m for pressure was introduced to avoid significant errors from extrapolating the assumption of a linear pressure: leakage relationship to systems with 100% flexible pipes at low pressures, where the N1 exponent would be close to 1.5 (note: Leakage varies with $\text{Pressure}^{N1}$) (Liemberger and McKenzie, 2005). The accuracy of ILI depends less on the accuracy of the (empirical) UARL formula but on the accuracy of annual value of real losses, average pressure and distribution network data. The proposed adjustment can help to manipulate the ILI for systems with unusual pressure conditions, and the existing approach has proved most useful in a variety of system (mainly in Asia) where very low pressures and intermittent supply are experienced (Seago et al., 2005).

In order to address water supply system in countries with a high level of leakage and correspondingly high ILI values, Liemberger et al (2007) state that the World Bank Institute have adopted, and are promoting internationally, a broader based banding system applicable to both developed and developing countries. This uses a matrix approach to identify a Technical Performance Category (Bands A to D) for a Utility's management of Real Losses, and guidance on the type of actions the Utility should be undertaking.

Table 3.3 shows the WBI Target Matrix, which is expressed in terms of litres/service connection/day, and average pressure. The values in the Matrix, in litres/connection/day, are based on the assumption that customer meters are located at the property line, with an average density of connections of 40 per km of mains. For meter locations and connection densities significantly different to these assumptions, users may wish to calculate the ILI and use it to identify the appropriate band for the system under consideration. On the other hand, a banding system to Interpret ILIs is shown in Table 3.4.

Liemberger and McKenzie, (2005) considered that this approach was appropriate for use in both developed as well as developing countries as it is after all deemed to be a relative indicator which is used to highlight whether or not a system has a serious leakage problem. A system with an ILI of 30 will be regarded as having a serious leakage problem as will a system with a value of 130. It is, however, important to understand that ILI values in low pressure situations tend to err on the low side and can often be up to 60 percent higher - depending on the material mix of mains and service connections.

Liemberger and McKenzie (2005) documented that, despite the accuracy limitations described above, the ILI is still the best indicator for quickly describing the level of real losses of a system. Although all the above points are valid concerns, the ILI has also proved to be extremely useful in South East Asia; even in instances where it has been used outside the normal acceptable ranges (Seago et al., 2005).

**Table 3.3:** Proposed use of ILI as a Performance Indicator in developed and developing countries

| Technical Performance Category | | ILI | Unavoidable Annual Real loss (Litres/connection/day) (when the system is pressurised) at an average pressure of: | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10 m | 20 m | 30 m | 40 m | 50 m |
| Developed Countries | A | 1 - 2 | | < 50 | < 75 | < 100 | < 125 |
| | B | 2 - 4 | | 50 - 100 | 75 - 150 | 100 - 200 | 125 - 250 |
| | C | 4 - 8 | | 100 - 200 | 150 - 300 | 200 - 400 | 250 - 500 |
| | D | > 8 | | > 200 | > 300 | > 400 | > 500 |
| Developing Countries | A | 1 - 4 | < 50 | < 100 | < 150 | < 200 | < 250 |
| | B | 4 - 8 | 50 - 100 | 100 - 200 | 150 - 300 | 200 - 400 | 250 - 500 |
| | C | 8 - 16 | 100 - 200 | 200 - 400 | 300 - 600 | 400 - 800 | 500 - 1000 |
| | D | > 16 | > 200 | > 400 | > 600 | > 800 | > 1000 |

Source: World Bank institution banding system cited in Liemberger and McKenzie, (2005)

**Table 3.4:** Banding system to Interpret ILIs

| Developing counties | Developed countries | Band | General description of real loss performance management categories |
|---|---|---|---|
| ILI Range | ILI Range | | |
| 1 - 2 | 1 - 4 | A | Further loss reduction may be uneconomic unless there are shortages; careful analysis is needed to identify cost effective improvement |
| 4 - 8 | 2 - 4 | B | Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance |
| 8 - 16 | 4 - 8 | C | Poor leakage record; tolerable only if water is plenty and cheap, even then analyze level and nature of leakage and intensify leakage reduction efforts |
| > 16 | > 8 | D | Very inefficient use of resources; leakage reduction programs imperative & high priority |

Source: Liemberger and Mckenzie (2005)

McKenzie, et.al, (2007) documented that for many developing countries, ILIs for some systems are usually found to be in excess of 10, or in some cases even in excess of 100, so very low ILIs can be considered almost an impossible target for such systems. In such cases the ILI values obtained for developing countries tend to be extremely large (often over 50) and are not suitable for general benchmarking with other data sets from developed countries

around the world. However ILI is still considered to be a useful indicator in its current form for identifying areas with the highest leakage.

**French Performance indicator: Linear Leakage Index performance indicator (LLI)**

Another performance indicator for evaluating water distribution network is the French Linear Leakage Index. The linear leakage index (LLI in $m^3/h/km$) is calculated by dividing the volume of leakage by the length of mains.

LLI = loss flow rate during distribution ($m^3/h$) ÷ length mains pipeline (km)

It is expressed in cubic meters per hour per kilometre ($m^3/h/km$). The recommended range for LLI band varies from Good to Poor. Table 3.5 shows the network category against LLI band.

**Table 3.5:** Water distribution network evaluation based on Linear Leakage Index (LLI) all values in ($m^3/km/hr$)

| Type of network | Rural | Residential | Urban |
|---|---|---|---|
| Good | <0.06 | <0.13 | <0.3 |
| Average | <0.1 | <0.2 | <0.4 |
| Bad | 0.1<LLI<0.16 | 0.2<LLI<0.33 | 0.4<LLI<0.63 |
| Poor | >0.16 | >0.33 | >0.63 |

Source: G2C report, (2006)

It can be used to separately qualify District Meter Areas (DMA's) or waste zones.

Leakage flow rate in distribution systems is defined as the sum of wasted flow rate, stolen flow rate and leaked flow rate.

This indicator takes into account the length of mains and level of urbanization (density of service connections). These two parameters characterize the importance and complexity of installations. The LLI has the advantage of enabling comparisons between different areas of the same network. The disadvantage is that it does not allow true international comparison as ILI claims, it requires co-ordinated readings of customer meters and bulk meters.

**Installation of water saving devices as WDM measure at domestic /non-domestic levels**

Water-saving devices provide one of the most effective short-term options for reducing water demand, particularly in the high-income domestic and institutional sectors. They include the use of low flush toilets, low-flow showerheads, tap aerators and pressure-

reducing valves, self-closing delayed action taps, constant flow regulators, and, dual-flush cisterns (Al Senafy et al., 2008; Biswas et al., 2008).

Vairavamoorthy and Mansoor (2006) found that by installing water-saving devices in government buildings or institutions such as university campuses, ministry buildings and government hospitals, water consumption could be reduced by as much as 20%. Studies often indicate that residential demands account for about three-quarters of the total urban water demand. Indoor use accounts for roughly 60% of all residential use and, of this, toilets (at twelve litres per flush) use nearly 40%. Toilets, showers, and taps combined represent two-thirds of all indoor water use (Al Senafy et al., 2008). These figures are valid for Bahrain as it has the same climate and environment and socio-economic conditions. Other studies indicate that installing one water-saving device can decrease household water use by as much as 8-10% in each instance (Renzetti, 2002; Biswas et al., 2008).

Al Senafy et al., (2008) reported that tap aerators, which break the flowing water into fine droplets and entrap air while maintaining wetting effectiveness, are inexpensive devices that can be installed in sinks to reduce water use by as much as 60% while still maintaining a strong flow.

**Use of wastewater as WDM measure at domestic /non-domestic levels**

Wastewater is a potential resource of great importance, with volumes rising and continuously available (Abid, 2005). The use of recycled or reclaimed water is the most significant of demand management strategies because it reduces the demands on available water resources by supplying reused water to activities which would have utilised potable water from the distribution system (Tate, 1990; Strauss, 1991; Al Alawi and AlKindi, 2005; Vairavamoorthy and Mansoor, 2006; Bukhari and Al-Harazin, 2010).

Wastewater re-use leads to savings in conventional water, which could then be reserved for meeting the demand for higher-quality water such as that for drinking, or for high value-added industrial and agricultural uses. Re-use can also help mitigate the impact of climate variability. Re-use should be integrated into water resource management strategies and planning (Abid, 2005; Al Qallaf, 2005; Biswas et al., 2008).

Potential applications of wastewater re-use includes centralised collection and re-use for landscaping and irrigation (parks, sports fields and cemeteries); industrial recycling and reuse (cooling water, and where industries reuse water with various qualities as required for various processes) (Al Senafy et al., 2008; Vairavamoorthy and Mansoor, 2006) and grey water reuse in households (mainly for gardening, flushing toilets or for lawn irrigation) (Bukhari and Al-Harazin, 2010; Vairavamoorthy and Mansoor, 2006; Haney and Hagar, 1985). Haney and Hagar (1985) (cited in Biswas et al., 2008) reported water saving of 39% in households retro-fitted with a grey water system. Wastewater reuse is also practised in large households, hospitals, schools, and government buildings, mainly for garden purposes. Treated wastewater is mostly used in irrigation, and other uses are also being tried out. It is used for groundwater recharge, golf courses, green spaces and industry (Abid, 2005; Bukhari and Al-Harazin, 2010).

Al Muamari (2005); Bukhari and Al-Harazin, (2010) and Zubari, (2010) state that in most of the Gulf Cooperation Council (GCC) countries, the primary use of treated wastewater is for municipal landscaping, while a significant volume is lost to the sea even after it is treated to the secondary level. The treated wastewater is also used on a pilot basis for groundwater recharge.

The potential gains from water reclamation or re-use include regulatory cost savings of reduced wastewater discharges, and economic benefits for customers with substantial demand for reclaimed water (Asano, 1990 cited in Tate, 1990).

**Information and education: change of behaviour as WDM measure at utility/domestic/ non-domestic levels**

Public awareness campaigns play an important role in any WDM programme. They consist of two distinct components: knowledge and information transfer; and education. Wilson (2006) suggests three movements away from the concept of knowledge. The first from ‘professionals know’ to professionals learn from other professionals and from the populations they seek to develop. The second is from ‘professionals learn’ to ‘the population learns’. The third movement is towards ‘professionals and population learn together and

synthesize new knowledge'. He also states that learning with is two-fold. Firstly, it provides something tangible from which to learn. Secondly, engaging in joint practice develops trust.

Emoabino and Alayande (2006) point out that creating awareness and improving people's understanding of WDM is the first step towards the implementation of WDM, and all stakeholders should see themselves as working towards the same goals and be ready to share information (Hani et al, 2011). The dissemination of information requires appropriate 'packaging' to suit the different target groups. Public involvement should be encouraged in public awareness campaigns. The use of mass media is the most cost-effective method in terms of passing information and knowledge transfer and adaptation (Vairavamoorthy and Mansoor, 2006; Abdel Khaleq, 2008; Kayaga, 2011a). However, it should be noted that public awareness is only one of the many factors that influence behavioural change (Jackson, 2005).

Platt and Wilson (1999) stated that for technology development, understanding and adapting to context is central to making learning more explicit and effective by participatory means. Participatory Technology Development can aid understanding of context, and help to understand value and build on prior experiential knowledge. Johnson and Wilson (2006) add that involvement of different practitioners from different local government and international practitioner partnerships can help in providing models for other type of partnership.

The focus of the campaign should be to improve the public's awareness of the urgency to conserve water now in order to prevent a crisis situation in the future (Vairavamoorthy and Mansoor, 2006). Atallah et al (2001) state that campaigning for conservation of the environment within the Islamic faith is productive. Specifically, by using the Islamic education system to address the public on important issues such as water conservation has beneficial effects in terms of raising public awareness. Raising public awareness using Islamic conservation concepts should always be integrated with the use of other communication tools and channels, while Hamdan et al. (1997) in (Faruqui et al., 2001) concluded that "there is a desperate need for Islamic environmentalism in our finite world".

Raising awareness using Islamic concepts of water conservation is feasible for the following reasons:

- Islam has a strong influence in the Eastern Mediterranean Region (EMR);
- Water conservation and protection are stressed in Islamic teachings; and
- Islamic communication channels are very effective in raising public awareness.

Information and education take a variety of forms at venues such as schools, workshops and seminars. Public information and education are important in every water conservation plan. Atallah et.al (2001) documented that water conservation must be seen as a basic component of integrated water resources management, and public awareness and education are basic tools needed to guarantee the participation and involvement of the public in water conservation (as cited in WMO 1992; UN 1993a, 1993b). Providing information, and educating the public, may be the key to getting public support for a utility's water conservation efforts. An information and education programme should explain to water users all of the costs involved in supplying drinking water, and demonstrate how water conservation practices will provide water users with long-term savings (fact sheet, 1998).

Atallah et.al (2001) reported that most water conservation activities require changes of behaviours and attitudes, which is usually a slow process. As a result, ad hoc occasional public awareness activities are not effective. Water authorities should plan continuous, long-term activities in close collaboration and co-ordination with ministries of Education and Islamic affairs (Atallah et.al, 2001; Kayaga, 2011a)

**School Programmes**

School education programmes are important for influencing short and long term water conservation. All levels of formal and informal education are essential to raising awareness. The topic of water shortages and conservation can be addressed in the course of teaching subjects such as Religion, Arabic, Science and Geography.

Water administrators can provide information on water conservation and encourage the use of water conservation practices through a variety of school media. Contacts in schools can

help increase awareness in young people about the value of water and conservation techniques, as well as communication with parents (Kayaga, 2011a).

**Workshops**

Informal education seems to be more feasible in the short term. Seminars, workshops, and lectures should be arranged for students and other groups. Workshops can be held for industries that might be able to contribute to water conservation efforts. These might include, for example, workshops for plumbers, plumbing fixture suppliers, builders or landscapers and irrigation service providers.

Educating the public about the need to conserve water resources is a common approach to demand management during times of water stress. Renzetti (2002), Timmins (2003) and Kenney et al., (2008) all point out that water conservation education can lead to reduction in water demand, but that these programmes are most effective when used in conjunction with pricing strategies or technical measures for demand reduction.

**Raising Awareness through Mosques**

According to Atallah et.al (2001), Imams (An Imam is a leader, usually the person who leads prayers in a Mosque) play a key role in delivering Islamic teaching and educating the public through Mosques. Therefore, Imams and Mosques should be a focus for public awareness activities on water conservation. Imams should be properly trained and informed, and should never be excluded from water resources planning and management activities. Atallah et al (2001) also state that Imams are more capable of reaching the public than water specialists.

Imams are usually well educated about *fiqh* (this refers to the science of Islamic law extracted from detailed Islamic sources (which are studied in Principles of Islamic Jurisprudence), *sunnah* (this means the way of life prescribed as normative for Muslims on the basis of the teachings and practices of Muhammad and interpretations of the Koran Familiarity information), and *sharia* (this means the code of Islamic religious law derived from the Quran and from the teachings and example of Mohammed). However, their knowledge of water resources and conservation practices is usually insufficient for them to act as educators on the subject. Therefore, water specialists must train, educate, and inform

Imams about water shortages, water conservation practices, the need to involve the public, and about audiovisual tools and materials in order to help them reach the public.

Alrubiai (2005) and Atallah et.al (2001) mentioned that Friday prayers, held in Mosques, are an important weekly occasion in the life of Muslims. Imams should prepare their Friday speeches in close collaboration with water conservation and communication experts, using reliable facts and figures. They also recommend that Friday speeches on a water-related topic should be frequent in order to achieve a change in behaviour. They also recommended that such speeches be made more often in summer and during periods where water demand is at its peak.

**Capacity Building**

Emoabino and Alayande (2006) documented that the role of the institutions and their capacities to effectively promote and implement WDM needs to be urgently understood. The technical and management skills required at the different levels of stakeholders must also be identified, and their capacities developed in a more integrated manner in order to cope with the challenges of marketing the ideas of WDM. Mulwafu, et al (2002) state that efforts must be made to train staff in water utilities, as well as water supplying institution in WDM. Such education must emphasise the significance of WDM in sustainable water resource management and must also promote a change in peoples' cultural attitudes towards water resources.

**Socio-political measures at utility level and government policy level**

Socio-political measures in the water demand management context refer to policy and related measures that can be taken by utilities to encourage water conservation. Techniques include public awareness programmes, laws such as building codes and application modifications, and government economic policies. These are designed to gain co-operation from the public in moving toward improved water management practices. Thus, one of the most important techniques in this field is effective public education (Kenney et al, 2008; Abdel Khaleq, 2008; Bakir, 2004).

**Water use regulation**

There is a variety of regulatory tools that can be developed to ensure uptake of WDM options. These Regulations should be in place, and enforced, to manage water use during droughts or other water supply emergencies (UN-HABITAT, 2006; Kayaga, 2011a). In some cases, as in water-stressed regions like arid Bahrain, utilities may find it desirable to extend water-use regulations to promote conservation even during non-emergency situations. There are various ways in which regulatory tools could be used to ensure efficient water use, with respect to the raw water abstraction, water distribution and end-use stages. Examples of water-use regulations are:

- Restrictions on non-essential uses, such as lawn-watering, car-washing, and filling swimming pools;
- Restrictions on commercial car washes, nurseries, hotels, and restaurants;
- Standards for water-using fixtures and appliances.

Another type of regulation is to impose standards on new developments with regard to landscaping, drainage, and irrigation practices. Water-use regulations can be summarised in the following steps (Al Senafy et al., 2008):

- Promoting the adoption of a water-conserving regulation which requires the installation of water-saving plumbing fixtures and fittings in all new buildings constructed or in existing homes where building permits are issued for kitchen or bathroom remodelling work.
- Instituting requirements for the installation of water-saving plumbing fixtures and fittings as a condition prior to hook-up for new customers.
- Encouraging the judicious use and management of water during peak use summer periods by restricting lawn/garden watering to non-daylight hours.
- Instituting fines for the unauthorised use of water such as illegal hook-ups and hydrant discharges.
- Promoting land-use regulations which protect critical groundwater recharge areas and potential well locations.

**Advantages and Disadvantages of WDM**

Water demand management offers a variety of benefits from the perspective of utility, customer and society as a whole. Cherian, (2009) states WDM measures at the utility level can reduce operation and maintenance costs that will result in lower water tariff levels for the customer. They will also reduce the marginal cost of production at the utility level by deferring the need for new capital investment, and customers will pay their bills based on volumetric charges. WDM measures have a positive impact on the environment. Reduced consumption leads to less demand on stream flow and groundwater resources, hence promoting equity, and fewer carbon emissions as a result of lower treatment and pumping load. Another benefit is a reduction of wastewater flows. Conservation measures on the side of the customers reduce the wastewater load onto the sewage system and subsequently the sewage treatment plant.

Nielson (2002) and Cherian (2009) both reported the following disadvantages of implementing WDM:

- Excessive demand management can affect general economic development;
- Risk of adverse social impact on the poor part of the population.

The negative effects of demand management will be reduced if measures are introduced incrementally, and in a transparent and predictable way (Nielson, 2002).

## 3.6 International experience in WDM

Water demand management techniques of various types have been used in many countries with varying degrees of success. This section examines selected international experiences with demand management in the municipal, industrial, and agricultural sectors. Most of these cases are pilot tests, few are on a large scale.

Singapore has successfully managed to find the right balances between water quantity and water quality considerations; water supply and water demand management; public sector and private sector participation; efficiency and equity considerations; strategic national interest and economic efficiency; and strengthening internal capacities and reliance on external sources.

With regard to the implementation of WDM programmes, Singapore has achieved considerable success in water-use efficiency and has adopted a total approach to water conservation which covers:

a. Keeping NRW low;
b. Conservation in customers' premises;
c. Tariff and use of economic incentives and disincentives.

In Singapore, the NRW was reduced from 11% in 1988 to 6.7% in early 1994 and currently (2008) it is 4% (Tay et. al, 2008). This was achieved by eliminating meter inaccuracies, losses through leakage (implementing detection and repair, replacement of aged mains), illegal connections, and certified plumbers doing in-house repairs and installations (G2C, 2006). The various measures and replacement programmes implemented to replace and rehabilitate the distribution system have proven to be effective. The number of leaks was decreased by more than 70% (Arlosoroff, 1998).

In 1985 in Singapore Tay et al (2008) documented that the number of leaks was about 95 leak/100km/ year. In 2007, the number of leaks dropped to 6.7 leak/100km/ year. The number of leaks is low compared with many other countries in the world. This is attributed to the Public Utility Board's (PUB) efforts to manage water supply networks, active detection of underground leaks, and responding quickly to customers, with integrated water network management. This effort has made Singapore a city with one of the lowest levels of NRW in the world (below 5%).

Singapore has successfully leveraged advanced water treatment technology to reclaim water of a quality that surpasses drinking water standards. Singapore is the first in the world to use high-grade reclaimed water (NEWater) as a feed source for the production of ultra-pure water for manufacturing processes. Water fabrication plants using NEWater have reported savings in the production of ultra-pure water. Similarly, commercial complexes, using NEWater for their cooling towers, have reported using less volume of NEWater by 20% or more, compared with using drinking water (Gin, 2003).

In Singapore, domestic water consumption was 172 litres per person day in 1995. By implementing a range of demand management measures, this was reduced by 9 per cent to 156 litres by 2008 (Cherian, 2009).

In South Africa, the cities of Windhoek, Hermanus and Bulawayo implemented WDM programmes and achieved success in water-use efficiency as they reduced the NRW values to less than 20% by investing in water awareness campaigns, customer education, water loss management, individual metering of consumers, water-efficient gardening, efficient and informative billing and appropriate management of information systems (Gumbo, 2004).

Kayaga et,al (2008) argued that a successful implementation of a project in Zaragoza, Spain has enabled Zaragoza to be categorised as a model city for efficient water use. Key achievements of the project were a reduction of over 5% in annual domestic water use and mapping of good practices for efficient water use in non-domestic sectors. This project was selected as one of the 100 most successful interventions for sustainable urban management by UN-HABITAT. The overall outcome of the project 'Zaragoza: the water-saving city' has been quite significant.

A US study demonstrated that installation of water-efficient washing machines and dual-flush toilets resulted in reduction of the total indoor water use by one-third (Bradely, 2004). Installing low-volume water closets and shower roses reduced overall water use by at least 25% in terms of domestic water consumption (Martindale and Gleick, 2001).

In Sydney, the examples show the effect of a demand approach on a micro level (water demand reduction in a commercial building), through wastewater reuse.
At Sydney Olympic Park, Australia, 2ML/d sewage and storm water are treated for non-potable reuse in sporting and recreation facilities, hotels and commercial premises and residential villages (Listowski and MacCormick, 2004 cited in Jalil and Njiru, 2006).

In Orange County, California, 70 MGD (0.32 $Mm^3$/day) clarified secondary effluent is reclaimed to produce water with quality higher than that of other conventional water sources

available to the area for a seawater intrusion barrier and for groundwater recharge (Deshmukh, 2004 cited in Jalil and Njiru, 2006).

According to Mckenzie and Wegelin (2008) in Gauteng, as the demand for water continues to grow, the Department of Water Affairs is investigating the various alternative water resource development options as well as the potential for reducing the growth in demand through water conservation (WC) and water demand management (WDM) measures. From the most recent investigations it has become clear that WDM is no longer considered a possible option but rather a necessity that must be implemented as a matter of urgency. It has been established that even if new water resource development options are implemented, it will still be necessary to introduce the WDM measures. In this regard, several of the large municipalities in Gauteng have already commenced with various WDM interventions, some of which are already in operation and showing significant savings.

The key problems delaying the successful implementation of WDM include the following:

- Poor maintenance of the reticulation system – both prior to and following the implementation of WDM interventions;
- Lack of support at the political level in the municipalities;
- Lack of consumer support.

From the practical experience of the authors, it is clear that there is currently insufficient political will in many municipalities to address water wastage in the key problem areas.

Iacovides (2001) argues that it is clear from the basic objectives of the water policy of Cyprus (1999 to 2003) in making the supply meet the demand, that the Government policy has effectively encouraged and adopted various water demand management measures and efforts have been made to utilise the latest technological advances in the common effort to efficiently control and protect from pollution the valuable potable water resources. Although a lot has been done in Cyprus to improve the management and protection of the water resources, efforts must continue on a larger scale as resources are dwindling by the use of pollution and the demand is increasing.

As a result of the above, a constant effort is being made to protect water resources and to reduce water losses. The Water Boards of the major urban areas (Nicosia, Limassol and Larnaca) made serious efforts in recent years to minimize unaccounted for water. These efforts resulted in a reduction of this percentage from around 29% to less than 20%. This effort includes:

- The enactment of legislation for the protection of water resources including "hosepipe bans" and the implementation of programs for increasing public awareness in this respect;
- The continued campaign through schools (classes, competitions, handouts, etc.) the media, posters, letter franking, stickers etc., to encourage water saving by the consumers;
- The encouragement of the use of lower grade water such as contaminated or recycled water for non-potable needs (e.g. subsidy for the drilling of wells for garden watering in urban areas and subsidy for the connection of low grade water sources to WCs);
- The adoption of operating methods, designs and practices that minimize water losses from dams (evaporation control), treatment works (sludge dewatering & recycling) conveyance and distribution systems (automation, immediate action on breakages, leakages surveys etc.);
- Water pricing to reflect the actual cost of water and water tariff structuring to discourage wasteful use;
- The involvement of consumers in the management of water distribution authorities;
- The installation of water-saving faucets in schools and public places;
- Attempts to enact by-laws requiring the installation of low-dual flush WCs;
- Encouraging and promoting the installation of units to separate, treat and re-use "grey water" in homes for secondary uses where low quality water is acceptable–i.e. local on site dual systems.

In Cyprus, the government authorities support homeowners to install a separate drainage system to collect grey water to be used for irrigation in gardens (Abu Qdais, 2004).

A study by Christodoulides (2008) on reducing apparent water losses corresponding to meter under-registration was also carried out in Larnaca (Cyprus) by the installation of Unmeasured Flow Reducers (UFRs). The NRW prior to the installation of UFRs was

16.38% of the total supply and NRW after the installation of UFRs was 8.81% of total supply. This is a 7.57% reduction.

Abdel Khaleq (2008) and Hijazi, (2010) pointed out that a Water Demand Management Unit (WDMU) was established at the Ministry of Water and Irrigation by the end of 2002 to undertake the responsibility of Water Demand Management Programmes for all sectors in Jordan. Water Demand Management Programs in Jordan vary from one sector to another. In the municipal sector the activities cover the following:

- Tariff structure that promotes water conservation; increasing water awareness through water media campaigns;
- Private sector participation in management of supply systems; introducing Water Demand Management concepts at school curriculum;
- Introducing new water laws and regulations that aims at conserving water, promoting the utilisation of technology and water saving devices;
- Retrofitting about 60% of consumers using more than 500 cubic meters of water per quarter (three month);
- Promoting the idea of water conserving garden; studying of the possibility of grey water reuse in areas with no sewer systems;
- Initiating a survey for a sustainable water and energy consumer protection program;
- Establishing a Master's degree programme in Water Demand Management at Jordan University for Science and Technology;
- Initiating the work on upgrading plumber's education programmes in Jordan's vocational schools, a community grants program to provide assistance to poor communities, and administering pilot projects in five rural communities to illustrate indoor and outdoor water and energy conservation.

A major part of those activities were implemented under a five year program known as the Water Efficiency and Public Information for Action Program (WEPIA**)**. A second programme has started recently with the title 'Instituting Water Demand Management in Jordan' (IDARA). This nationwide program is focusing on instituting sustainable water demand management by helping to establish the required institutional and regulatory framework in the country.

In the industrial sector, some of the measures taken include:

- Using treated wastewater for industrial purposes: For example, fertilizers industries in Aqaba, which is major water user have replaced fresh water with treated wastewater for its industrial processes;
- Use of Water of lower quality: Potash industries which is another major industrial water user, have introduced the use of irrigation drainage water and the use of brackish water in its processes;
- Use of technology that uses less amounts of water for the same industrial product; installing water saving devices;
- Preventive maintenance and stopping leakages for internal networks at industrial facilities.

Water Demand Management measures in the Agricultural sector include:

- Reuse of treated wastewater in irrigation (In 2004, treated wastewater reused for agricultural irrigation purposes was about 80 MCM, that is 14% of the total irrigation water use);
- Policy for Reduction of water use in highlands, which over-pumps groundwater, for more productive and efficient irrigation in Jordan Valley;
- Change of irrigation techniques; and the utilisation of modern irrigation technologies; and
- Change of agricultural production patterns into crops that use lower amounts of water and have higher economic returns.

According to Haddadin (2010) Jordan could be taken as an example of what could be applied elsewhere in MENA in the field of demand management of agricultural water. When the Jordan Valley Project was initiated in the 1960s, the irrigation water tariff was one fils per cubic meter, and the flow to farms was measured on time basis. Ten years later, the tariff was tripled, and thirty years later the tariff was made a function of consumption; the more consumption the higher the water charge. Also the change in irrigation systems in Jordan Valley from surface irrigation to modern drip irrigation has increased the irrigation efficiency from 38% to 56% (Abu Qdais, 2004).

Hijazi (2010) stated that in August 2008, the water demand management policy has been issued and got the approval of the Prime Ministry of Jordan with cooperation of IDARA project / USAID Funded project. While a study by Dziegielewski (2003) revealed that the Water Demand Management Policy of Jordan addresses the management of water demands in all sectors of the Jordan's economy including municipalities, industry, tourism, agriculture and other activities of national importance. Many provisions of this policy are already in practice. Specific policy statements address the following ten specific considerations:

1. Universal Water Metering and Loss Control
2. Fulfilling "Unserved" Water Demands;
3. National Plumbing Standards and Water Conservation Codes;
4. Water Pricing and Cost Recovery;
5. Comprehensive Water-Use Information Program;
6. Public Awareness and Education;
7. Best Management Conservation;
8. Public Buildings Efficiency Improvement Program;
9. Water Demand Management Research and Development; and
10. Recognition of Individuals, Institutions and Industry for Advancement in Water Efficiency.

Other aspects of WDM policy address Legislation and Institutional Arrangements for the development and implementation of water demand management policies and programmes.

Efforts to overcome the unsatisfied water demand in Jordan include supply enhancement, optimization of water use in all sectors, and demand management. Besides the conventional ways to address this issue through supply augmentation, many measures were taken to enhance water supply and reduce demand. These include: wastewater reuse, desalination, water harvesting, cloud seeding, and increasing public awareness. Besides the rehabilitation of water networks in Jordan, the Ministry of Water and Irrigation (MWI) and the Jordan Environmental Society (JES) Jordan launched water conservation and public awareness campaigns in 1994-1999. The results of these efforts showed a positive impact on water conservation. To address water demand management, MWI and JES worked on the Water Quality Improvement and Conservation Project (WQIC). This project aimed to improve the

situation by building awareness among the general public and increasing participation in water quality and conservation programmes.

Jordan Environment Society (JES) is a leading environmental non-governmental organisation based in Amman. In the early 1990s, JES implemented an Awareness-Project-in-Water (APW), to create awareness among various target groups.

Arlosoroff (2002:3) states *'There is no doubt, in my mind, that unless political courage would lead to the adoption of a comprehensive Water Demand Management strategies, the region will face serious water scarcity crisis.'*

A paper published by Arlosoroff (1998) comments that in Israel, water demand management effort in the agriculture and industrial sub-sectors revealed that applying increased block tariff of water saved from US$0.05/m$^3$ to US$0.40/m$^3$. Israel applied appropriate irrigation technology such as drips, sprinklers, and automation, while changes in industrial water use and water processes included 'cascading' water use and cooling methods.

Training, public education, and effective extension services must continue to accompany the promotion and implementation instruments. Finally, the efficiency of pricing mechanisms and application of a market or trading system can play a dominant role in the whole operation.

The significant achievements of Israel's agricultural sector have led to a 300% real-term increase. Israeli farmers pay an average of 0.20 $/m$^3$ (three blocks, the upper over 0.3 $/m$^3$); one of the highest in the world (Arlosoroff, 1998).

With regard to urban water conservation, Non Revenue Water (NRW) causes significant water and financial losses to urban utilities and municipalities. NRW has been substantially reduced in Israel (down to 10% on average) due to private consultants involved in NRW reduction level projects (Arlosoroff, 2002, 2004).

A study by Davidesko (2007) on reducing apparent water losses corresponding to meter under-registration was carried out in Ein Karem, Jerusalem (Israel) by the installation of Unmeasured Flow Reducers (UFRs). The under registration percentage was recorded prior

to and after the installation of UFRs and is a comparison of the sum of domestic water meter readings to that of the main water meter. The average contribution of UFR was 8.50%.

In Seoul, South Korea, at Lotte World (a resort, shopping mall and hotel complex) 18% (900$m^3$/d) of the total water supply was provided from reclaimed wastewater for toilet flushing (Ann and Song, 2000 cited in Jalil and Njiru, 2006).

In Kuwait, the Ministry of Electricity and Water (MEW), in cooperation with Kuwait Institute for Research (KISR), is in the process of developing and adopting a plumbing code for residential consumers with the aim of conserving the supply of fresh water to residents of Kuwait. It is also going to retro-fit a large number of taps in residential units with aerators on an experimental basis to study their effects on water consumption (Al Senafy et al., 2008).

Kuwait is considering the implementation of a tariff structure that will encourage scaling down the water demand in consumer units where water usage is particularly high. Burney et al (2001) carried out a regression analysis exploring the dependence of annual water demand in Kuwait on factors like real gross national product, population and real price index of water (nominal price of water divided by the consumer price index) based on historical data. Analysis showed that fresh water consumption in Kuwait is price-elastic. Therefore a suitable pricing structure should result in a reduction in water demand in Kuwait.

At the Millennium Dome, a large entertainment complex in London, reclamation of water for toilet flushing from a combination of poor quality groundwater, grey water and rainwater saved approximately 50% of the potable water supply (Smith et al., 2001).

Jalil and Njiru (2006) also state that a study carried out (Christopher et al., 2001) in three UK industries achieved a reduction of 30% in water consumption by installing water saving devices, new technology combined with recycling and reusing water. The payback period of each of the projects was within a year.

Nkhuwa and Mtine (2007) document that a study was carried out on Thornpark, Lusaka in Zambia to reduce the NRW level to 20% in February 2001. This was done by implementing

some of the WDM measures such as leak detection and repair, improvement in water use on domestic properties, water tariff setting, and improvement in revenue collection rate.

In Durban, South Africa, a study was done (Scruton, 2004), using the approach and methodology adopted by the International Water Association as the model for benchmarking and reporting of Infrastructure Leakage Index. The Infrastructure Leakage Index (ILI) at the start of the programme was calculated as being 9.8. Although the number of consumers is growing, the increase in demand has been checked and the ILI has been reduced to 6.6. These demand reductions were achieved through pressure management, improvement in billing records and leak detection.

Bakir (2003) reported that small waste-water recycling systems at the scale of households, residential buildings or neighbourhoods present a cost-effective means of closing the gap between water supply and demand. In Saudi Arabia, a residential development company reports water savings of 40% in residential buildings equipped with small wastewater recycling systems (Badruddin, 2000).

As documented by Abderrahman (2001) the following measures have been introduced in order to domestic reduce water demand in Saudi Arabia:

- In 1994, water tariffs were introduced
- Leakage control measures have been implemented to minimise water losses from water supply network
- Treated wastewater recycling has been implemented; for example ablution water is recycled for toilet flushing at the two holy Mosques at Makka and Al-Medina Al-Monawwarah
- Highly saline water from wadi Malakan near Makka is used instead of desalination water for toilet flushing at the Holy Mosque at Makka.

In Riyadh, the capital of Saudi Arabia, a study of the water distribution system revealed that system rehabilitation reduced the water losses from the system by 70% (Khadam et al., 1991 cited in Abu Qdais, 2004).

In GCC countries, it is believed that conservation of natural resources in general, and water resources in particular, are a principal component of Islamic teachings. It is also believed that the most important and effective ways to make the public aware of conservation from an Islamic perspective are through the media and the educational system (Akkad, 1990 cited in Atallah et.al 2001).

In Jordan, on the occasion of World Water Day 1989, and upon the request of the ministries of Islamic Affairs, imams were requested to devote their Friday speeches to the theme of Islam and water conservation (Salih, 1998 as cited in Atallah et.al 2001). But such public awareness about water conservation campaigns needs to be integrated through a comprehensive and long-term plan of action that targets behavioural change; otherwise their effect will be limited.

In Jordan, a project to make water of improved quality available in increased quantity on a sustainable basis in the course of implementation. A major part of the project involved public awareness activities. Various education and awareness material (posters, games, newspaper reports, television programmes, seminars and so on) have been prepared using Islamic teachings and concepts. Several Friday prayers were devoted to water and conservation issues (Ayesh, 1996 as cited in Atallah et.al 2001).

In collaboration with the Ministry of *Awqaf* and Islamic Affairs, a pilot project entitled "Week of the Mosque" was implemented in Jordan in early 1998. Imams in all the Mosques of the Amman Governorate were trained for one week to incorporate issues of daily life, including water conservation, into their Islamic education (Atallah et.al 2001). They were provided with information about Jordan's water resources and the shortage of water the country faced, and about the need for public co-operation and participation in water conservation. The Imams then started educating the public. It is planned to replicate this activity in the other governorate of Jordan.

In Tunisia, sustained leakage control efforts over a period of ten years (1990-1999) reduced non-revenue water (NRW) from 24.1% to 14.5%. Tunisia has implemented WDM programmes since 1990. Its WDM strategy combines the following: increasing water supply

efficiency and controlling leakage; universal water metering and pricing for conservation (applying an increasing block tariff); public awareness and education (Bakir, 2003). Its major achievements were:

- NRW decreased from 24.1% to 14.5%;
- Institutional and public buildings and commercial water connections ($m^3$/year/connection) dropped by 37%;
- Household consumption ($m^3$/year/connection) dropped by 5%;
- All users' per connection consumption dropped by 11.6%.

Additionally, in Tunisia, domestic water and sanitation tariffs are progressive, rising with each 'block' of consumption. The over-150 $m^3$ block accounted for 3.3% of customers and 52% of consumption in 1984, and, in 2000, these figures were only 1.9% and 35% respectively (Limam, 2002 cited in Abid, 2005).

A case study in Zaragoza, Spain, used a combination of economic instruments. Reforming the tariff to make it more demand-responsive and equitable, and incentives for water conservation which started in 2002, households that reduced their consumption by at least 40% during the financial year were entitled to a 10% discount on the bill (Kayaga, 2011b).

## 3.7 Gaps in knowledge about WDM in Bahrain

As seen from the above it can easily be concluded that although Bahrain is a typical example of imbalance between the scarce water resources and the ever increasing water demand, insufficient research activities have been undertaken in Bahrain regarding Water Demand Management. This is a major reason as to why this research was developed.

In the early 1950s Bahrain depended on groundwater abstractions to satisfy water demand by all sectors. The country rapidly moved to solutions such as desalination plants but they were assessed as expensive to the level where they imposed a burden on the country's budget. An immediate reaction was to consider demand-oriented management but this was never studied in satisfactory detail, something that this study aims to achieve in order to help decision-

makers move in the right direction and to alleviate the consequences of the existing sharp imbalance between water supply and demand.

This study is the only study that will address WDM in Bahrain by considering the following:

- This study will address the regulation issue in Bahrain in detail that was not analysed in previous studies. The speciality of studying regulation arises from the fact that Bahrain is a country with scarce water resources and uses, at the same time, desalination as the main water supply in addition to limited volumes of groundwater abstractions. This requires special regulations.
- This study will include in WDM measure for the first time, the blended water supply.
- This study will also address water tariff reform for highly subsidised tariffs as is the case in Bahrain.
- This study will address water demand management measures taking into account economic, technical and institutional measures.
- Most of the WDM studies were carried out for irrigation sectors and few were for domestic sectors.

Most of the case studies were on a small scale. Only in the cases of Singapore, Cyprus and Jordan, was the success due to the support of political parties and government, and National Water Board in those countries.

Therefore, in order for Bahrain to implement WDM, it needs the support from government and to establish a water board. The Kingdom of Bahrain, through its 2030 vision, has put forward a National Economic Strategy plan which includes an implementation plan to ensure better water demand management to support water demand management measures, and it is getting the support from both EDB which is under the control of Crown Prince, and the Water Resources Council which was established in 2009.

## 3.8 Conclusions

This Chapter has provided an overview of sustainable water management and various options for solving water shortage have been discussed. An overview of integrated water resource management was then presented, and it showed that integrated resource management cannot be transferred wholesale to the urban context because the management boundaries in IWRM are catchment-based and therefore IUWRM has to be applied to urban areas as it is operated at a local scale. This was followed by a description of water supply management and water demand management, in which different WDM strategies and a combination of measures and instruments at different levels and their savings were discussed. Finally, international experience in applying water demand management strategies was presented. The gap in knowledge that drives the initiation of this research was then identified and described.

The traditional approaches of resource handling are now considered as unsustainable. Water demand management (WDM) is a new approach that aims at influencing demand and thus improving distribution efficiency. There is a need to change the way that water resources are managed. In order to maintain sustainability, water demand management (WDM) application tools are required in addition to supply management.

There are many instruments available for implementing WDM and these instruments are interdependent. Effective water tariff, political support and the establishment of a National Water Board are the most important parts in addition to public awareness and participation and other structural and operational measures, which are equally important tools for the success of WDM.

# Chapter 4: Research Strategy and Methods

## 4.1 Introduction

This Chapter outlines the methodology adopted in this research. Details of the research design are provided in this Chapter. The various research approaches are reviewed, the selection of a single case study approach is discussed and the justification behind the methodological approaches is explained.

The most appropriate methods that should be adopted for this study are discussed in terms of their strengths and limitations. The methods of data collection and design are explained. The steps used to maximise the validity and reliability of this research findings are stated. Then the processes of the fieldwork as well as the detailed contents are described. The database summary and the analytical framework are also explained in this chapter, additionally, the ethical issues that were considered during the research are enumerated. A case study methodology was used to collect data from key relevant government departments/institutions involved in water demand management as well as from customers at different levels of the chain. The main methods used for data collection were reviews of relevant departmental documents/publications, key informant interviews, field pilot tests and a questionnaire survey. Figure 4.1 summarises the stages of setting the research methodology. In summary this methodology is a combination of desk study, field work and interviews in addition to pilot testing and observations.

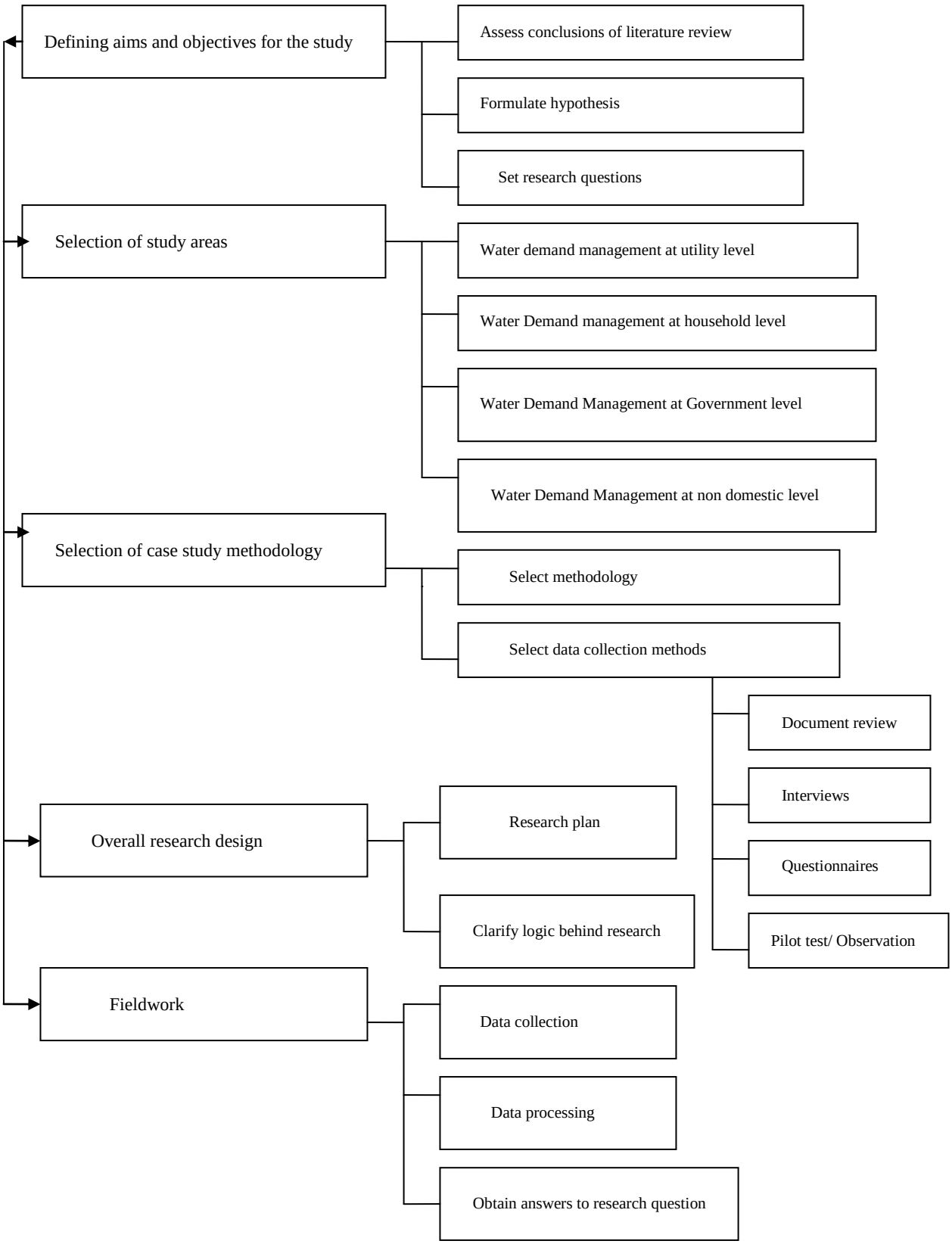


**Figure 4.1**: The process of setting the research methodology

## 4.2 Strategy for research design and methods

Research requires repeating a search for something and assumes that the earlier research was not extensive and complete in the sense that there is still room for improvements (Sufian, 1998 cited in Jing 2008). Research is a process of inquiry, based on earlier knowledge. It is defined as a systematic way of asking questions, and a detailed method of inquiry. Research is a systematic investigation to increase the sum of knowledge (Fellows and Liu, 2003). While the research design is a plan, structure and strategy of investigation in order to obtain answers to research question or problems, it shows the logical sequences that link the empirical data to the study's initial questions and ultimately lead to its conclusions (Yin, 2009, Silverman, 2000). Research design usually is introduced after first identifying the research question and before starting to collect data. It is defined as 'the principles and procedures of the logical thought processes which are applied to a specific investigation' (Fellows and Liu 2003). It is the framework through which the different components of a research project are brought together: research question, literature review, data, analysis and findings (Royer and Zarlowski, 2001; Tan, 2004). William (2006) provides the relationship between methodology, strategy and data collection and analysis. Figure 4.2 illustrates the research designs, methods and strategies.

In this research, after the literature review was undertaken in order to understand the existing knowledge of water demand management, the research questions were defined. Then the most important step was to choose the appropriate research strategy.

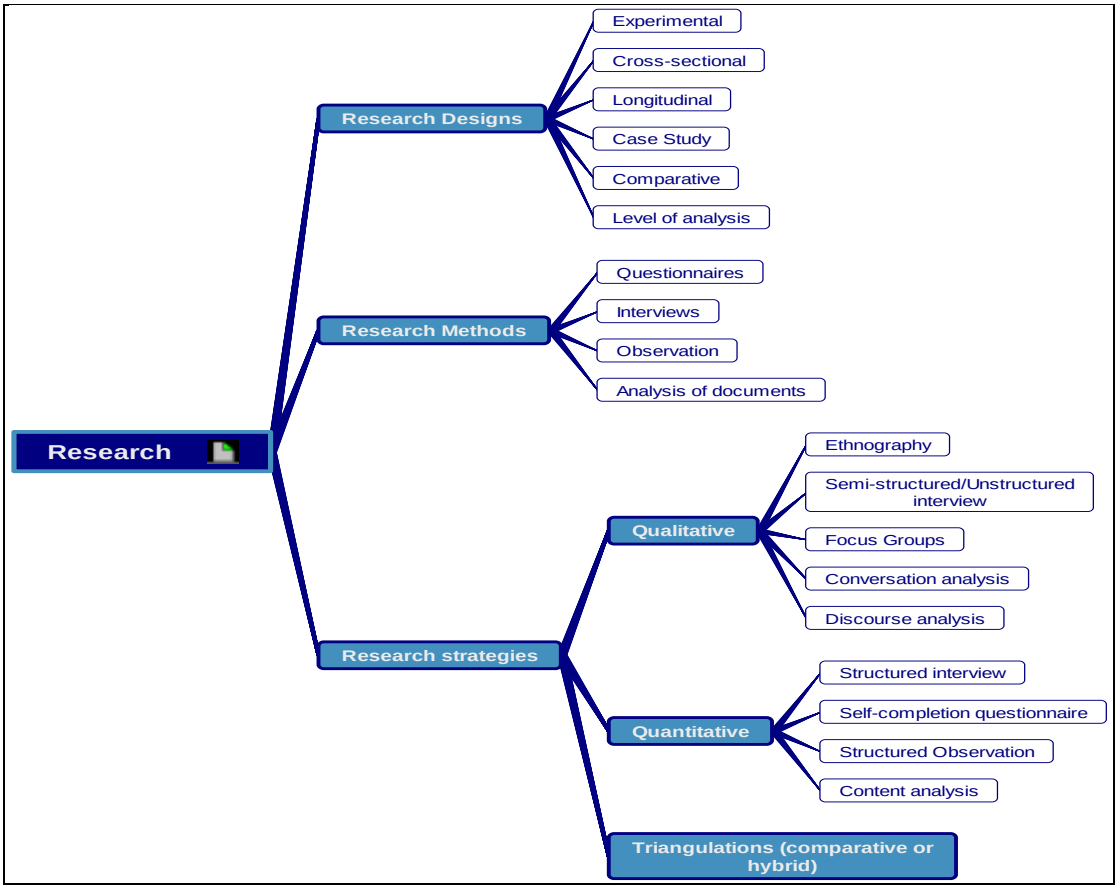


**Figure 4.2:** Research designs, methods and strategies, Source: Fellows and Liu (2003)

### *4.2.1 Research methodology approach*

Fellows and Liu (2003) documented that researchers have to make a decision about what type of approach they want to follow to collect and to analyse their data. A research strategy is about the way research is conducted. There are three types of research strategies: qualitative, quantitative, or a combination usually called the triangulation or hybrid method. Punch (2005) states research strategies can be broadly classified into two different approaches. They are the scientific empirical tradition (quantitative research method) and the naturalistic phenomenological (qualitative research method) respectively. Quantitative data deals with numbers mainly while qualitative data is mainly words, or images. Also the qualitative approach is supported by action research or case study methods. Both quantitative and qualitative approaches have strengths and limitations The main strengths of the quantitative approach lie in accuracy which is reached through quantitative and reliable

measurement and control, and is achieved by sampling and design (Blaxter et al., 2006) and the generalisation of findings which can be reached from the accuracy provided by the measurement (Bryman and Bell, 2003, Blaxter et al., 2006). However this approach has some limitations in that the results provide less detail on human behaviour, attitude and motivation (Silverman, 2000; Bryman and Bell, 2003). Also quantitative methods may not be suitable to the complexity, embedded character and specificity of real-life phenomena (Gilham, 2000). Many researchers are concerned that the quantitative approach makes it difficult to generate theory (Silverman, 2000).

In the case of qualitative research, its main strength is that it is best used for depth, rather than breadth, and for discovering underlying motivations, feelings, values, attitudes, and perceptions (Yin, 1994). Qualitative research can take many forms and there are a variety of methods for conducting this type of research (Silverman, 2000; Bryman and Bell, 2003). The qualitative research has limitations in that the findings are not statistically projectable to the population under study (Blaxter et al., 2006). Furthermore, qualitative research is context-specific, and thereby, the relevance of theory is not known until data is gathered and analysed, which requires a more inductive approach (Gilham, 2000).

As indicated above, both quantitative and qualitative approaches have limitations. Many authors (Walliman, 2005; Blaxter et al., 2006, Bryman and Bell, 2003) agree that a mixture of quantitative and qualitative research methods may be used within certain limits. This method is usually called the triangulation, mixed or hybrid method and it is used because it provides more perspective on the phenomena being investigated (Smith et al., 2002). In this research data collection was based on semi-structured interviews, questionnaire surveys, observation, pilot test and documents. The data was, therefore, a mixture of numbers and narrative. Based on the nature of the research questions, a qualitative case study methodology was used, which utilised various data collection and analysis methods.

### *4.2.2 Research design and methods*

The primary research questions influence the choice of research strategy. Many authors on research methods recommended that the research strategy adopted for a study should be guided by the nature of the research questions (Yin, 2009; Silverman, 2000).

According to different authors research is carried out for the following three main purposes:

- To describe a phenomena (descriptive). It is focused on fact finding and focuses on a few dimensions of a 'well defined entity', measuring them systematically and precisely (Singleton, Jr. et al., 1993; Voss et al., 2002). This research is carefully planned with a complete strategy before the start of data collection.

- To explore phenomena (exploratory). When very little is known about something (Singleton, Jr. et al., 1993; Voss et al., 2002) exploratory research is needed. It is less structured than descriptive research. In this research the fieldwork and data collection are initiated prior to the final definition of research questions and hypotheses following intuitive paths where the goal may be to develop theory (Yin, 2009).

- To examine and to formally test relationships among variables (explanatory). Explanatory research is used to test relationships and to seek answers to problems and hypotheses, where the difference with explanatory research is in the scope of the description. Descriptive research seeks information about isolated variables and explanatory research seeks the relationship between the variables (Singleton, Jr. et al., 1993; Voss et al., 2002).

As stated earlier, Bryman (2003) defined a research design as a framework within which data is collected and analysed and a research method is a procedure of how data is collected. Research method is the set of available techniques which are actually used in a research project (Fellows and Liu 2003).

Yin (2009) states that the main research designs include the following: experiments, survey, histories, analysis of archival information and case studies. These are different research methods. Each strategy is a different way of collecting and analysing empirical evidence,

following its own logic, and each method has its own advantages and disadvantages. The matching research strategy to the particular research question needs to be chosen depending on the following three conditions:

(a) The type of research question posed.

(b) The extent of control an investigator has over actual behavioural events.

(c) The degree of focus on contemporary as opposed to historical events.

Table 4.1 below displays these three conditions and shows how each are related to the five major research methods.

**Table 4.1:** Selection criteria for different research strategies

| Strategy | Form of research question | Requires control of behavioural events? | Focuses on Contemporary Events? |
|---|---|---|---|
| **Experiment** | How, why? | Yes | Yes |
| **Survey** | Who, what, where, how many, how much? | No | Yes |
| **Archival analysis** | Who, what, where, how many, how much? | No | Yes |
| **History** | How, why? | No | No |
| **Case study** | How, why? | No | Yes |

Source: Yin, (2009)

According to Table 4.1, the first and most important condition in the selection criteria for research strategies is to identify the type of the research question being asked. The case study method is ideal when a “how” or “why” question is being asked about a contemporary set of events over which the researcher has no control. It relies on many techniques and has two important sources of evidence: direct observation of the events being studied and systematic interviews of persons involved in the events and interviews.

The research questions in this research are “How can WDM measures taken at **utility level** contribute in providing a sustainable water supply for Bahrain?”, “How can WDM measures taken at **household level** contribute in providing a sustainable water supply for Bahrain?”,

"How can WDM measures taken at **non-domestic consumer level** contribute in providing a sustainable water supply for Bahrain?" and "How can WDM measures taken at **government policy level** contribute in providing a sustainable water supply for Bahrain?". This type of "how" question may be tackled by history or case study.

One further key difference between experiment, history and case study is the extent of the researcher's control over and access to actual behavioural events. For example, experiments involve the manipulation of circumstances while histories and case studies do not. This research focuses on the water demand management issues in Bahrain that cannot be controlled, so experiments can be excluded. Histories are used when there is no access to actual behavioural events. The historical method is dealing with the past and relies on primary documents, secondary documents, and cultural and physical artefacts as the main sources of evidence. The survey strategy was not selected because the research goal does not require obtaining quantitative data on the problem nor was it studying a certain population (Marshall and Rossman, 2006). The archival survey strategy was also found unsuitable as the research questions were of an "exploratory" nature rather than a "descriptive" one. Thus the case study is preferred in examining contemporary events and is particularly fitting for gathering comprehensive, systematic and in-depth information about a case of interest. It relies on many of the same techniques as a history, but it adds two more important sources of evidence: direct observation of events being studied and systematic interviews of the persons involved in the events. To summarise, when a "how" question is being asked about a contemporary set of events, over which the researcher has little or no control, the case study will be preferred. In this research the Water Demand Management issue is a contemporary event and, based on the considerations mentioned above using Yin's research design selection criteria, the case study has been chosen as the main research strategy.

This research (guided by its questions), is placed entirely as an exploratory research undertaking. The research is set to explore Water Demand Management measures that are applied in practice and to contribute in providing sustainable water supply to Bahrain.

### *4.2.3 Justification for using case study with mixed methods approach*

The reasons for selecting case study for this research are as summarised below:

The present research involves asking 'how?' and 'why?' questions and the study focus on real life, contemporary and human situations, involving many variables and with no control over the phenomena under study.

The case study method is largely used for exploration (Yin, 2003), which allowed flexibility in investigating WDM measures in great depth. The flexibility allows the selection of a combination of qualitative and quantitative research techniques that are appropriate and effective in this research. This will allow the research to be adaptive to changing contexts and circumstances, as well as acting as a means of triangulation.

This research focuses on one instance: the water demand management issue in Bahrain, and focuses on the water demand management measures at different levels and the link between these measures. It can deal with the case as a whole and thus have the chance of being able to discover how the many parts affect one another, and then explain why certain outcomes might happen.

Employing multiple methods (Fellows and Liu, 2003; Bryman and Bell, 2003) provides the opportunity for (a) data triangulation, with the attendant effect of enhancing the study's validity; (b) adding depth and breadth to the study result and interpretation, and (c) providing the opportunity for presenting greater diversity of views. In this research data included interviews, documents provided by EWA, observation, questionnaire surveys and pilot tests.

Although single cases may provide the opportunity to study several contexts within the case (Voss et al., 2002), they have limitations. The first involves the limitation of generalisability of the conclusions, models or theory developed from one case study, and the second limitation include risks of misjudging of a single event, and of exaggerating easily available data (Voss et al., 2002). Despite the disadvantages of single cases it was deemed necessary in this research due to there being one utility only in Bahrain who is responsible for municipal water.

## 4.3 Data collection technique

The main purpose of collecting data is to provide evidence for the research study (Gillham, 2000; Yin, 2003). Yin (2003) provides three principles for data collection whenever possible in case study research. These are:

- Use of multiple sources of evidence.
- Creating a case study database.
- Maintaining a chain of evidence.

There are many different ways of collecting data, range from interviews, observational techniques such as participant observation and fieldwork, through to archival research. Written data sources can include published and unpublished documents, company reports, memos, letters, reports, email messages, faxes, newspaper articles and so forth, and which method or combination of methods should be adopted will depend upon the research topic (Yin, 2009). Yin (2003, 2009) provides six main sources of evidence that may be used for case studies, highlighting their strengths and weaknesses. These six sources of evidence are generally supported by Gillham (2000), Silverman (2001) and Smith et al., (2002). Table 4.2 summarises the data collection methods as provided by Yin (2003).

In consistence with the mixed methods approach (Triangulation), a mixture of quantitative and qualitative data methods were employed in the study. The main data collection methods used in this study were *interviews, questionnaires, direct observation, pilot tests, and documentation*. One or more of these methods were used to collect data on each of the research question. The choice of methods for each research question was based primarily on the type of data sought and type(s) of respondents involved.

Data were collected over 3 years. In order to check that all data were still relevant, the researcher carried out data evaluation which is reported in Chapter 7. The result of this evaluation confirmed that the research findings were accurate and valid.

**Table 4.2:** Six sources of evidence: strengths and weaknesses [Developed from Yin (2003)]

| Source of Evidence | Strength | Weakness |
|---|---|---|
| Documentation | • Stable – can be reviewed repeatedly<br>• Unobtrusive – not created as a result of the case study<br>• Exact – contains exact names, references, and details of an event<br>• Broad coverage – long span of time, many events, and many settings | • Retrievability – can be low<br>• Biased selectivity – if collection is incomplete<br>• Reporting bias – reflects (unknown) bias of author<br>• Access – may be deliberately blocked |
| Archival Records | • [Same as above for documentation]<br>• Precise and quantitative | • Same as above for documentation]<br>• Accessibility due to privacy reasons |
| Interviews/ Questionnaire | • Targeted – focused directly on case study topic<br>• Insightful – provides perceived causal inferences | • Bias due to poorly constructed questions<br>• Response bias<br>• Inaccuracies due to poor recall<br>• Reflexivity – interviewee gives what interviewer wants to hear |
| Direct Observations | • Reality – covers events in real time<br>• Contextual – covers context of event | • Time consuming<br>• Selectivity – unless broad coverage<br>• Reflexivity – event may proceed differently because it is being observed<br>• Cost – hours needed by human observers |
| Participant Observations | • [Same as above for direct observations]<br>• Insightful into interpersonal<br>• behaviour and motives | • [Same as above for direct observations]<br>• Bias due to investigator's manipulation of events |
| Physical Artifacts | • Insightful into cultural features<br>• Insightful into technical operations | • Selectivity<br>• Availability |

### *4.3.1 Data collection methods chosen*

This research uses both primary and secondary data sources:

The primary data was collected through interviewing experts in related WDM issues, staff at the Water Conservation Department (collecting data about water saving devices), staff at the Waste Control Unit (collecting data about leakage control and management), staff at the Customer Services Department (collecting data about water tariff and billing), and staff at the Water Metering workshop (collecting information about water meter management at utility level); household and industrial questionnaire surveys for water tariff reform and customer knowledge about WDM; pilot tests for leakage detection and use of water-saving devices in household premises and commercial buildings; plus studies regarding wastewater reuse in industrial and commercial buildings.

The secondary data sources comprised documentation provided by the Water Transmission Directorate, Water Conservation Directorate, Waste Control Unit, Metering Workshop, and Customer Services Directorate at the Electricity and Water Authority and the Sewage

Department at the Ministry of Works, which generally keep the documents of government publications, early research reports, project reports, conference documents, academic theses, journal papers, newspaper articles, books and internet, and illustration photographs.

All these different methods were combined in order to increase the credibility of this research. Every specific research question was corresponding to its own potential methods. The analysis of the above-mentioned data is detailed in chapter 5, while the various tools that were employed in collecting information during the fieldwork are outlined in Section 4.3.2 below.

### *4.3.2 Overview of research instruments and development*

**a) Semi- Structured Interviews**

One of the most important sources of case study information is the interview (Yin, 2009). There are several types of interview questions that are provided in the literature (e.g. Smith et al., 2002; Fellows and Liu, 2003; Bryman and Bell, 2003; Yin, 2003). In this research, interviews were adopted as the main instrument for collecting the primary data on the water supply situation in Bahrain and the potential of water demand management measures in different sectors. The interview is particularly good at producing data which deal with topics in depth and detail as a substantial proportion of data comes from interviews. Most advantages of the interview are the richness and clarity of the material it uncovers. As Gray (2004) points out, the well-conducted interview is a powerful tool for eliciting rich data on people's views, attitudes and the meanings that underpin their lives and behaviours. Interviews not only provide insightful information, but they also suggest sources of corroborating evidence, and initiate access to such sources.

In this research the interview guide was semi-structured, in order to find the existing problems during the implementation of WDM measures at different levels as well as the interviewees' own opinion about the WDM issues, open-ended questions were prepared. This type of interview has the advantage that the interviewer asks key respondents for the facts of a matter as well as respondents' opinions about events, allowing the interviewees to develop their own ideas and speak more widely on the issues raised in the research. The interviews conducted for this research were for a short period of time, such as one hour. In such cases, the interviews

may still remain open-ended and the interviewer uses a set of questions derived from the case study protocol.

The clear lists of specific research questions and more detailed questions to be asked during the interviews were prepared in order to guide the topics of the interview and control the focusing of its relevance. In appendix 5 the semi-structured interview questions are listed according to different informants as well as the detailed timetable and content of fieldwork, including detailed information about interviewees. All these questions are flexible in terms of order, and adjustments can be made during the interview itself. Data can be checked for accuracy and relevance as it is collected. In order to reduce the dependence on interviewees and negative impacts, such as individual bias, official documents, literature, observation pilot tests and questionnaire surveys were combined with interviews in order to corroborate the facts using a variety of independent sources. All interviews were made by appointment to ensure the availability of interviewees. The interview questions were in English when designing this research, but before interview they were all translated into Arabic for the convenience of interviewees.

In general, interviews generated qualitative data in sufficient depth to provide a detailed understanding of relevant WDM issues concerning water-metering management practice; leakage management and control; water bills as well as water conservation practice in Bahrain. The insights gained, together with some of the issues that came up during the interview stage of the research, were incorporated into the subsequent data collection phase of the research.

*Selection of respondents for interviews*

A selective rather than a random sampling technique was employed in identifying respondents for interviews. This was because the interviews were primarily aimed at generating data for understanding the phenomena of interest, rather than for making generalisations. Particular attention was given to selecting the people who were likely to provide representative answers to the questions being asked. The semi-structured nature of the interviews allowed for new information to arise in conversation and to be explored within the context of the interview. In this way the sampling was focused, and therefore justified the use of a 'one at a time' sample

size in each WDM measure question. As noted by several research writers, focusing a sampling strategy in such a way helped to enhance the credibility of data collected (Babbie, 1979, Kemper et al, 2003). A single category of staff was selected for the interviews. They were referred to as *key informants*. Interviewees drawn from this category were selected on the basis of their experience and knowledge of the subject concerned, and they were all from the Electricity and Water Authority (EWA). Permission from senior staff was secured before conducting the interviews (Appendix 1). Table 4.3 shows the number and type of EWA members interviewed.

Subsequent interviews were conducted on the basis of response. Owing to the huge amount of work associated with the interview methodology (Gillham, 2000), time constraints, and the fact that multiple data sources were being used, no more than six individual interviews from each department or unit were conducted.

**Table 4.3** Number and type of EWA members interviewed

| Authority | Department/ unit | Interviewees |
|---|---|---|
| EWA | Waste Control Unit | 1Engineer, I technician, 1 Sr. Technician, 3 Inspectors |
| | Metering Workshop Unit | 1 Engineer, 1 lead fitter, 1 Sr. technician, 1 Technician, 1 Inspector |
| | Water Conservation Department | 1 Sr. Engineer, 1 Sr. Technician, 1 technician, 1 Inspector |
| | Customer Services Department | 1 Chief Revenue &Accountants Control, 1Customer Care Supervisor, 1 Meter Reader |

Source: Author's fieldwork, (2009)

Informants were selected according to their experience or their specialised knowledge. This form of sampling is thought to be more relevant for selecting interview respondents. Care was taken to avoid bias in the sample of respondents. This was done by interviewing more than one employee at the same position and from the same department/unit, as well as documents, questionnaire survey and observation was combined with interviews to corroborate the facts.

Four groups of different interviews were carried out for this research. The first group of interviews was aimed at gaining an insight into the water meter management, type of meters in the distribution network, problems with meters, policy of replacement of aged meters, and maintenance practices. The interview was semi-structured, so the interviewer knew what to look for. The interview was conducted at the 'Salmabad' workshop in Bahrain. Five interviewees were involved.

The second group was aimed at (i) gaining an insight into different water-saving devices implemented by the Water Conservation Department at household and non-domestic level and the saving obtained by installing these devices; (ii) identifying the research carried out by the Department regarding the implementation of the saving devices and waste water reuse; and, (iii) discovering any education and awareness programme the Directorate was implementing. This interview was also semi-structured, and it was conducted at the Water Conservation Office. Four interviewees were involved.

The third group was conducted with six staff members from the Waste Control Unit of the Water Distribution Directorate. The interview was conducted in order to gain information about the responsibility of the leak detection policy, the procedure implemented for detecting leaks, and constraints faced in night exercises to detect and repair leaks. The interview was semi-structured and was held at the Waste Detection Office in Juffair.

The fourth group was aimed at gaining insight into water billing consumption and revenue, problems faced in collecting revenue, and water tariff reform. The interview was also semi-structured, and it was conducted with staff from the Customer Services Directorate. three interviewees were involved. Interviews took place at the Customer Services Directorate, Manama.

*The interview process*

Key informants identified for the interviews were contacted personally by the researcher and a time and location for the interview were arranged. Each key informant was briefed on the aim of the research and the key areas to be covered by the interview. All key informant interviews were held at their offices. Interviews were held between Jan 2009 and May 2009.

Each interview lasted between 45 and 50 minutes. As was anticipated before the fieldwork, many respondents were reluctant to have the interviews recorded, so all responses were written down in the form of notes. All the interviews were conducted by the researcher. On each day of the interviews the researcher wrote a summary of each interview. The summaries were written on the same day the interviews were conducted to ensure that the majority of issues that emerged during the interviews could be considered. Most of the interviews were conducted in Arabic, and only three were in English, so interviewees were able to express themselves fluently. No more than two interviews were conducted on each interview day.

**b) Questionnaire survey**

Surveys represent one of the most common types of quantitative social science research. In survey research, the researcher selects a sample of respondents from a population and administers a standardised questionnaire to them (Creswell, 2003).

Questionnaires are research tools through which people are asked to respond to the same set of questions in a predetermined order. Questionnaires are one of the most widely-used methods for gathering primary data and it remains the only method involving direct contact with people that can make some claim to being representative as it is understood by numerical criteria (Creswell, 2003; Berestord and Corft, 1986 as cited in Cavill, 2005). Gray (2004) observes that questionnaires should be used when they fit the objectives of the research.

Surveys may be "self –completion questionnaires' or require that someone else, an enumerator, ask the questions face to face with respondents- "interview survey". Interview surveys are based on standard, prepared questionnaires that the interviewer works through with the respondent. The procedure for the development of the questionnaire survey closely followed the recommendation of several scholars in social sciences (Babbie, 1979, Oppenheim, 1993, Sekaran, 2003).

Two sets of questionnaire were designed: the first was for householders and the second was for industries. The questionnaire was designed to elicit information on the three main areas of concerns: (a) awareness of water conservation; (b) willingness to pay for better water

supply quality; and (c) acceptability of increased tariff for improved water quality. In the case of industries additional information about wastewater reuse was elicited. The main purpose of designing the questionnaire was to relate the items in the questionnaire to the application of WDM measures to Bahrain.

Most of the questions were closed (requiring yes or no answers, or answers chosen from a limited range of options) for ease of data analysis, and the rest were open-ended. Instructions for the respondent, as well as the cover sheet, were designed before the pre-test. The questionnaire was pre-tested in order to ensure that the questions were understandable and appropriate for different contexts, to eliminate ambiguous wording, and to ensure a suitable length of interview, before the questionnaire was administered to a wider group of respondents. Respondents for pre-tests were chosen at random, instead of a rigid sampling framework as was used in the actual survey. Comments and insights obtained during the pre-testing phase were used in improving the questionnaire design and administration process. These included reducing the number of questions and the rephrasing of some questions.

The following steps were taken in order to enhance the validity of data obtained from the questionnaire, as recommended by Oppenheim (1993):

- The questionnaire was viewed by other professionals, including a planning supervisor, staff at EWA, and a social scientist.
- Leading or loaded questions were avoided.
- Natural and familiar language was used.
- Questions were phrased in such a way as to facilitate easy translation into the local language without loss of meaning.
- The questionnaire enumerators were sufficiently trained to perform the exercise.

It took about one year to develop the householders' questionnaire (due to the fact that the research was supposed to be quantitative not a case study, also being a part time researcher and primarily based in Bahrain), and as a last step before the pilot study, the researcher discussed it with several utility personnel. For the industrial questionnaire it took less time: 2 months. After an initial measurement instrument had been developed, pre-testing was carried out in order to ensure completeness and precision. The questionnaire was administered by

trained staff from the utility using the face-to-face method. They asked the questions and ticked the answers given by the respondents. The face-to-face method had the advantage of ensuring a high response rate, quick return of completed questionnaires, and the chance to provide explanation of the questions where necessary. The questionnaire was written in English and was then translated and administered in Arabic. In this way, errors owing to misunderstanding or wrong interpretation were minimised. The household population chosen for the questionnaire consisted of all dwelling units located within the residential areas in Bahrain (the questionnaire was sent in January to March 2007). The data was analysed with the Statistical Package for Social Science (SPSS) and a series of cross-tabulation analyses was performed. Analysis was completed by the end of December 2007. Analysis for the Industrial questionnaire was completed in March 2010.

*Selection and training of questionnaire enumerators*

Enumerators for the questionnaire survey were recruited from the Waste Detection Unit at the utility (it was purely for convenience of getting the questionnaire answered). The interviewers were all inspectors holding high school degrees (Secondary education). This group of people were targeted because of the fairly high level of education they had received, having gained several years of experience on water issues and because they needed a supplementary source of income. In addition to being inspectors they were familiar with the community and addresses of households and were likely to find it less daunting knocking on people's doors to administer the questionnaire.

A meeting was held with the volunteer enumerators at which they were briefed on the aims of the research, the nature of the task, the conditions involved, and the remuneration. A four-hour training programme was held over two days for those who were willing to take part in the exercise. On the first day of the training programme, the recruited enumerators were taken through the questionnaire and the meaning and relevance of each question was explained. There were also discussions on some of the challenges they were likely to face and ways of dealing with them.

*Administration of Questionnaires*

Respondent households for the questionnaire were selected by means of a stratified random design, covering five Governorates in Bahrain. It consisted of all dwelling units located within the residential areas in Bahrain. Access was given to the database for all registered customers as per the Customer Services Directorate 2006.

Yin (2009) states that the case study is not an experiment and that the goal of the case study is not to achieve statistical generalisation, but rather to expand or generalise theories. Thus, while using sampling to select respondents for the questionnaires, this research did not set out to perform a statistically significant survey. Sample size was arrived at by a rule of thumb method, as recommended by Perry (2001). Although the guiding principle for the number of questionnaires distributed was to obtain at least 350 completed and usable questionnaires, as recommended by Perry (1998, 2001) for PhD research, the study targeted 600 questionnaires to be distributed among the sample households in order to obtain a high response and to cater for inaccuracies of the water utility's billing databases, or wrong addresses.

An Excel spreadsheet was used to extract the category of domestic consumers for each Governorate as at November 2006. The spreadsheet entries showed (a) customer account number, (b) customer name, and (c) customer address.

From 600 households, a total of 545 householders' questionnaires were completed and usable, which represents a cumulative response rate of 91%.

The questionnaires were administered over a period of twelve weeks from January 2007 to the end of March 2007. The timely response was because of the financial incentives given to interviewers to speed up the task.

The survey approach used in this study was consistent with the objective of achieving a rapid overall assessment of willingness to pay an increased tariff for improved water supply, public awareness and public involvement in making decision about water issues, rather than gaining detailed information on any particular issue.

The data from a survey of this type could be expected to be limited in their precision. First, the quantities of water consumption reported by the household are considered to have limited accuracy since they were based mainly on household reporting regardless of summer or winter season.

A second area of potential bias relates to the water prices reported by households. It is likely that households might not have reported prices on a consistent basis; for example, some residents might have stated the highest price they had paid, while others might have stated current prices.
For the reasons mentioned above, data from surveys were cross-checked with the Customer Services Directorate database for water bills and they were all within ±20%.

In addition, industrial questionnaires were also conducted with 34 industries in Bahrain. The questionnaires were conducted in order to elicit information regarding willingness to use wastewater in industries, use water saving devices, and pay an increased tariff. The questionnaires were administered over a period of six weeks from October 2009 to mid December 2009.

**c) Field Observations**

Observations can range from formal to casual data collection activities. Observational protocols can be developed as part of the case study protocol. Observational evidence is useful in providing additional information and gaining rich insight into about the topic being studied. If the case study is about a new technology, observation of the technology at work is an invaluable aid in the further understanding of the limitations of or problems with the technology.

In this study, three different field tests were carried out in Bahrain in order to explore the suitability of some of the measures of water demand management: Low Flow Control device (LFC) and water-saving devices pilot tests, and leak detection equipment and evaluation of field staff efficiency.

**Low Flow Control (LFC) device pilot test**

A pilot test was carried out in Isa Town, residential Block 803, in February 2007, to study the performance of low-flow control valves (LFC) which is known in South Africa, which are also known as unmeasured flow reducers (UFRs) in the United States and Europe, in enhancing the performance of individual domestic meter registration and to verify the results and evaluate the Non-Revenue Water (NRW) level at the tank boundary level that covers many zones. This valve is a simple instrument installed on the water main adjacent to the water meter. The LFC valve alters the flow discipline through the water meter in order to measure the low-flow rates. Twenty LFCs were installed on the service water main adjacent to the domestic water meter (where pressure was in the range of 5 to 7 m) for a period of two weeks. The field test was carried out following procedures recommended by the literature and the manufacturer. This pilot test was carried out as an initiative of the researcher for this research.

*Process of pilot test*

The pilot test area was selected and meters were checked. Real losses and apparent losses were eliminated and then daily readings were recorded for four days prior to the installation of LFCs. Then LFCs were installed on domestic meters and daily readings were recorded for another four days. The difference in consumption before and after the installation of LFCs indicates an increased inflow rate.

Another pilot test was carried in Muharraq in zone 234 in order to evaluate NRW using an LFC valves.

**Leak detection equipment and evaluation of field staff efficiency**

The information collected by general observation of staff work was used to evaluate the Waste Control Unit staff and equipment involved. The researcher made visits to inspectors on site and watched them locating and repairing leaks detected during leak detection exercises.

**Water-saving devices pilot tests**

A Pilot test was carried out in order to evaluate the suitability of installing faucet aerators at houses in Bahrain and to assess the water savings resulting from their installation.

Faucet aerators are devices that work by mixing air into the water flow, breaking the flowing water into fine droplets and entraining air while maintaining wetting effectiveness. 210,000 aerators were distributed to 26,640 customers all over Bahrain during a Water Conservation National Campaign in June 2007. The national campaign lasted for 295 working days. The total number of employees in the team in the national campaign was 42, including the researcher. The team explained to customers the benefits and methods of installation of aerators and then distributed them among the customers (6 pieces per customer) in order for them to install them in their homes, they were also informed that any customer reduced the water bill by 5% would be entitled to incentives. Later, readings were taken in order to find out the water savings by comparing before and after installation readings.

Faucet aerators are inexpensive devices that can be installed in sinks to reduce the volume of water used.

The pilot test was carried out following manufacture procedures and the procedures recommended by the literature in the water use conservation handbook (Vickers, 2001). Incentives were given to customers who reduced their water bill by 5% than the previous month before installing the aerators.

**d) Analysis of technical Data**

As part of the analysis of technical data, assessment of the implementation of Infrastructure Leakage Index and Linier Leakage Index as a performance indicator for evaluating real losses were evaluated. This was an initiative of the researcher and it was specifically done for this research.

**Calculation of Infrastructure Leakage Index (ILI) and Linear Leakage Index (LLI)**

The assessment of the implementation of the International Water Association (IWA) Infrastructure Leakage Index (ILI) as a benchmarking performance indicator was carried out

following the procedure recommended by the International Water Association task force (IWA). While LLI was evaluated applying the French procedure.

## 4.4 Secondary Sources (Official documents and literature)

Documents and literature do not only provide background information which is used as a platform for research, but can also be sources of data in their own right. They can provide specific details in order to corroborate and augment information from primary data sources (Yin, 2009). This research focuses on the implementation of WDM measures. Much of the information about the legislation system, water demand management measures, and important articles come from official documents. Therefore, systematic searching for relevant documents is a very important part of this research. The required information can also be extracted from early research reports, academic theses, conference literature, project reports, articles, journal papers and books. The internet offers a convenient instrument for data collection, but information was carefully selected and combined/triangulate with other data collection sources in order to improve reliability.

Some general data regarding population and population growth rate, climate conditions and economic status were collected from reports provided by the Central Information Organisation in Bahrain (CIO).

Other data were collected from the Electricity and Water Authority (EWA). These data included available natural water resources and desalination capacity, various departments' annual reports, and other data and information relevant to the domestic/municipal water sector in Bahrain. These data were collected in order to analyse existing constraints and situation of activities carried out in the implementation of WDM measures, and to look at the options available for the country to overcome these constraints.

Three research reports regarding wastewater reuse from ablutions at mosques, wastewater reuse from the Arad Health Centre therapy swimming pool and installation of Electronic tap in toilets at commercial buildings as measurements for the WDM pilot test were collected

from Mr. Mahfood, Water Conservation Department, (2007) and a report of Bahrain Airport Service (BAS) Model using Air- Conditioning water for uses other than drinking water was collected from Zubari, Gulf University, (2007).

Fellows and Liu (2003) and Creswell (2003) argue that the most frequent concerns regarding secondary data are:

- They are often generated for a purpose that does not match the need of a particular researcher.
- Particularly in the case of organisational records, data may deliberately be recorded inaccurately.
- Material may be incomplete

In order to minimise those deficiencies a data triangulation was used in this research, where information was carefully selected and compared with other source to improve reliability.

**Triangulation**

Triangulation is used to describe the collection of evidences by different methods and from various sources in order to enhance the validity and reliability of the research case study by adding depth and breadth to the study results and interpretation (Creswell, 2003, Silverman, 2006). Yin (2003) provides four types of triangulation. These are:

- Data triangulation – triangulation of data sources.
- Investigator triangulation – triangulation among different evaluators.
- Methodological triangulation – triangulation of methods.
- Theory triangulation – triangulation of perspectives to the same data set.

This research used first three type of triangulation methods mentioned above to ensure the reliability of the data.

Each method of data collection can look at the topic from a different perspective and produces different kinds of data on the same topic. At the same time each has certain unique advantages as well as disadvantages. Triangulation can overcome the deficiencies of any

data collection method used by complementing each with another. Using multiple sources of evidence, the essence of triangulation is one of the most important characteristics of a case study, and is also the best way to increase the validity and reliability of the research. Documents, literature and field results were used in this research in order to triangulate the findings from the semi-structured interviews.

Data triangulation is a major research concern. Data is provided from various sources to achieve data convergence. Triangulation was achieved through: (1) interviews with various people; (2) documents from EWA; (3) questionnaire survey, and; (4) observations and field notes.

Triangulation in this research was achieved in several 'stages'. In the first stage, each interview was transcribed and checked for any contradictions in statements (Investigator triangulation). The second stage involved cross-checking with other sources of data (Data triangulation), including observations made and field notes. Documents and questionnaire surveys also were used as another source of data, but it was largely to check the public awareness and answers given by informants against the feedback from household level and industrial respondents to confirm their convergence. Finally, methodological triangulation was used in data analysis by applying both quantitative and qualitative approach methods. Having achieved triangulation, the next main issue is the validity of the research.

## 4.5 Validity and reliability

There are four tests which have been commonly used to establish the quality of a research design in case studies (Yin, 2009).

1. Construct validity: establishing correct operational measures for the concepts being studied.
2. Internal validity (for explanatory or causal studies only, and not for descriptive or exploratory studies): establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships
3. External validity: establishing the domain to which a study's findings can be generalized

4. Reliability: demonstrating that the operations of a study - such as the data collection procedures - can be repeated, with the same results.

Table 4.4 lists these four widely used tests and the recommended case study tactics as well as a cross-reference to the phase of research in which the tactic is to be used (Yin, 2009). These tactics were used not just at the beginning of the case study but throughout the whole investigation process.

The accuracy/credibility of research is assessed by its reliability and validity qualities. Generally they are the two most important quality control factors in research design (Creswell, 2003). Gorman and Clayton (1997) define reliability as 'the extent to which a measurement procedure yields the same answer however and whenever it is carried out', and validity as 'the extent to which a piece of research gives the correct answers'. Denzin and Lincoln (1994) note that reliability and validity represent key questions that must be answered one way or another and so cannot be disregarded. Also, the credibility of findings and conclusions depends on the reliability and validity of a piece of research, and therefore needs to be considered throughout the research process. This means that if another researcher followed the same procedures as described by the earlier researcher, and conducted the same case study all over again, the same findings and conclusions would be arrived at (Yin, 2009). The objective of reliability is to minimise the errors and bias in the research. The protocol plays an important role in increasing the reliability of a case study, and guides the researcher in carrying out the data collection.

**Table 4.4:** Case study tactics for four design tests

| Test | Case study tactic | Phase of research in which tactic occurs |
|---|---|---|
| Construct validity | Use multiple source of evidence<br>Establish chain of evidence<br>Have key informants review draft case study report | Data collection<br>Data collection<br>Composition |
| Internal validity (for explanatory or causal studies only, and not for descriptive or exploratory studies | Do pattern-matching<br>Do explanation-building<br>Address rival explanations<br>Use logic models | Data collection<br>Data collection<br>Data collection<br>Data collection |
| External validity | Use theory in single-case studies<br>Use replication logic in multiple- case studies | Research design<br>Research design |
| Reliability | Use case study protocol<br>Develop case study database | Data collection<br>Data collection |

Source: Yin (2009)

The case study protocol has four main sections: an overview of the case study project; field procedures; case study questions; and a guide for the case study report (Yin, 2009).

- An overview of the case study project that includes objectives and theoretical issues.
- Field procedures, including access to the case study site and people, and the sources of information.
- Case study questions, table templates for collecting data and sources of information for answering each question.
- A structure and guide for the final report.

In this research, the overview covered the background knowledge of water demand management, the issues arising from it, the current situation in Bahrain, and relevant readings about WDM. Four groups of interviews were selected to be carried out with the key interviewees from EWA in Bahrain. Before conducting the interviews, permission from senior staff was taken, and an outline of this research; its purpose; the issues about WDM and the research plan was offered to all interviewees. Specific research questions to be asked in interviews and potential methods for each question were carefully prepared and objectives of this research were always kept in mind when collecting data. A clear schedule of the data collection activities in fieldwork studies was made and completed within a specified period of time, and this is illustrated in Appendix 1 and Appendix 2. The procedures are

documented for repeatability. The database for this research was prepared in order to conveniently analyze the evidence. All the above factors were carefully controlled in order to maximize the reliability of this case study.

In this research, construct validity and external validity were both considered in research design and the data collection processes. The research design and data collection methods were developed and refined by peer review. Data were gathered from various sources and collected in multiple ways. The study was also reviewed by peer researchers, participants and interviewees. Research findings included achieving project aims and answering the research questions were evaluated by sending an email of the summary of findings and the main questions. This was the most appropriate for use in evaluating the research findings. This is discussed in detail in chapter 7. All of these methods were employed in order to improve the validity of this research.

Another way to ensure the reliability of data specific to the case study methodology is the case study database. This database comprises case study notes, documents, spreadsheets, and transcriptions. Care was taken during fieldwork to ensure that a database was carefully maintained. For example, the majority of interviews conducted were noted and transcribed the same day. In this way a chain of evidence was created between the questions asked, the data collected, and the conclusions drawn, in order to increase the reliability of the information presented in a case study.
The validation of research findings includes achieving project aims and objectives, and answering the propositions of the research were evaluated by evaluators.

## 4.6 Database summary

This study generated a large quantity of qualitative and quantitative data from questionnaire survey, interviews, documents and notes relating to the water demand management. Subsequent chapters of the thesis contain only a combination of the data collected. Although the bulk of the raw data is not presented in this thesis, all the information is publicly accessible and can be made available upon request. A record was kept of all the information

collected, and notes made during the research in the form of a case study database. A summary of the data used in this study is presented in Table 4.5 below.

**Table 4.5:** Summary of research database

| Data | Number analysed |
|---|---|
| Questionnaires<br>Householders Questionnaire<br>Industrial Questionnaire | <br>545<br>34 |
| Structured interviews | 18 |
| Pilot test | 3 |
| Documentary records | More than 240 |

Source: Researcher (2011)

## 4.7 Data analysis

Gray (2004) points out that there are two ways in which case study evidence can be analysed: the first is to analyse the data on the basis of the original theoretical propositions and research objectives that flow from them. The second is to develop a descriptive framework once the case study has been completed.

Typically of a mixed methods research, the information gathered from the fieldwork included both quantitative and qualitative data. Both sets of data were analysed separately using suitable data analysis techniques; bearing in mind the objectives of the research.

The analysis consisted of examining, categorising, tabulating, testing, or otherwise recombining both qualitative and quantitative data in order to address the primary research questions of the study. In this case study the analysis is more dependent on qualitative data and interpretive methods than quantitative data and statistical procedures. This is because of the character of this case study and the methods used in the data collection process. Throughout the analysis, data from the interviews was compared and contrasted in order to highlight any similarities and differences in the characteristics and behavioural trends within data from the pilot study and the questionnaires.

This decision is an explicit attempt to overcome the 'gap between qualitative studies whose reliability and validity are uncertain and open to challenge, the quantitative methods that tend to be crude and superficial' (Beresford and Croft, 1986 as cited in Cavill, 2005). The qualitative techniques used were semi-structured interviews with key informants, literature review, and participatory observations; the quantitative part refers to the use of questionnaires, aspects of the literature review and direct observation.

The data collected throughout this research was both quantitative and qualitative. Table 4.6 shows which research technique was used to answer each research question.
As can be seen from Table 4.6, all research questions were triangulated; only for the government policy level was there no triangulation.

**Table 4.6:** Application of research tools

| Research Questions | Questionnaire | Semi-Structured Focused Interview | Pilot Test | Document Review |
|---|---|---|---|---|
| How can WDM measures taken at utility level contribute to providing a sustainable water supply to Bahrain? | • | • | • | • |
| How can WDM measures taken at household level contribute to providing a sustainable water supply to Bahrain? | • | • | • | • |
| How can WDM measures taken at non-domestic level contribute to providing a sustainable water supply to Bahrain? | • | • | | • |
| How can WDM measures taken at government policy level contribute to providing a sustainable water supply to Bahrain? | | | | • |

Source: Researcher's fieldwork (2009)

The qualitative data analyses incorporated three main phases. These were the *description* phase (relying heavily on verbatim quotes from respondents), the *analysis* phase (identifying important factors, themes and relationships) and the *interpretation* phase (making sense of meaning in context). Due to the small number of transcriptions (18 interviews), transcripts were used to provide a comprehensive overview of issues concerning constraints in implementing WDM at different levels.

The quantitative data was generated from the questionnaire. Both univariate and bivariate analyses were carried out on the data. The univariate analyses gave descriptive statistics for the various data items. While bivariate was use in examining the relation between pairs of data items. All the statistical analyses were carried out with the Statistical Package for Social Sciences (SPSS) software (version 13), and Microsoft Office Excel 2003.

After enumeration was completed, the questionnaires were checked and the data was entered into a spreadsheet. Responses to the closed questions were processed using a quantitative code and checked for error before being analysed using SPSS (Statistical Package for Social Sciences). This package was used to provide descriptive statistics.
Where the data generated from the interviews and questionnaires are supported by the data generated from pilot tests and secondary data the findings have been integrated within a case analysis.

## 4.8 Research ethics consideration

These are issues related to the moral rightness of the research. Just as there are certain procedures that would not be used in research because they are scientifically unsound or impracticable, Babbie (1979) notes there are also some procedures which cannot be used on moral grounds. Such procedures may be either morally unacceptable, or politically difficult or impossible. The ethical issues that were taken into consideration during the conduct of this research are listed below:

- Permission was obtained from relevant authorities before data were collected from the research communities.
- All respondents, enumerators, and assistants who participated in the research did so voluntarily. No one was forced to take part in the research.
- All responses were treated as confidential and the identity of respondents was kept anonymous.
- Care was taken to ensure that participants were not exposed to danger as a result of the research.

## 4.9 Summary

This chapter has presented the methodology and research questions that guided the study. It has provided an overview of the mixed method (triangulation) used for the research and the justification for adopting a mixture of qualitative and quantitative methods. The chapter has also discussed the issues of reliability and validity in research. The different data collection methods employed in the study have been presented together with the procedures by which data were collected. The procedure of conducting research surveys and interviews with respondents was also presented, together with the reasons for the choice made. The chapter also discussed the techniques and methods employed in analysing the data and some ethical issues that were taken into consideration during the conduct of the research.

# Chapter 5: Water Demand Management: data analysis and presentation of findings

## 5.1 Introduction

Chapter 4 described the methodology utilised and the procedures followed for collecting data that were employed in order to answer the research questions for the analysis of applicable WDM implemented in Bahrain. It listed methods used in analysing the collected data, and provided justification for using the case study methodology and the choices of methods made for data gathering and analysis techniques involved. This Chapter is restricted to presenting the findings and analysis of data obtained from the fieldwork. It includes qualitative analysis of interviews and documents from the water authority, and quantitative analysis of questionnaire survey and pilot studies. Where applicable, data from the quantitative analysis have been used to support issues emerging from the qualitative analysis, and vice versa. Direct quotations from some respondents have been used, where applicable; to provide insight into specific issues which were representative of the views expressed by respondents.

Discussions of the findings in the context of the reviewed literature are presented in Chapter 6, validation of research findings and conclusions are presented in Chapter 7, while conclusions and implications of the thesis are presented in chapter 8.

This Chapter is divided into four main sections (5.2 to 5.5) as follows:-

- Section 5.2 Measures at utility level
- Section 5.3 Measures at household level
- Section 5.4 Measures at non-domestic consumers level
- Section 5.5 Measures at government policy level

## 5.2 Measures at utility level

This section addresses the research question: “How can WDM measures taken at the utility level contribute in providing a sustainable water supply for Bahrain?” The objectives were to

identify WDM measures and instruments that can be applied in the context of Bahrain at utility level, and to assess their sustainability for Bahrain.

In order to answer the above question the WDM measures applicable to Bahrain were identified as follows:

- Reduction in system losses by a leak detection and repair programme
- Water metering policy and billing
- Public education and awareness
- Increasing the water tariff and effective pricing

In order to assess the efficiency of the above measures, the researcher conducted interviews with EWA staff involved in applying WDM measures at utility level in Bahrain such as those who are in charge of the metering system and those who are responsible for public awareness and education about water saving devices. Also the researcher conducted household questionnaire surveys and reviewed the official and utility documents regarding the above WDM measures.

### *5.2.1 Interviews*

In order to identify the existing problems during the process of practising and enforcement of WDM, interviews with experts from key departments, who are responsible for activities related to WDM measures at utility level in the Electricity and Water Authority (EWA) in Bahrain, were conducted from January to June 2009 during the fieldwork of this research. The main interviewees were listed in Table 4.5 in Chapter 4.

The main questions (see Appendix 5) asked in the interviews were as follows:

1. What are the activities carried out by each unit and department contributing to WDM measures?
2. What deficiencies are there in the present organisation in running WDM measures?
3. How do different departments which are responsible for practising WDM work with each other and what kind of relationship do they have?

The interviewees pointed out the shortfalls in the present WDM initiatives and said that the shortfalls include departmental organisation, staff training, technology transfer & implementation, and availability of funds.

All of those who were interviewed from the Waste Detection Unit, the Metering Workshop Unit, the Water Conservation Department and the Customer Services Department of the EWA mentioned that standards exist for coordination between units and departments within EWA but these standards are not always followed. Each unit and department has specific responsibilities.

It was pointed out from interviews that the prime responsibility of the Waste Control Unit is to lower the high rate of water losses from the distribution network (before the customer's meter) to an economically viable limit in an efficient, scientific and financially feasible manner. This is done through a leak detection programme for all mains in the system throughout the year. This involves visual inspection for leaks along all distribution pipeline routes, and conducting leak detection tests for distribution system. Staff responses from the Waste Control Unit show that they were aware of their roles and responsibilities; all the respondents said that there is a lack of capacity in terms of number of staff, skills, technical equipment and updated network drawings. The need for hiring of qualified and well skilled staff, and continuous professional development were articulated by all respondents. All these challenges seemed to be pointing to an inadequate budgetary provision for the Unit.
The entire above are in line with the researcher's experience that the unit has some constraints.

On the external environment, Waste Control Unit staff felt they did not get all the necessary cooperation from the public when they carried out their duties. One common problem pointed out was that they were usually barred from residential housing areas for high ranking governmental officials, commonly known as Very Important Customer (VIC) areas, as highlighted by the following comment:

> *"VIC areas affect our productivities, as security does not allow us to work in these areas. Once I had a gun pointed at me and I was told to leave the area*."
>
> (Inspector, Waste Control Unit)

The responsibility of the Metering Workshop Unit is to replace old domestic and bulk meters, assist maintenance in attending meter complaints, calibration of bulk and domestic meters, and replacement of stopped meters. The respondents showed that they were aware of their roles and responsibilities. However, all the respondents pointed to lack of capacity in terms of numbers, skills, and technical equipment. Again they said that they need to hire more qualified and skilled staff. All these constraints seemed to be related to an inadequate budgetary provision for the Unit. One common problem pointed out was that mechanical meters had problems and were not replaced based on policy, as highlighted by one respondent, who said:

> *"Due to small particles of sand (in piston type meters), Pistons get stuck and stop while in Turbine type meters brass parts get corroded and are difficult to replace. Domestic Meters are replaced according to the condition of the meter and not necessarily after 6 years in service as indicated in the policy. This is because of shortage of staff and spare parts*."
>
> (Technician, Metering Workshop Unit)

The role of the Water Conservation Department is to optimise the usage of domestic water supply due to the alarmingly increasing per capita consumption. This is done through detecting leaks at the customers' premises, installing water saving devices, national campaigns and public awareness programmes. The staff were aware of their roles and responsibilities although they required professional training in order to enhance their capabilities. All the respondents pointed out that there was no problem with the policies and standards as all interviewees indicated that standards being practised and that some shall form the part of water bylaws. Nevertheless, all the respondents pointed out that there was a lack of capacity in terms of public awareness courses regarding water conservation and the benefits of water conservation amongst the utility employees. The need to take (or provide/deliver) courses in public awareness about WDM was articulated by all respondents. All these responses seemed to be pointing to an inadequate budgetary provision for the department thus leading to staff shortage. One common response was that the Water Conservation Department staff face few difficulties in carrying out their duties. The Water Conservation Department target students at primary schools where they distribute tap aerators to students as water saving devices. This job was described by a member of this Department as follows:

> *"Our target group in public awareness and education is students at primary schools where we give them demonstration on benefits of using tap aerators and how to install them*."
>
> (Inspector, Water Conservation Department)

The responsibility of the Customer Services Department is to take monthly water meter readings, generate water bills and collect revenue, also coordinate with metering unit in case the meters have stopped and arrange for replacement or repair. The interviewees from the Customer Services Department were aware of their roles and responsibilities. However, all the respondents pointed out the lack of capacity in terms of numbers and skills. The need for hiring of well skilled staff, and continuous professional development, was articulated by all respondents. All this feedback seemed to be pointing to an inadequate budgetary and capacity provision for the department. On the external environment, Customer Services Department staff felt they did not get all the necessary cooperation from the customers when they carried out their duties. It should be noted that the Customer Services Department has limited authority in taking action against customers not paying for their water bills. One common problem pointed out by the Customer Services Department, and very similar to that experienced by staff in the Waste Control unit, was that they are usually barred from residential areas housing with high ranking governmental officials, commonly known as VIC areas. This problem can be better understood from the following quotation:

> *"VIC customers sometimes do not allow the meter reader access to the property to read the meter. This forces staff to estimate the readings and this has an effect on the generation of water billing reports and the calculation of NRW, also limited authority has negative impact on our duties because of Water tariff was last reformed by government in 1992 without consulting EWA*." (Chief, Revenue & Accounts Control Section, Customer Services Department)

The high committee of NRW are discussing whether to issue a request for the Minister Mr. Fahmi Al-Jawder to ask VIC customers to allow readers of water meters to be allowed to have access to VIC meters (Minutes of meetings of NRW Committee, 2010).

**Summary of key themes identified from interviews**

Four (4) categories of problem issues were identified from among the respondents of the individual in-depth interviews. The problem issues and causes of the problems per department are shown in Table 5.1.

**Table 5.1:** Problems and causes matrix identified by interviewees in the EWA Departments/Units

| Problem Issues | Electricity & Water Authority Departments/ Units | | | | Causes of the problems |
|---|---|---|---|---|---|
| | Waste Control Unit | Meter Workshop | Water Conservation Department | Customer Services Department | |
| **Shortage of Budget allocated for each unit** | √ | √ | | √ | In house financial management |
| a. Shortage of water meters and spare parts | | √ | | | |
| b. Shortage of leak detection equipment | √ | | | | |
| c. Shortage of staff | √ | √ | | √ | |
| **Weak capacity building development** | √ | √ | √ | √ | Human resources management by Technical staff |
| a. Communication skill courses | √ | | √ | √ | |
| b. Technical training in using equipment | √ | √ | | | |
| **Lack of WDM awareness among utility staff** | √ | √ | √ | √ | Lack and shortages of research and development and public awareness system |
| Shortage of training courses in WDM for utility staff | √ | √ | √ | √ | |
| **Weak enforcement of policy and standards** | √ | √ | | √ | Policy / Weak enforcement against customer |
| a. Weak enforcement of policy and standard due to shortage of staff and equipments | √ | √ | | √ | |
| b. Limited authority in taking action to access VIC area | √ | | | √ | |
| c. Limited authority in taking action against customers not paying their water bills | | | | √ | |

Source: Researcher's fieldwork from interviews, (2009)

The above mentioned problems lie largely within the higher level authority. Even though the EWA is trying its best to minimise and resolve those problems.

According to many of the respondents, they indicated that the constraints presented in the above table forced them:

- To change their work plans very often;
- To reduce the level of their productivities to the fact that they could not follow the mandate of their duties;
- To take longer times to complete their task;

- To be unable, sometimes to fulfil their duties. This has a negative impact in implementing WDM measures.

From Table 5.1 it can be seen that the Water Conservation Department has the least constraints. However, this Department still faces a lack of WDM awareness among its staff and weak capacity building development. The Waste Control Unit, Metering Workshop Unit and Customer Services Department all have to deal with all categories of constraints. Both Waste Control Unit and Metering Workshop unit suffer from shortage of equipment needed to carry out their duties and technical training in using such equipment. Also it can be seen that Customer Services Department is the only department that has limited authority in carrying out its duties as it is directly dealing with customers in collecting revenue and there is no clear regulation in handling such situation.

### *5.2.2 Field observations*

This section describes the pilot tests carried out in Isa Town to evaluate the use of Low Flow Control (LFC), to improve the accuracy of domestic meters at low flow rates, and the evaluation of Waste Control Unit staff performance and equipment involved in leak detection. Details of what was done are given below.

#### a. Pilot technical studies implementing low flow controller (LFC)

The vast majority of water meters do not record very low flows (< 14 l/h) as they require a threshold flow rate in order to trigger the meter counter (Davidesko, 2007). In order to address the problem of meter under registration, the literature review indicated that several studies (Christodoulides, 2008; Davidesko, 2007) during the last three years (since 2007) have been carried out to evaluate the use of Low Flow Controller (LFC); they are also known as unmeasured flow reducers (UFRs) in several countries.

LFCs are used to improve the accuracy of meters at low flow rate by regulating the flow pattern. A pilot test was carried out in Isa town residential Block 803 in February 2007 to study the performance of LFC devices to enhance the performance of individual domestic meters.

Twenty (20) LFC devices were installed for the study purpose (where pressure was in the range of 5-7 m) for a period of two weeks. The installation procedure was followed as recommended by the manufacture and as explained in Chapter 3. The results were encouraging as a 36% increase in recorded average consumption was observed after installing the LFCs, which resulted in an increase in annual revenue of BD 1,915 (£ 3191.6) for the said 20 installed LFC's. The cost of one LFC is BD 30 (£ 50) giving a payback period of 3.8 months. It was found that installing an LFC would be useful to be implemented in Bahrain in order to solve meter under-registration at low flow rates. Figures 5.1 and 5.2 show the installation of an LFC, and Table 5.2 summarises the findings from the pilot test in Isa Town. Currently the WDD has installed 17,000 LFC in different areas in Bahrain; it is EWA strategy to continue installing LFCs across all areas in Bahrain.


**Figure 5.1:** Installation of LFC (Pipework has yet to be connected to take flows through the LFC), Source: Researcher, (2007)


**Figure 5.2:** Fixing meter after installing LFC, Source: Researcher, (2007)

**Table 5.2:** LFC Pilot study Isa Town Block 803 (3–20 February 2007)

| No | House no | Road | Average Consumption $m^3/d$ | | Difference $m^3/d$ | % increase |
|---|---|---|---|---|---|---|
| | | | Before LFC | After LFC | | |
| 1 | 2 | 304 | 2.67 | 3.50 | 0.83 | 31 |
| 2 | 5 | 304 | 1.33 | 1.60 | 0.27 | 20 |
| 3 | 7 | 304 | 0.67 | 1.00 | 0.33 | 49 |
| 4 | 13 | 304 | 3.00 | 3.50 | 0.50 | 17 |
| 5 | 14 | 304 | 1.67 | 2.50 | 0.83 | 50 |
| 6 | 15 | 304 | 1.33 | 1.50 | 0.17 | 13 |
| 7 | 38 | 306 | 3.00 | 4.00 | 1.00 | 33 |
| 8 | 39 | 306 | 2.50 | 4.00 | 1.50 | 60 |
| 9 | 40 | 306 | 0.67 | 1.00 | 0.33 | 49 |
| 10 | 57 | 308 | 2.00 | 3.67 | 1.67 | 84 |
| 11 | 60 | 308 | 1.00 | 1.67 | 0.67 | 67 |
| 12 | 62 | 308 | 1.50 | 2.00 | 0.50 | 33 |
| 13 | 75 | 308 | 2.33 | 2.50 | 0.17 | 7 |
| 14 | 76 | 308 | 2.00 | 3.00 | 1.00 | 50 |
| 15 | 104 | 310 | 2.33 | 3.50 | 1.17 | 50 |
| 16 | 106 | 310 | 1.00 | 1.20 | 0.20 | 20 |
| 17 | 708 | Reyadh Ave | 1.67 | 2.00 | 0.33 | 20 |
| 18 | 712 | Reyadh Ave | 2.00 | 2.33 | 0.33 | 17 |
| 19 | 714 | Reyadh Ave | 0.50 | 0.67 | 0.17 | 34 |
| 20 | 718 | Reyadh Ave | 3.67 | 5.00 | 1.33 | 36 |
| **Total** | | | **36.84** | **50.14** | **13.30** | **36** |

Source: Fieldwork, researcher, (2007)

Table 5.2 shows that the total average consumption of 20 houses (averaged over a period of one week) before installing an LFC was 36.84 $m^3$/d and this increased to 50.14 $m^3$/d after installing a LFC.

Another pilot test was undertaken in Muharraq in waste zone (zone 234) to evaluate the accuracy of customer meters with LFC. 'Zone 234' was selected because all mains and connections were recently replaced within 4 years (2007) and there were no reported existing leaks in the system during that period.

Weekly readings of all domestic meters were taken for three weeks prior to installation of LFC. Meter under-registration was then calculated and a comparison of the sum of domestic water meter readings to that of the main water meter of the waste zone (zone 234) was made. Eighteen (18) LFCs were installed. A second round of record readings for three weeks after installation of LFC was taken and then meter under-registration was calculated The Customer Meter Under registration value showed a reduced value due to the LFC functionality.

In order to calculate zone balance and compare customer meter under-registration with and without LFCs. Zone balance calculation and Customer Meter Under-registration are shown in Table5.3 for pilot zone.

Results achieved for Customer meter under-registration before and after LFC installation are as follows:

• Customer meter under- registration (without LFCs) = 22 %

• Customer meter under- registration (with LFCs) = 7 %

This clearly indicates that approximately 15% (22% - 7%) can be attributed to actually consumed water, rather than considered as leakages from the water distribution system or NRW. A high value of customer meter under- registration is due to old inaccurate meters and the presence of storage tanks. Consequently, expensive equipment and human resources utilization to look for leakages which are actually not there can be avoided.

During the test period the LFC proved to be effective in reducing customer meter under-registration allowing to get additional 15% revenue.

These figures are consistent with (or better than) the ranges indicated in the literature review (Chapter 3) (the ranges indicated in the literature review were between 6% and 9.9%) and a

test carried out in Cyprus (Christodoulides, 2008) where NRW dropped from 16.36% before installation of LFCs to 8.81% after installation of LFCs, giving a difference of 7.57%. In another test carried out in Israel (Davidesko, 2007) the NRW dropped from 16% before installation of LFCs to 6.1% after installation of LFCs, indicating that consumed water that had not previously registered was 9.9%.

**Table 5.3:** NRW, LFC Evaluation

| **No. of Premises 38** | **Consumption $m^3$** | | **NRW** |
|---|---|---|---|
| **LFC Installed 18** | **Zone meter** | **Individual meters** | |
| **Without LFC** | 665 | 543 | 22% |
| **With LFC** | 572 | 534 | 7% |
| **Contribution of LFC** | | | 15% |

Source: Researcher's field work, (2007)

**b. Leak detection equipment and evaluation of field staff efficiency**

The information collected by general observation of staff work has been used to evaluate the Waste Control Unit staff and equipment involved. The Waste Control Unit is presently equipped with vehicles used for field operations. Most vehicles are of the pick-up type.

There are 13 operational inspection teams. One inspector generally forms a team with 2 trade workers. Some of the teams presently consist of 2 inspectors and one trade worker. Another problem is that the Waste Control Unit has one pipe fitter and one trade worker doing the job of a pipe fitter, and this has an effect on the rate of repairing leaks found by inspectors during leak detection exercises.

It is important that these problems be solved in order to optimise the unit's performance in terms of field inspection. The Waste Control Unit has established that field teams composed of one inspector and two trade workers represent the best team configuration in terms of accuracy and speed (Nimal, 2008; WDD Annual Report, 2005).

Table 5.4 lists the field equipment both presently available and required, according to Waste Control Unit database records. From Table 5.4, note that the column headed 'required equipment as per existing staff capacity' means that some inspectors do not have this equipment, while the column headed 'overall equipment required' covers the numbers of

items of equipment needed by inspectors, as well as spares equipment required for future use.

It is clear from the table that there are shortages in some equipment as currently only nine (9) inspectors are fully equipped with the minimum requirement of equipment. This shortage has an effect on the performance of inspectors in carrying out leak detection during night exercises.

**Table: 5.4:** Field equipment available and additional required according to Waste Control Unit

| Equipment Name | Total Quantity available | Required equipment as per existing staff capacity | Spare equipment required | Overall equipment required |
|---|---|---|---|---|
| **Pressure measurement** | | | | |
| Fire Hydrant Caps | 0 | 13 | 10 | 23 |
| Pressure gauge | 9 | 4 | 10 | 14 |
| **Flow Measurement** | | | | |
| Pulse unit (3000) | 13 | 13 | 10 | 23 |
| Pulse unit (4000) | 13 | 13 | 10 | 23 |
| **Pipe Detector** | | | | |
| Areal Pipe Locator | 13 | 0 | 6 | 6 |
| Metal Locator | 9 | 4 | 5 | 9 |
| **Data Loggers** | | | | |
| Logger | 13 | 13 | 10 | 23 |
| **Leak Detection** | | | | |
| Leak Detector | 15 | 0 | 10 | 10 |
| **Snap Connector** | 13 | 13 | 10 | 23 |
| **Listening Stick** | 2 | 11 | 10 | 21 |
| **Leak Noise Correlator** | | | | |
| Correlator- Palmer | 2 | 0 | 1 | 1 |
| Correlator- Fuji | 1 | 0 | 1 | 1 |
| **Radio Detection Equipment** | 3 | 0 | 4 | 4 |
| **Radio Detection cable (50 m)** | 1 | 1 | 2 | 3 |
| **Measuring Wheel** | 2 | 3 | 3 | 6 |

Source: Compiled by Researcher from Waste Control Unit database, (2010)

According to policy each inspector should ideally have a logger, a listening stick as well as an electro-acoustic leak detector, one metal locator, fire Hydrant cap, and 1 pipe locator.

These equipments presently perform most of the leak detection tasks, but because of equipment shortages (such as listening sticks, fire Hydrant caps) some inspectors need to share equipment.

A number of inspection teams are not fully equipped due to lack of equipment or spare parts. Table 5.4 also summarises the internal document on the unit's technical needs for the year 2010. This table was generated by the author by looking at the waste detection equipment database and checking the list of available instruments with each inspector.

The lack of training for inspectors on handling software and instruments has loaded an unnecessary burden onto the night shift technicians. Also due to the unavailability of an on-site programming unit, evaluation of logger data in the office represents a loss of time for the inspectors on leak detection as they have to wait until the following night to view step test data before undertaking a leak survey.

Because of the constraints (previously mentioned) such as meter failures and delays for repairs and the resources currently available, the Waste Control Unit showed low performance.( see Section 5.2.4, Table 5.13).

### *5.2.3 Analysis of technical data*

In this section the calculation of IWA's Infrastructure Leakage Index (ILI) and French Linear Leakage Index (LLI) as performance for assessing real losses are discussed.

**a. Calculation of Infrastructure Leakage Index**

From the literature reviewed for this study it was found that there were various disadvantages arising from using a straight forward percentage of water produced/distributed to express water losses an indication of leakage or NRW in Bahrain. This is because they are affected by factors such as customer demand which can vary seasonally even when the absolute volume of water loss remains the same (Trow, 2007; Liemberger et al, 2007). Also the practice of expressing NRW as a percentage of either system input volume or a percentage of water supplied means that the percentage of NRW is substantially influenced by the following (non-exhaustive list) as documented by Liemberger et. al. (2007):

- Whether the calculation uses, as the denominator, system input volume, or water supplied
- Difference in consumption levels, and change in consumption
- Whether the utility's customers have individual storage tanks or direct pressure
- What average supply time in the system is, i.e. level of intermittency
- The average pressure

A more accurate means of benchmarking takes into account the number of properties served. Lambert in 2005 recognised that leakage rates for "good" systems are a function of the connection density and the pressure, amongst other inputs. Further work needs to be carried out in breaking the present levels down into types of leakage.

The present units of measure used for NRW and leakage within WDD in Bahrain are currently expressed as percentages; this is not the appropriate measure as it can be misleading to ensure clear benchmarking ability. WDD needs to express both of these terms in cubic metres or litres per customer per day.

Real losses should be assessed by an additional method which is more presently acceptable as a performance indicator as indicated in chapter three. One of these methods is the Infrastructure Leakage Index (ILI) indicator which is presented by the International Water Association (IWA) as described by Lambert, (2005). The Infrastructure Leakage Index (ILI) is an indicator of how well a distribution network is being managed and maintained at the current operating pressure. The advantage of this performance indicator is that it includes a reasonably reliable estimate of the 'Unavoidable' Real Losses which are obvious – it identifies not only what the current losses are, but also permits an initial estimate of the maximum potential for reduction in real losses at the current pressure(Liemberger et. al. 2007). It is calculated as follows:

$ILI = CARL/UARL$ [Equation 1, Lambert 2005]

$UARL = [18 \times L_m + 0.8 \times N_c + 25 \times L_p] \times P$ [Equation 2, Lambert 2005]

Where, CARL: current annual real losses (l/day)

UARL: unavoidable annual real losses (l/day)

$L_m$: length of mains (km)

$N_c$: number of service connections (connections)

$L_p$: total length of pipe between property line and customer (km)

P: average operating pressure (m)

Work has been carried out by the author in calculating the figures for Bahrain for the period 2005-2010. This indicator is used for determining and comparing leakage in water distribution systems. Table 5.5 presents ILI values calculated. When reading this table it should be noted that a level above 50 indicates poor control over leakage levels.

**Table 5.5:** Bahrain ILI values calculated for period 2005-2010

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| **ILI** | 57.5 | 59.0 | 61.1 | 78.9 | 119.0 | 102.2 |

Source: Researcher's fieldwork, (2010)

Due to its limitations it has been identified internationally that there are concerns when using this process for benchmarking against other countries, it requires accurate data rather than estimated one as the formula becomes unreliable in countries which they operate distribution system below 25m pressure head. However it is useful to use the ILI process in Bahrain as a means of prioritising between various waste zones within the same distribution tank area zones, calculating the ILI by zone, and comparing one zone against another because the pressure is the same, thereby the unreliability's of the formula are negated.

As per the World Bank Institute, banding system for developed and developing countries, the use of matrix approaches are used to identify a technical performance category (Bands A-D) for a utilities management of real losses as indicated in Table 3.4 Chapter 3. This matrix will cover limitation mentioned by ILI developer.

The Infrastructure Leakage Index (ILI) method was tried in Bahrain by the author.

In calculating ILI for Bahrain for year 2005 the following factors were considered:

- Average pressure in the network (*calculated as 7 m by EWA*)
- Length of mains (*calculated as 3734 km based on figures from EWA annual report*)

- Length of service connections (*calculated on the basis of an average of 7 m per connection according to the EWA reports*)
- Real losses, which is currently only deducted after evaluating VIC consumption and meter under-registration (*calculated with low confidence*)

ILI = CARL/ UARL

UARL = 1,307,706 l/day (18 × 3734 + 0.8 × 122.670 + 25 × (122,670 × 7)) × 7

CARL = 75,207,395 l/day (27,450,699 / 365 × 1000 – (figure from EWA annual report 2005)

**ILI for Bahrain = 57.5** = (75,207,395 / 1,307,706)

Real losses are calculated with low confidence due to the estimates of apparent losses percentage. All of these factors lead to inaccurate value of ILI.

The result showed that ILI in Bahrain is 57.5 which is far outside the acceptable range. The Bahrain distribution network runs under low pressure and literature (Mckenzie, et.al,2007) shows that at low pressure, ILI for some system are usually in excess of 10. Table 5.5 shows ILI calculated for Bahrain for the years 2005- 2010 and all figures show values above 50. With reference to Table 3.3 and Table 3.4 in Chapter 3, it was found that Bahrain ILI values are higher than 16 and it is in category D for developing countries which indicates a very inefficient use of resources; leakage reduction programs are imperative & a high priority to reduce real losses by reducing ILI to below 16.

A similar result was observed in South East Asia and Thailand (McKenzie, et.al, 2007). For many developing countries, ILIs for some systems are usually found to be in excess of 10, or in some cases even in excess of 100, so very low ILIs can be considered almost an impossible target for such systems (McKenzie, et.al, 2007).

The existing approach has proved useful as performance indicator when benchmarking leakage in water distribution system mainly in Asia where very low pressure and intermediate supply are experienced (Seago, et.al, 2007; Radivojević, et.al, 2007). According to Winarni (2009) ILI could be used by operators to measure their attempts at water loss reduction.

On comparing ILI values for Bahrain with other international countries (developing and developed countries) it is evident that the situation for Bahrain is out of the range, as it is exceeding the Max values listed in Table 5.6 for developing countries.

As documented by Radivojević, et.al (2007) as soon as utilities start to introduce active leakage control, it will improve overall data quality and band width of ILI will dramatically be reduced. Table 5.6 shows ILI values for different countries. Note. Additional values for ILI in Bahrain are in Table 5.5.

**Table 5.6**: ILI values for different countries/ regions

| Country | No of data sets | ILI values | |
|---|---|---|---|
| | | Min | Max |
| Australia | 1 | 0.5 | 1.7 |
| Burkina Faso | 1 | 8 | |
| Canada | 17 | 1.1 | 9 |
| Cyprus | 1 | 2 | |
| Ethiopia | 1 | 20 | |
| Finland | 1 | 3 | |
| Kingdom of Bahrain | 1 | 57.5 | 102.2 |
| Kosovo | 7 | 3.3 | 23 |
| Malawi | 2 | 12 | 26 |
| Namibia | 1 | 10 | |
| Netherlands | 1 | 0.3 | 0.6 |
| South Africa | 54 | 0.4 | 16.9 |
| South East Asia | 15 | 19 | 598 |
| Spain | 1 | 12 | |
| Tanzania | 2 | 16 | 32 |
| Thailand | 14 | 46 | 543 |
| UK | 2 | 1.7 | 1.8 |

Source: McKenzie et al. (2007); researcher, (2010)

From the different data sets, it was revealed that developed countries with strict regulation tend to have low ILI while developing countries such as South East Asia, Thailand tend to have high ILI.

From Tables 3.4 (in Chapter 3) (as indicated by Liemberger and Mckenzie (2005); McKenzie et. al, 2007) and 5.5 it is evident that ILI figures are not always appropriate for comparing systems from different countries, but they do tend to be helpful in comparing systems within the sample country or even systems within the same classification of service delivery –e.g. all systems in fully developed countries. Also it is evident that pressure

management affects both CARL and UARL, and, as previously mentioned, ILI is effectively independent of 'supply pressure'. ILI measures how well real losses are being managed at the current pressure, but it does not imply that the current pressure is the optimal pressure (Taylor, 2008).

The benefits of using ILI include measurement of how effective a utility is in managing Real Losses. It also allows for comparisons to be made between water systems worldwide. However, its calculation requires a lot of laborious data input. This information is difficult to have to hand in water utilities where GIS and modelling are not thorough and complete. This is the case in Bahrain, where some values are still estimated ones.

**b. Calculation of French Linear Leakage Index performance indicator (LLI)**

The linear leakage Index is a French index which is used in part of France and French Outer territories. It requires only a few parameters and allows good monitoring and performance evaluation of a network and gives good results to benchmark different networks. The knowledge of LLI is however, sufficient for local network management and will be at the centre of the network monitoring process to guide field teams to priorities sectors for inspection. It only requires production volume, leakage volume and length of mains. It is easier to calculate than ILI. LLI Performance varies from good to poor distribution network depending on type of distribution network.

The French index (LLI) is less thorough than the IWA's ILI, but it is much easier to apply, especially when the full information to apply the IWA method is not available or has low confidence limits. The LLI is calculated by dividing the volume of leakage by the length of mains. It can be used to separately qualify District Meter Areas (DMA's) or waste zones and it is calculated as follows:

LLI = loss flow rate during distribution ($m^3/h$) ÷ length mains pipeline (km)

In calculating LLI for Bahrain for the year 2005 the following factors were considered

- Length of mains (*calculated as 3734 km based on figures from EWA annual report*)

- Annual leakage value (*calculated as 27,450,699 $m^3$/year based on figures from EWA annual report*)

**LLI for Bahrain = 0.84** =27,450,699 ÷ (3734 × 365 × 24)

LLI = 0.84 $m^3$/h/km

The following Table 5.7 shows performance indicators for Bahrain when compared to other countries

**Table: 5.7:** Performance indicator for Bahrain with other countries/region

| | Bahrain | | | | Singapore | Paris |
|---|---|---|---|---|---|---|
| Gross Per Capita Consumption (l/c/d) | 2005 | 2008 | 2009 | 2010 | 2005 | 2005 |
| | 491.12 | 497.18 | 516.52 | 525.17 | 170 | 262 |
| Annual Production ($Mm^3$) | 159.3 | 200.8 | 220.6 | 236.6 | 490 | 216 |
| Percentage of leakage (%) | 17.6 | 23.03 | 33.24 | 27.39 | 4.6 | 3.7 |
| Length of distribution mainline (km) | 3734.31 | 5173 | 5788 | 5965 | 4850 | 1800 |
| Linear Leakage Index ( $m^3$/hr/km) | 0.84 | 0.97 | 1.4 | 1.2 | 0.53 | 0.51 |

Note: one data set were used in each country, Source: Author's fieldwork, (2011), G2C report, (2007)

The LLI for Bahrain is greater than the French recommendation of > 0.63 $m^3$/h/km (which is the poor band as presented in Table 3.5 Chapter 3). This shows that the leakage level in Bahrain, as calculated for the period 2005 to 2010, is very high (> 0.63 $m^3$/h/km) and it is in the bad range as indicated in Table 5.7. Despite the efforts of the Waste Control Unit with the current means and manpower, the loss from the network, which did not appear alarming when considering percentage, appears to be very important in terms of the linear leakage index.

Both results ILI and LLI are far from the recommended range (refer to Tables 3.4 & 3.5). Consequently reducing real losses to below ILI figure of 16 will be the initial goal for EWA which can be achieved through active leakage control.

**Summary of themes identified from observation**

The result from LFC pilot test showed an increase in metered consumption after installing LFCs. It was found that it would be useful to install LFC in Bahrain in order to reduce meter under- registration at low flow rate. Evaluation of NRW after installations of LFCs showed

that 15% of NRW can be attributed to under registration of meter rather than considered as leakage from the water distribution system.

From a review of leak detection equipment and observation to evaluate field staff efficiency it was found that the waste detection unit has a shortage of staff and leak detection equipments in addition to insufficient training in using the available leak detection equipment.

On the other hand it was found that for real losses ILI could be used as a performance indicator (Liemberger and McKenzie (2007). Also ILI could be used by operators to measure their attempts at water losses reduction. Although it is useful to use LLI in Bahrain, it cannot be applied for international comparison as LLI is only used elsewhere systematically in France and the French Outer territories.

### *5.2.4 Questionnaires regarding public awareness*

The effectiveness of the public awareness and education campaign implemented by EWA in Bahrain was evaluated through a household questionnaire survey conducted by the researcher in 2006 on 545 respondents. The results of a household survey regarding awareness of water conservation and water demand management indicates that 54.2% respondents were aware of water conservation. The respondents said that they were aware of water conservation through different media means but mainly from television (67.3%) and through newspapers (33%), and then by the Electricity & Water Authority (EWA) (28.9%) and finally, radio and relatives (13.6% and 14.6% respectively). This shows that the Electricity and Water Authority is doing well through different media (TV and newspaper) but is less effective at raising awareness through its staff. The utility staff receives regular training from EWA. In future training, the capacity of field staff should be developed to engage in personal selling as they go about with their duties, as an another channel of raising public awareness. However, it should be noted that the mass media will remain the main channel of raising public awareness.

**Table 5.8:** Level of household awareness on water conservation and water demand management

| Question | | Percent | Total Respondents |
|---|---|---|---|
| The term water Conservation is used to refer to using less water. Have you heard about this term in Bahrain? | Yes<br>No | 54.2<br>45.8 | 545 |
| Where did you hear about the term water conservation in Bahrain? | TV<br>Newspaper<br>EWA staff<br>Relatives<br>Radio | 67.3<br>33.0<br>28.9<br>14.6<br>13.6 | 294 |
| Water Demand Management refers used to efficient use of water. Have you heard about this term in Bahrain? | No<br>Yes | 82.1<br>17.9 | 546 |
| Where did you hear about Water Demand Management in Bahrain? | Newspaper<br>TV<br>Radio<br>EWA staff<br>Relatives | 57.6<br>40.2<br>27.2<br>25.0<br>13.0 | 92 |
| What is your opinion on current water supply services provided by Electricity and Water Authority (EWA) in Bahrain? | Good<br>Very poor<br>Poor<br>Very poor | 44.8<br>42.7<br>10.9<br>1.7 | 543 |

Source; Analysis of primary data, Researcher (2008)

In the following discussion, the researcher used some conservation techniques as part of WDM. However, only 17.9% said that they heard about the term WDM (see table 5.8). This implies that media on water demand management do not fully contribute to rising the level of public awareness regarding water demand management, and currently the most effective media is newspaper (57.6%), while the Electricity & Water Authority is significantly less effective (25%). Thus there is a need for action to be taken by the authority to strengthen its effort to increase public awareness about water demand management and its importance.

Also, households were asked their opinion on the current water supply service provided by the Electricity & Water Authority. Almost half (44.8%) revealed that the service provided by the authority is good while a marginal proportion (10.9%) indicated it was poor. This indicated that respondents are quite happy with the service provided by EWA.

It is clear from the table that 82.1% (454 respondents) were not aware of the term WDM as this term is known to the specialists in the field of water and is not a common term used by the public. While on the other hand 294 respondents were aware of the term water conservation as it is commonly used and more understandable by the public. Most of the

respondents (57.6%) said they heard about the term water conservation from the newspaper. Most of the respondents rated EWA services between poor and very good.

### *5.2.5 Selected core studies from Official documents and other secondary sources*

This section provides information on some of the selected data from utility reports and documents, which includes a detailed analysis of the problems associated with application of WDM tools in Bahrain on both the utility's and end users' sides. It describes relevant departments responsible for WDM. Thereafter, it highlights key limitations of current WDM activities implementation at utility level.

**The Electricity and Water Authority (EWA) Organisation**

To respond to such an unsustainable situation (water supply management), the EWA of Bahrain conceptualized a programme in 1986 to apply WDM at the utility and consumer levels. Even though the programme was initiated about 24 years ago, not much been achieved due to non realistic enforcement by the government as more priorities were directed to water supply management. Figure 5.3 shows the relevant departments and units responsible for WDM tasks. The main tasks are distributed as follows:

- The Maintenance and Engineering Services Department is responsible for active leakage control, timely repair of pipe network, and accuracy of meters (physical loss management)
- The Customer Services Department is responsible for customer water meter reading and generating monthly bills (Apparent loss management)
- The Water Conservation Department is responsible for carrying out research and development in water conservation, investigating high consumption and locating leaks on consumers' premises, installing water saving devices, and carrying out public education and sensitisation (end user management).

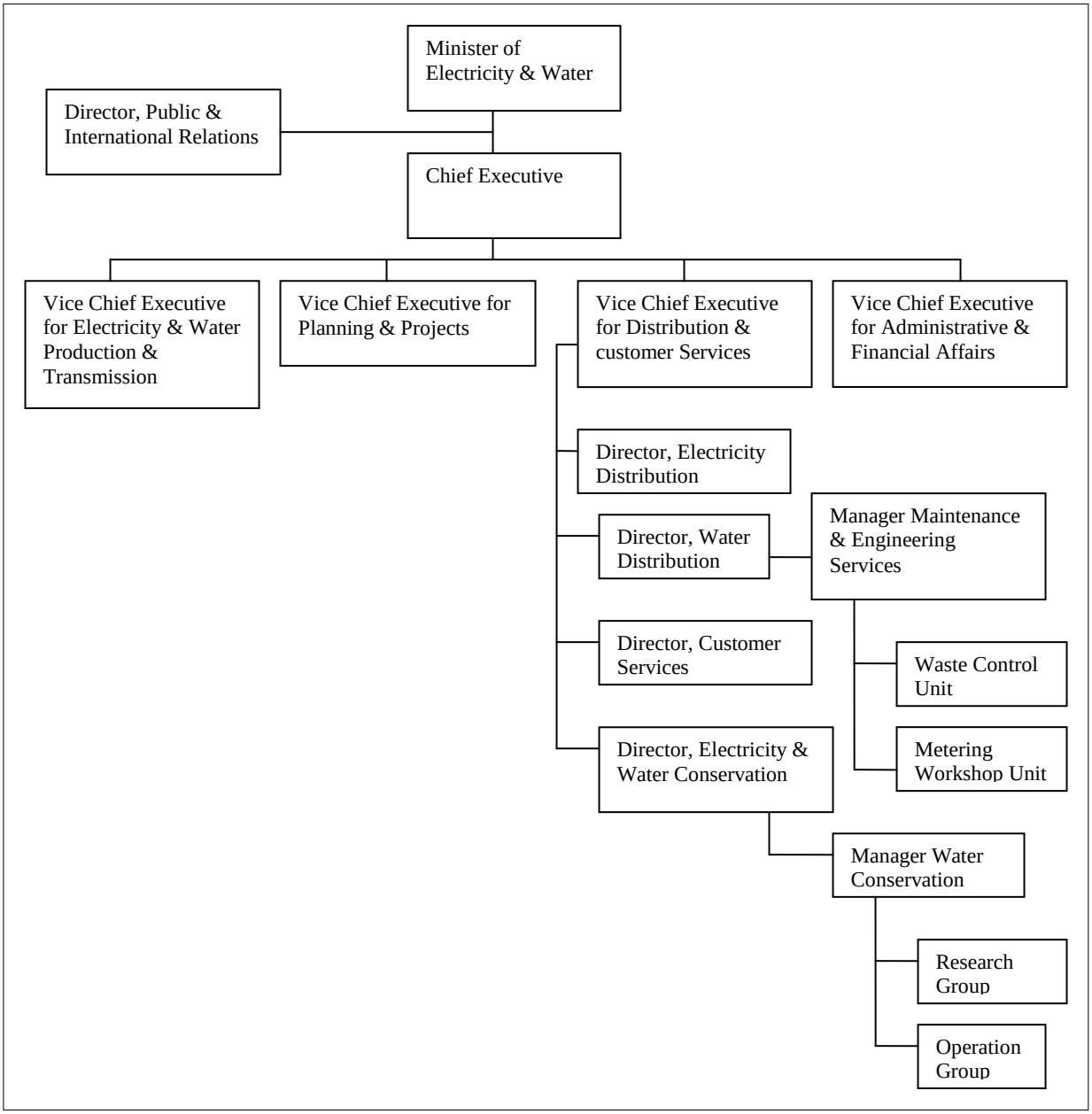


**Figure 5.3:** Department of Electricity & Water Authority responsible for WDM, Source: EWA (2009)

From the Waste Control Unit, annual reports, Meter Workshop Unit annual reports, Water Distribution Directorate reports, Water Conservation reports and research studies, Customers Services monthly water billing reports, data were analysed and the following results were found:

**Shortage of Budget and Human Resources allocated for each unit**

From the Waste Control Unit organisation chart (Figure 5.4) it was found there was a shortage in pipe fitters, draughtsmen and r. Engineer. This has caused delays in repairing leaks found by inspectors. This means that the current organisation does not have sufficient human resources capacity for running WDM, and there is a need to increase the number of staff to fill the vacant positions.

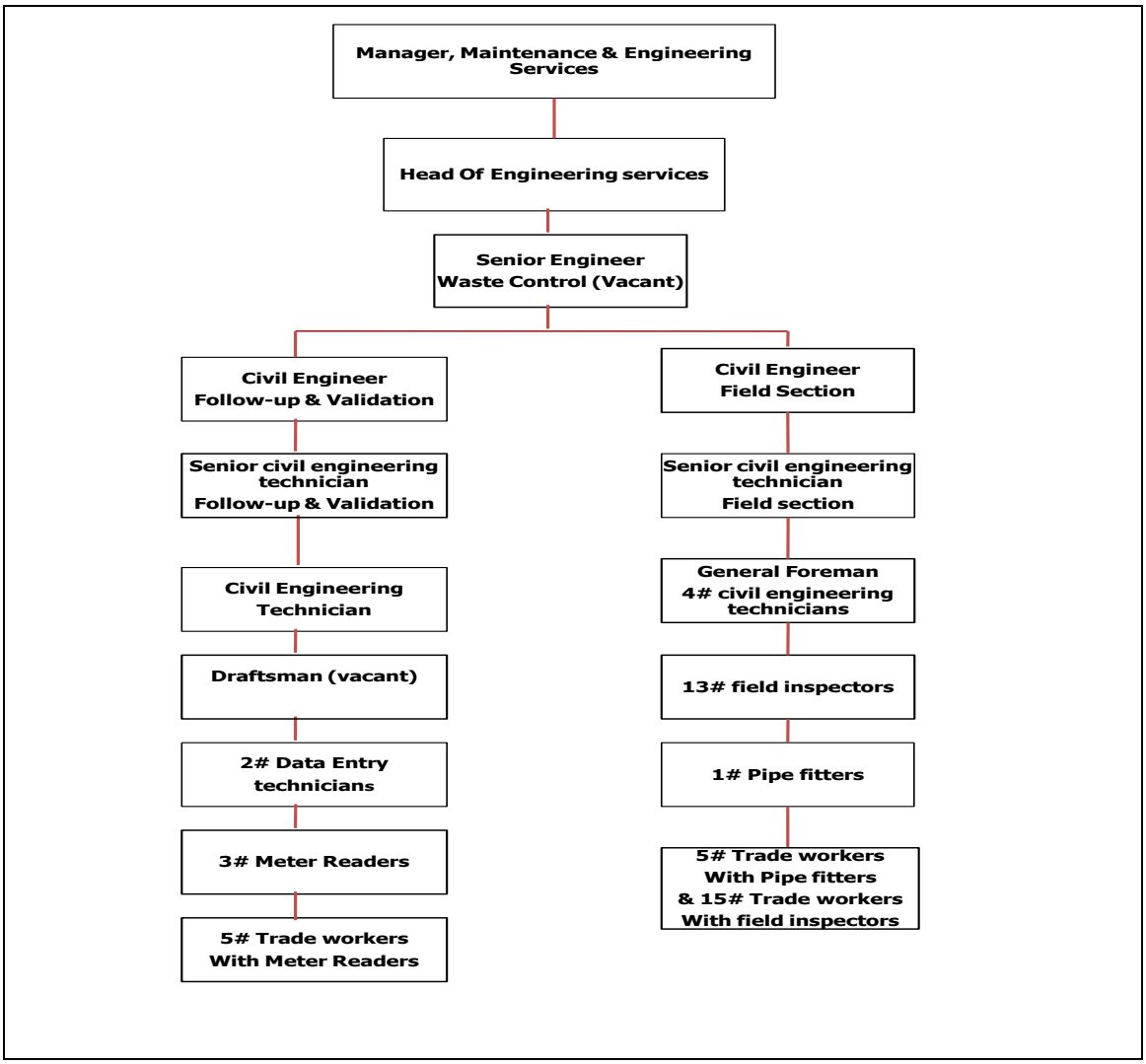


**Figure 5.4:** Waste Control Unit Organisation Chart, Source: Researcher (2011)

From meter workshop annual reports it was found that meters were replaced only when they were found to be stopped or to be defective, and replacement was not based on the age of

meter. This is due to poor maintenance because of shortage of budget allocated and priority was given to replace stopped meters. Table 5.9 shows the number of meters installed and replaced annually in Bahrain. In 2008, only 49 domestic meters were tested, while in 2009 it was reduced to 42 meters and then in 2010 it was increased to 100 meters. Therefore, it is likely that a considerable proportion of apparent losses are due to metering errors.

Although the policy for meter replacement in Bahrain is to replace domestic meters in the distribution system after 6 years of service due to deterioration in accuracy with age, this is not happening and the policy is not being applied. During 2008, 2009 and 2010, 20,885, 39, 707 and 16,269 meters were replaced respectively due to stoppage, and no meters were routinely renewed during the period 2006 - 2008 due to no plans for the renewal of aged meters because of unavailability of meters and shortage of spares. But during the year 2009 33,373 (89.6%) meters (meter installed in year 2003 and before) out of 37,231 planned for renewal were renewed because meters were available. Unfortunately in 2010 only 9,594 meters were renewed due to shortage of meters. In the case of Bulk meters, no preventive maintenance took place during 2008– 2009 due to the lack of availability of spare parts/meters. But in 2010 168 meters were maintained.

**Table 5.9:** Meter maintenance works carried out on site during the period 2002– 2010

| Nature of work | Year 2002 | Year 2003 | Year 2004 | Year 2005 | Year 2006 | Year 2007 | Year 2008 | Year 2009 | Year 2010 |
|---|---|---|---|---|---|---|---|---|---|
| Customer Meters Leaks/ Attended Via Complaint Centre | 9,365 | 14,400 | 15,589 | 18,617 | 14,816 | 16,858 | 16,551 | 14,504 | 14,173 |
| Customer Meters Defects Attended (Reported by CSD) | 21,031 | 14,323 | 19,319 | 23,278 | 14,350 | 24,740 | 32,590 | 40,556 | 26,232 |
| Domestic Meters Replaced due to stoppage | 11,474 | 11,362 | 10,576 | 14,613 | 9,150 | 16,237 | 20,885 | 39,707 | 16,269 |
| Installed new customer meters | 41 | 171 | 1,315 | 1,523 | 604 | 1,101 | 782 | 381 | - |
| Preventive maintenance PPM Bulk Meter (50mm & over 50mm) | 1,267 | 2,077 | 916 | 1,126 | 1,195 | 493 | - | - | 168 |
| Domestic Meters renewal | - | - | - | 721 | - | - | - | 33,373 | 9,594 |
| Repair (Recycled) Domestic Meters | 1,381 | 1,001 | 1,840 | 252 | 434 | 154 | - | 28 | 64 |
| Domestic Meters Test | 6,959 | 4,200 | 2,635 | 2,628 | 615 | 180 | 49 | 42 | 100 |
| Meter Fabrication | 2,554 | 3,646 | 1,217 | 3,900 | 1,860 | 2 | - | - | - |
| Valve Fittings/ Glass wing recycled | 198 | 513 | 600 | 120 | 440 | 166 | - | - | - |

Source: WDD Annual reports year 2002- 2010 compiled by researcher, (2011)

The table above shows that the numbers of meter complaints are generally on an upward trend. This is because of limitations of budget, fewer staff to repair meters, fewer spare parts. etc. Also the table shows decline in preventive maintenance and domestic meter testing. This is also because of shortage of budget allocated and priority was for replacement of stopped meters.

Also, from the Internal Documents generated by the Waste Control Unit it was reported that there was a shortage of leak detection equipment, and defective zone meters which negatively impacted on the productivities and achievements of the Unit in detecting and repairing leaks (see Table 5.10) as several leak detection night exercises were cancelled due to zone meter defects and unavailability of spare parts. This is shown Section 5.2.5, Table 5.4 which lists the unit's technical needs for 2010.

The information in Table 5.10 was collected from various Waste Control Unit annual reports that include: detailed field reports regarding leak detection zone exercises carried out per year; number of leaks detected during leak detection exercises; number of waste zones and district meter areas created per year; number of zone meter defects reported, and the water saved by repairing leaks found during exercises.

The table shows that in the year 2010 the number of leak detection night exercises was higher than in previous years. This was because many exercises had to be cancelled due to meter defects or shortage of leak detection equipment. As can be seen from the table, only 75 exercises were completed. The findings of the leak detection exercise include the following: 1 un-metered connection, 14 customer meter defect. A total of 8,657 $m^3$/day water saving was achieved in the year 2010. This is due to a total of 851 leaks that were found and repaired. Nevertheless, it shows low overall performance. At the current rate, it would theoretically, take 2 years to inspect the whole network; one waste zone is only inspected every 2 years. In this fashion, any unseen leak not associated with specific complaints could remain undetected and unrepaired for an average period of 1.6 years.

According to Reynolds and Preston (2004) the BABE concept indicates that if the active leakage control policy is to carry out a leak detection survey across the whole network on

annual basis, some leaks will be up to one year old having just occurred after leak survey, while some will be a few days old. The average duration of the unreported burst will be half of the interval survey in this case six months. If the frequency survey increased to twice a year the average duration of the unreported bursts would be reduced to three months. The annual volume of water lost from unreported burst would be halved but the annual cost of the survey would be doubled. An economic balance would be reached when the cost of the survey equals the cost of water saved.

**Table 5.10:** Achievements of Waste Detection Unit during period 2002-2010

| ***Description*** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** |
|---|---|---|---|---|---|---|---|---|---|
| ***Exercises*** | | | | | | | | | |
| Exercises started | 246 | 186 | 183 | 223 | 240 | 230 | 208 | 253 | 356 |
| Exercises completed or acceptable IMNF | 184 | 119 | 135 | 118 | 126 | 102 | 120 | 71 | 75 |
| ***Exercises results*** | | | | | | | | | |
| Underground leaks | 698 | 706 | 814 | 728 | 779 | 881 | 753 | 468 | 620 |
| Customer meter leaks | 296 | 395 | 607 | 543 | 578 | 593 | 638 | 254 | 219 |
| Visible leaks | 56 | 31 | 72 | 60 | 37 | 31 | 35 | 11 | 4 |
| Leak inside premises | 200 | 68 | 70 | 74 | 58 | 72 | 51 | 28 | 8 |
| **Total No of leaks (completed exercise)** | **1250** | **1200** | **1493** | **1405** | **1452** | **1577** | **1477** | **761** | **851** |
| ***Findings*** | | | | | | | | | |
| Un-metered connections | 36 | 9 | 9 | 7 | 2 | 12 | 2 | - | 1 |
| Customer meter defects | 70 | 55 | 22 | 20 | 40 | 48 | 45 | 24 | 14 |
| Illegal connections | 10 | 5 | 5 | 3 | - | 3 | 2 | 3 | - |
| Abandoned connections | 5 | 3 | - | 2 | 1 | - | 2 | 1 | - |
| **Total volume saved ($m^3$/day)** | **5648** | **4947** | **4440** | **6810** | **6310** | **7020** | **13166** | **8344** | **8657** |
| ***Zoning*** | | | | | | | | | |
| Waste zones created | 2 | | - | - | - | - | - | - | - |
| District meter areas created | - | - | 3 | 3 | 1 | - | - | 1 | - |

Source: Waste Detection Annual reports year 2002-2010 compiled by Researcher, (2011)

**Weak enforcements of policy and standards**

From the utility documents it was found that there is a policy issued for each department but due to some constraints, these policies are not followed. For example from Waste Control Unit documents it was found that the Unit should follow the policy of conducting waste zone exercises designed to last for 5 weeks. This allows for 220 zones to be covered in one year and a maximum interval of 2 years between exercises on the same zone. Due to regular constrains, such as budget, manpower and equipment, this target is not achieved.

Also from Metering Workshop documents it was found that the policy is to replace domestic meters every 6 years because the meter accuracy profile will be highly affected during

minimum flow ($Q_{min}$) and meters tend to under register some 15% of water at low flows after six years in service as indicated in Table 5.11 below. Besides the revenue losses, the leakage level indicated would be misleading. Based on that, water meters in Bahrain are supposed to be replaced after six years in service, as it is not economical to maintain them further. As previously stated, however, meters are not replaced routinely based on the time for which they have been in service. Currently (as in March, 2011) there are 140,007 domestic meters in the system, the majority (89%) of domestic meters in service are of age less than five (5) years and the minority (10%) are aged between 10 and 13 years. The remaining are of an age between 13 and 26 years (Mahfood, 2011).

**Table 5.11**: Domestic Meter Average Accuracy result

| No of years installed | Average Accuracy (%) | |
|---|---|---|
| | $Q_{nom}$ [1500 l/hr] | $Q_{min}$ [20 l/hr] |
| Initial | 0.05 | -0.24 |
| 1 | -0.58 | -1.31 |
| 2 | -0.98 | -1.63 |
| 3 | -1.68 | -6.17 |
| 4 | -3.27 | -9.05 |
| 5 | -3.71 | -13.79 |
| 6 | -4.60 | -15.00 |
| 7 | -30.00 | -77.00 |
| 8 | -90.00 | -100.00 |
| 9 | -100.00 | -100.00 |

Source: Qamber, (2009)

**Summary of findings from official documents**

Two (2) categories of problem issues were identified from documents within the three departments (Waste Control Unit, Meter Workshop, and Customer Services Department). The problem of water demand management issues with which they were associated are shown in Table 5.12.

These findings are from documents, annual reports, and published papers. It was carried out to establish link with findings from interviews in order to establish data triangulation.

**Table 5.12:** Problems identified from document in the EWA departments

| Problem Issues | Electricity & Water Authority Departments/ Units | | |
|---|---|---|---|
| | Waste Control Unit | Metering Workshop Unit | Customer Services Department |
| **Shortage of Budget allocated for each unit** | √ | √ | √ |
| a. Shortage of water meters and spare parts | | √ | |
| b. shortage of leak detection equipment | √ | | |
| c. Shortage of staff | √ | √ | √ |
| **Weak enforcement of policy and standards** | √ | √ | √ |
| a. Weak enforcement of policy and standard due to shortage of staff and equipments | √ | √ | √ |
| b. Limited authority in taking action against customers not paying their water bills | | | √ |

Source: Researcher's fieldwork from official documents

## 5.3 Measures at household level

This section addresses the research question: "How can WDM measures taken at the household level contribute in providing a sustainable water supply for Bahrain?" The objectives were to identify WDM measures and instruments that can be applied at household level and assess their sustainability for Bahrain.

Currently, the following WDM measures are in practice at household level in Bahrain and their efficiency is to be evaluated:

- Installation of low water use appliances.
- Behavioural change in water consumption in response to tariff.
- Behavioural change in water consumption in response to public education.
- Wastewater and grey water use at household.

The analysis starts with the findings from interviews with Water Conservation staff followed by pilot tests of water savings devices and other fittings, analysis of household questionnaires and ends with analysis of official and utility documents.

### *5.3.1 Interviews about potential WDM strategies at household level*

To find the existing problems during the process of practicing WDM, and the deficiencies in the enforcement process at household level, interviews with relevant staff in the Water Conservation Department from EWA were conducted as a part of the fieldwork of this research.

The main questions asked in the interviews are shown below (the detailed questions are listed in Appendix 5)

1. What are the activities carried out by the department in order to promote conservation of water at household level?
2. What deficiencies are there in the activities carried out at the department to promote water conservation?
3. What are the saving devices that are installed in households?
4. How effective are the conservation campaigns?

The interviews were carried out with 6 interviewees on 18 Jan, and 2 Feb 2009 in Bahrain during the fieldwork. This section provides information on the main responses, and provides some detailed analysis of the initiatives associated with WDM implementation at household level. It should be noted that in April, 1996, the Electricity and Water Conservation Department was formed under a manager who reported directly to the assistant Under Secretary of EWA. In the middle of 1999, this department was changed to the Electricity and Water Conservation Directorate (EWCD).

From the interviews with Water Conservation Unit staff at EWA, the following findings were established:

a. Coordination: all interviewees thought there was strong Coordination between Water Conservation staff and other departments and ministries as follows:
   - There is coordination with the Ministry of Education for updating the curriculum at education levels in order for students to know about the water situation in Bahrain and the various ways of saving water. As a result of this coordination, regular reviews of all subjects in the textbooks used by the Ministry of Education

are now conducted on a routine basis in order to add or update information related to water conservation aspects.

- There is coordination with the University of Bahrain to undertake some research about re-using grey water for domestic use.
- There is coordination with the Waste Control Unit whenever high consumption is found during a leak detection exercise. For example during leak detection night exercise whenever a Waste Detection Inspector finds any meter running, leaks or the Inspector suspects high consumption, he/she will give the address of that property to the Water Conservation Department for investigation.
- The Water Conservation Department arranges water conservation campaigns with the Ministry of Education (for Schools), and the Ministry of Health (for Health Centres).
- The Water Conservation Department established groups in each primary school called “Conservation Groups" headed by a teacher. A member of the Water Conservation Department staff communicates with this committee to pass messages to school students about water conservation. Also the coordination includes programmed visits by EWA staff to the schools to give demonstrations regarding water saving devices, how to detect water leaks by simple methods and the way to use water wisely. These visits aim to target all levels of student.

b. From responses about conservation in households it was found:

The main water saving devices distributed were faucet aerators (Aerators restrict the flow of water from your tap without reducing water pressure.

- Fit an aerator to your taps and reduce the amount of water use by more than 50%, while displacing toilet bags (it is a bag filled with crystals that expands to save approximately one litre of water every time a toilet is flushed. These devices are suitable for toilets with a cistern size greater than seven litres, but should not be used in dual flush toilet), garden timers and drip irrigation items(electronic water timer with dial programming, offering a variety of watering durations from once per a week up to four times per day) were last distributed in 2005. Participants were issued with those devices after they received instructions on how to install them and information on the benefits expected from installing them, and were then asked to

install them. 210,000 aerators were distributed to 26,640 customers all over Bahrain during the Water Conservation National Campaign from June 2007. Through calls 21,900 (82%) customers installed aerators and 4,740 (18%) customers did not install them

- Educating householders about water conservation and using saving devices at home was appreciated. 11,354 premises were issued or installed with aerators in 2008 during national campaign, 500 extra premises per year are planned (EDB report, 2009)

- Advertisements of water conservation were in the forms of billboard in streets and on public transport vehicles. Some of these advertisements were paid for.
- No grey water or waste water reuse is implemented at household levels. There is a need to conduct studies to assess the suitability of water re-sue in the future.

c. Public awareness campaigns are carried out regularly with extra campaigns in summer benefiting from summer campaigns and public gathering places (such as clubs, social gathering events).

From the above information it can be noted that the WDM work at household is still in need of more efforts especially in the area of using grey water in watering gardens, toilet flushing etc. the WDM work is a step in the right direction but this work should be further enhanced.

### *5.3.2 Field observations*

A Pilot study was carried out in order to evaluate the suitability of installing aerators at houses and to assess the water savings resulting from their installations. This pilot study was the initiative of Water Conservation Department with the participation of the researcher.

Faucet aerators are devices that work by mixing air into the water flow, breaking the flowing water into fine droplets and entraining air while maintaining wetting effectiveness. They are low cost (BD. 2.500, £ 4.95/ piece) devices that can be installed in sinks to reduce the volume of water used. Aerators are easily installed and can reduce the volume of water use at a tap by as much as 60% while still maintaining a strong flow.

Some 210,000 aerators were distributed to 26,640 customers all over Bahrain during the Water Conservation National Campaign from June 2007. The national campaign lasted 295 working days. The total number of employees' in the team in the national campaign was 42 including the researcher. The team explained to customers the benefits and method of installation of aerators and then distributed them free of charge among the customer (6 pieces per customer depending on number of taps per household) in order to install these devices their homes. As an incentive the customers were told that any customer who reduces his water bill by 5% or more than the previous month will be entitled to economic incentive from the EWA. The programme includes positive incentives (BD. 100) to those who succeed in reducing their consumption and total budget allocated for the incentive was BD. 10,000. It is recommended by the author to increase the incentive in order to encourage more consumers to participate.

Following up the customers through telephone calls it was found that 21,900 (82%) customers installed aerators and 4,740 (18%) customers did not install them because (1) their plumbing system is old and these devices cannot be installed in plumbing system constructed before 1999, (2) pressure problems occurred as customers wanted to enjoy higher water pressures.

Readings were taken to find the gains in saving of the water network by comparing readings before and after installation of water saving devices. The daily saving was 3,040 $m^3$, while the amount of daily saving in terms of money was BD 1,216 (US $3,127, £1,737), and annual saving was BD > 450,000 (US $11,911,476 & £450,000). The payback period to EWA on all spent money on national campaign was 4 months. Figure 5.5 shows the process of installing aerators. From the observation it was found that aerators can be used in Bahrain in households and can give savings of 10% to 13% in water use.

**Figure 5.5:** the process of installing aerators
Source: Researcher's field study, (2008)

### *5.3.3 Questionnaires regarding Public awareness and water tariff*

- **Public awareness**

A household questionnaire survey conducted by the author in 2006 for 545 householders indicated that 477 (87.5%) out of households thought that current water consumption 125 g/c/d (568 l/c/d) was wasteful, 45 (8.3%) thought there were leaks in the system, while 22 (4%) thought it was satisfactory. They also offered some suggestions for reducing water consumption at home. 126 respondents (32%) suggested educating household members and servants; 124 respondents (31.6%) suggested that house members should not misuse water; 23 respondents (5.8%) suggested the use of water saving devices, 45 respondents (11.4%) suggested repairing leaks and 7 respondents (1.8%) suggested increasing the water tariff ( see Table 5.13). This is in reference to Section 5.2.4

**Table 5.13:** Household opinions whether the current consumption of water per person (568 litres/day) is appropriate?

| Question | | Percent | Total Respondents |
|---|---|---|---|
| Do you think that the current consumption of water per person (568l/day) reasonable? | No, consumers are wasteful | 87.7 | 545 |
| | No, there are leaks in the system | 8.3 | |
| | Yes | 4.0 | |
| What is your suggestion to conserve water at home? | Educate all house member including servants | 32.0 | 394 |
| | Do not misuse water | 31.6 | |
| | Repair leaks | 11.4 | |
| | Use water saving devices | 5.8 | |
| | Close tap water properly | 5.6 | |
| | Use water only when it is needed | 3.5 | |
| | Drip irrigation at home | 3.0 | |
| | Do not use hose to wash car | 2.3 | |
| | Increase water tariff | 1.8 | |
| | Do not leave kids play with water | 1.0 | |
| | Store water | 0.8 | |
| | Monitor consumption | 0.8 | |
| | Wash clothes using washing machine only when it is full | 0.2 | |
| | All the above solutions | 0.2 | |

Source: Researcher's field study, (2008)

From the above Table 5.13 it is clear that 87.7% of respondents think that 568 l/capita /d is not reasonable. Also the table shows that 31.6% of respondents feel that this quantity of 568 l/c/d is being wasted as a result of misuse of water. About 11.4% of respondents feel that leakage should be repaired. It is clear that the respondents have an idea about how to conserve water, which is a good opportunity to convince customers to change their behaviour about water consumption. The table shows there is a little support from respondents to use the following measures to conserve water at home:

- Water saving devices
- Storage of water
- Drip irrigation system
- Increased water tariff

Households were also asked about managing and protecting water resources and how important these are. The majority of respondents (435, 80.4%) said it was important. This majority (80.4%) were from the income range BD 300- 599. 87 (16%) respondents had no idea about how important it is to manage and protect water resources. This indicates that household of different income regardless of their knowledge and level of education need to have more public awareness in order to encourage them to reduce their water consumption and inform them about the social and environmental effects of saving water. Table 5.14 shows the relation between the rates of importance of managing and protecting water resources with household income.

**Table 5.14:** Relation between rate of importance of managing and protecting water resources with household income

| | | What is your monthly income in BD? | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 - 99 | | 100 - 299 | | 300 - 599 | | 600 - 999 | | ≥1000 | | | |
| | | No | % | No | % | No | % | No | % | No | % | No | % |
| Perceive of the importance of managing and protecting water resources | Important | 13 | 3.0 | 79 | 18.2 | 219 | 50.34 | 87 | 20 | 37 | 8.5 | 435 | 80.4 |
| | Not important | 0 | 0.0 | 7 | 36.8 | 6 | 31.58 | 5 | 26.3 | 1 | 5.3 | 19 | 3.5 |
| | Don't know | 10 | 11.5 | 33 | 37.9 | 30 | 34.5 | 12 | 13.8 | 2 | 2.3 | 87 | 16.1 |
| Total who answered the question | | 23 | 4.3 | 119 | 22 | 255 | 47.13 | 104 | 19.2 | 40 | 7.4 | 541 | 100 |

Chi Square= 38.777 p=0.0001
Source: Researcher's field study (2008)

The chi square test conducted on the importance of managing and protecting water resources with household income gives Chi square of 38.777 and significance value of 0.0001<0.05. This implies significant statistical correlation between the importance of managing and protecting water resources with monthly income ranking.

Household members gave their opinion regarding their involvement in decision making about water issues. A majority (387, 71.7%) stated that it is necessary for household members to be involved in making decisions, and the majority of these were from households of level income range BD 300 – 599 as indicated in Table 5.15.

**Table 5.15** Relation between opinions about involvement of public in making decision about water supply with household monthly income

| | | What is your monthly income? | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 - 99 | | 100 - 299 | | 300 - 599 | | 600 - 999 | | ≥1000 | | | |
| | | No | % | No | % | No | % | No | % | No | % | No | % |
| Your opinion about involvement of public in making decisions about water supply issues | Necessary | 15 | 3.9 | 72 | 18.6 | 194 | 50.13 | 82 | 21.19 | 24 | 6.2 | 387 | 71.7 |
| | Unnecessary | 0 | 0.0 | 5 | 7.5 | 36 | 53.73 | 14 | 20.9 | 12 | 17.9 | 67 | 12.4 |
| | Don't know | 8 | 9.3 | 41 | 47.7 | 25 | 29.07 | 8 | 9.31 | 4 | 4.7 | 86 | 15.9 |
| Total who answered the question | | 23 | 4.26 | 118 | 21.85 | 255 | 47.22 | 104 | 19.26 | 40 | 7.41 | 540 | 100 |

Chi square= 66.7 p= 0.0001
Source: Researcher's field study (2008)

The information in Table 5.15 is related to the research question: how can WDM measures at household level contribute towards providing a sustainable water supply to Bahrain (in terms of public awareness and their involvement in taking decisions about water supply issues)?

It can be concluded from Table 5.15 that there is a strong relation between household income and having an opinion of involvement in decision making about water supply. This means that households with a middle income (ranging BD 300-599) have better ideas about water and more concerns about it because it seems they have sufficient knowledge in water management. This proportion of people is interested in reducing their water expenses on so far. The people from lower income groups are usually those with minimal knowledge, while high income people are usually busy and do not bother to contribute. Therefore households with low level of income need to be made aware about water and ways of saving water.

- **Water tariff**

  The information in Table 5.16 is related to the research question: how can WDM measures at household level contribute in providing sustainable water supply to Bahrain (in terms of public awareness and their involvement in taking decisions about water supply issues)?

Results from the household questionnaire survey conducted by the author (2006) for 545 households revealed that the majority (87.3%) were opposed to increasing the water tariff as they think the current tariff is reasonable, and that increasing the tariff will affect their budget. Only a few household customers (62, 12.7%) were in favour of increasing the water tariff (as shown in Table 5.16) and this is for the following reasons:

a. The majority (93.4%) thought it would result in a better quality of service,
b. (4.9%) thought increased tariff would not affect their income, and
c. (1.6 %) of respondents said that the current tariff was too low and that an increase in water tariff should be considered. Refer to Table 5.16.

**Table 5.16:** Household response regarding their acceptance to increase tariff to cover the true cost of water and reason behind acceptance

| Question | | Percent | Total Rspondents |
|---|---|---|---|
| Would you accept increasing the water tariff to cover the true cost of water? | Yes | 12.7 | 490 |
| | No | 87.3 | |
| What is the reason for accepting an increase in water tariff to cover true cost of water production? | Will result in a better quality of service | 93.4 | 62 |
| | The present tariff is too low | 1.6 | |
| | The increase tariff is not a significant drain on my income | 4.9 | |

Source: Researcher's field work, (2008)

This shows that EWA should educate the public about water issues and the cost of water. In the case of willingness to pay true cost of water when respondents were asked about their willingness to pay the true cost of water for improved services the majority of them (85% or 446) said No; only 7% (36) were willing to pay the true cost. Figure 5.6 illustrates this fact.

The 85% of respondents who said that they are not willing to pay the true (recovery) cost of water justified that on the grounds that it is the duty of the government to subsidise the true cost of water and the consumers should not be burdened with such cost.

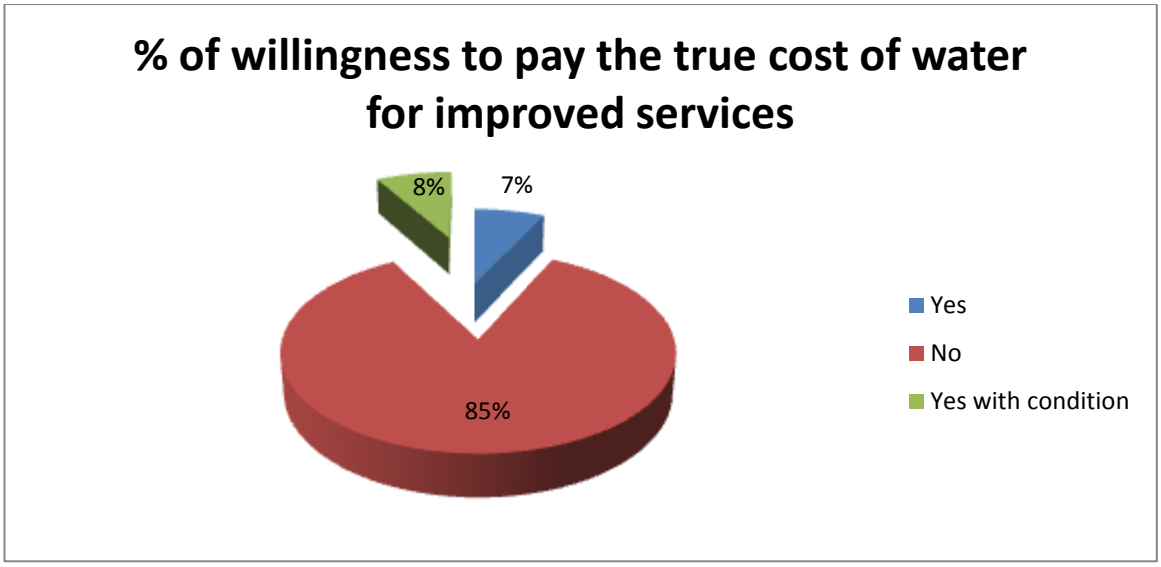


**Figure 5.6:** Willingness to pay the true cost of water for improved services
Source: Researcher's fieldwork, (2008)

Households (545 in total) were asked about the basis of charging for water consumption: 306 (55%) said it should be charged based on the volume of water used, 97 (18%) said it should be charged based on household income, 86 (16%) based on quality of water, 52 (10%) based on the number of members in the household, while 5 (1%) said it should be charged on a seasonal basis as indicated in Figure 5.7.

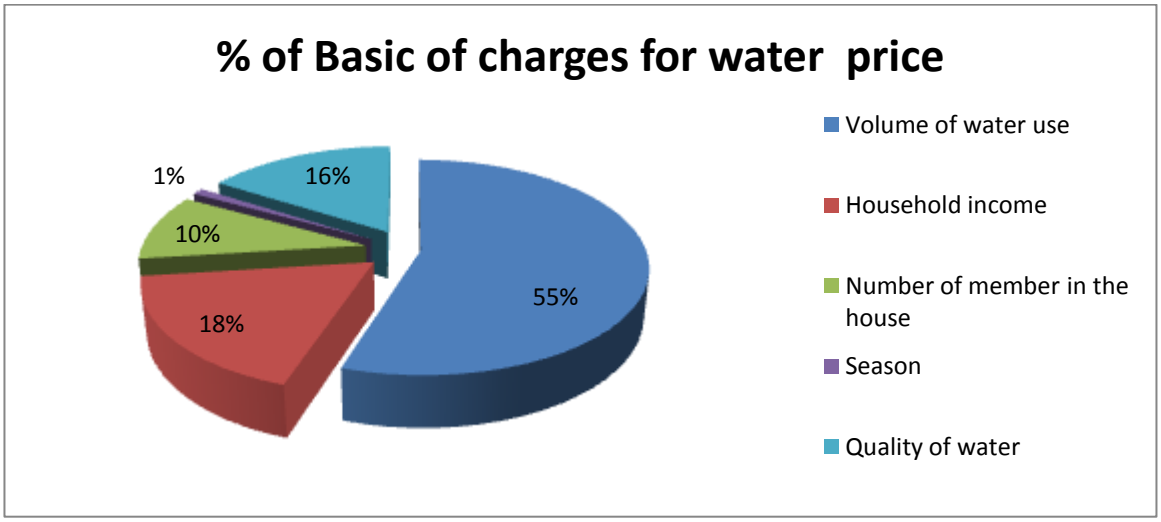


**Fig 5.7:** householders' opinions on the basis of charging for water price
Source: Researcher's fieldwork, (2008)

In the case of household expenditure on water, the majority of respondents (408, 74%) indicated that their water bills were in the range of BD 1.5-10. The next largest category was households who pay less than BD 1.5. This information reflects that an increase in consumption in the third tariff block (consumption for the third block >100 $m^3$/ month, BD 0.2) is based on the subsidy of the first tariff block (consumption in the first block (01-60 $m^3$/ month, BD 0.025) and second tariff blocks (water consumption in the second block (61-100 $m^3$/ month, BD 0.08). A majority of respondents (447, 82.6%) indicated that their expenditure on water is reasonable and the majority of these (349, 85.5%) were from water bill range BD 1.5 – 10 (whose consumption between 60 -120 $m^3$/month, and falls in second and third tariff block) as indicated in Table 5.17.

It can be concluded that households with high income spend more on water than low and middle income households, and it depends on size of house, whether it has garden or swimming pool.

**Table 5.17**: Relation between monthly water bills and household expenditure on water

| | | How do you perceive your expenditure on water? | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | Low | | Reasonable | | High | | | |
| | | No | % | No | % | No | % | No | % |
| What is your monthly water bill? | < 1.5 | 14 | 15.2 | 76 | 82.6 | 20 | 21.7 | 92 | 17.0 |
| | 1.5 - 10 | 31 | 7.6 | 349 | 85.5 | 28 | 6.9 | 408 | 75.4 |
| | 10 - 50 | 1 | 2.6 | 21 | 55.3 | 16 | 42.1 | 38 | 7.0 |
| | 50 - 100 | 0 | 0.0 | 1 | 33.3 | 2 | 66.7 | 3 | 0.6 |
| Total Who answered the question | | 46 | 8.5 | 447 | 82.6 | 48 | 8.9 | 541 | 100.0 |

Chi-Square= 76.917 p=0.0001 Researcher's fieldwork (2008)

The table shows that there is a strong relation between monthly income and expenditure on water as p=0.0001 and is less than 0.05.

**Summary of key findings from questionnaire**

The results from the questionnaire with regard to public awareness showed that household customers thought that current per capita consumption is high and wasteful and it should be reduced. They gave some suggestions for reducing water consumption at household level. This indicates that customers have an idea about water conservation. A majority of the respondents (387, 71.7%) considered that involvement in making decisions about water is necessary. In the case of water tariffs a few respondents (62, 12.7%) considered the current

tariff to be low and that it should be increased. The majority were against increasing the tariff (328, 87.3%), and thought that if the tariff has to be increased it should be charged based on volume of water use.

### *5.3.4 Selected core studies from official documents and other secondary sources*

This section describes the outcome from analysing official documents regarding public educational campaigns carried out by Water Conservation Department, Water conservation education carried out at government school and Installation of Irrigation Timers in the Customers' Premises.

**a. Special events participation & educational campaign**

From the Water Conservation Department Annual reports, special events can enhance a community education strategy by drawing attention to the objectives of the campaign. Bahrain has started celebrating Water Day on 22 March, when lectures about water issues are given at schools, and universities. Exhibitions and school competitions are also held, and distributions of water saving devices take place. Figures 5.8 & 5.9 show two activities taking place: distribution of aerators, and an educational lecture in a school.

**Figure 5.8:** Distribution of saving devices (Aerators) during National Campaign 2008
Source: Mahfood, (2009)

**Figure 5.9:** An educational lecture in Kanoo School about water conservation
Source: Mahfood, (2009)

**b. Water conservation education**

Es'haqi (2009) argued that there is a deficiency in water related educational programmes in Bahrain, both in curriculums and activities. This reflects negative impacts on society and the young with regards to water conservation behaviour and attitude. Also it was documented that most people in Bahrain, despite their high living standards or educational level, lack adequate knowledge of "How" and "Why" to conserve water. This is because of shortcomings of the curriculum. Also students showed no willingness in learning about the acute water situation as a national problem, and had little knowledge about water issues. The students' activities participation in water related programs was very weak and ineffective (Es'haqi, 2009).

**c. Installation of irrigation timers in the customers' premises**

It was noticed from water conservation reports that in most of the places where drip irrigation of gardens is installed, the water consumption is higher than average since water is kept running for a long time or continuously. To overcome this problem the Department started a project for the installation of timers (in 25 premises) which are free of charge. The average reduction in consumption after installation was around 22.3%, i.e., by 1.42 $m^3$/premises/day, from 6.37 to 4.95 $m^3$/premises/day (Ali, 2003; Mahfood, 2007). Generally garden timers can give 27% water saving (WCD, 2010)

## 5.4 Measures at non-domestic consumers level

This section addresses the research question: "How can WDM measures taken at the **non-domestic consumers level** contribute in providing a sustainable water supply for Bahrain?" The objectives were to identify WDM measures and instruments that can be applied to the non-domestic consumers and assess their suitability for Bahrain. The analysis concentrated on the role of non-domestic users to conserve water and reuse wastewater to reduce water demand in industrial, commercial, institutional and commercial buildings and to assess the implementation of a strategy for Bahrain.

The analysis starts with the findings from interviews with Water Conservation staff followed by pilot test of water savings devices and other fittings, industrial questionnaires and ends with analysis of official and utility documents.

### *5.4.1 Interviews about potential WDM strategies at non domestic customers level*

Interviews with Water Conservation key staff (1 senior Engineer, 2 Technicians, 2 inspectors as indicated in Table 4.5, Chapter 4) stated that the same water-saving devices applied to households were also tested for non-domestic use such as in commercial building, industries, schools, hotels and institutions.

The following were found from the interviews

a. Water saving devices used by non domestic consumers. These devices are aerators at toilet and kitchen taps. In addition, flow regulators, timers for garden irrigation and auto mixer could be used.
    - All interviewees mentioned that grey water is currently not in use at non domestic level but the Water Conservation Department made a study on using grey water from ablutions at mosques and from health centre swimming pools for irrigating the surrounding areas. Also they indicated that 20% of treated wastewater from Tubli wastewater treatment plant is used for irrigation Public Park and landscape irrigation only.

b. Non-domestic customer awareness

- Three Interviewees (Water Conservation Inspectors) staff revealed that there are no specific lectures or demonstrations given to or targeting non domestic customers on using water saving devices in commercial or industrial buildings.
- Despite the previous point, two interviewees (Sr. Engineer, and Technician) thought that the lectures given to non domestic consumers were sufficient.

This indicated that Water Conservation Inspectors are more familiar with the situation as they are the ones who prepare lectures and conduct demonstrations about the use and benefits of saving devices. While the Sr. Engineer and Technicians are engaged in the technical field work.

It is obvious that WDM at non-domestic level needs more work to involve engineers and technicians in the public awareness campaigns. This is needed in order to help a sustainable water situation in Bahrain.

### *5.4.2 Field observations*

A Pilot study was carried out to evaluate the suitability of installing electronic taps at commercial buildings and to determine the savings created by installing them.

**Installation of Electronic Taps (ETs) at commercial buildings pilot tes**t

Implementation of a variety of water-saving devices such as installing electronic taps in some places was studied in Bahrain. Three locations were selected based on their high water consumptions and large number of users. These locations were as follows

- AlSeef shopping Mall, which contained five single level washbasin mixers.
- Bahrain shopping Mall which contained two toilets, one for Gents with three manual washbasin mixers and another for Ladies four manual washbasin mixers, and
- AlAbraj Restaurant which contained a Gents toilet including four manual washbasin mixers.

A visit to these various locations was made in order to evaluate their suitability for the study and to select specific sanitary conveniences in each location to install Water Meters (WM) for initial monitoring of consumption and to Electronic Taps (ET) at a later stage.

Evaluation of current measures implemented in Bahrain, such as the application of water-saving devices by installing electronic taps in some places resulted in a range 42–53% as water saving. Electronic taps work via electronic sensors, and savings reached 50% in individual locations.

Daily water meter readings were recorded for each study location (to establish Reference Average Daily Water Consumption (RADWC) and the daily consumption was obtained by subtracting consecutive readings from each other. Determination of daily consumption was necessary in order to monitor the variation in consumption and to establish the magnitude of abnormalities during special events or due to leaks and misuse. Average Daily Water Consumption (ADWC) was determined after correcting daily consumptions for any abnormalities. The RADWC, ADWC and the saving percentages from the use of ETs at each location were obtained by comparing the (ADWC) after installing ETs with (RAWC) as presented in Table 5.21. The results of the investigation at the various locations are discussed below.

*Al Seef shopping Mall*

Daily water meter readings were recorded during the period from 22 July to 15 September 2005 to establish RADWC. This was found to be 2.753 $m^3$/day. On August 13 the five manual mixers were replaced by five ETs and readings of daily water meter continued up to September 1$^{st}$. The average flow rate through the tap was in excess of 6 l/min and the LTs had a closing delay time of 3 sec. The ADWC during this period was 2.171 $m^3$/min. This represents a reduction of 21.1% in consumption. Starting from September 2$^{nd}$ ETs close delay time was cancelled and flow was reduced to about 4 l/min. Monitoring of delay consumption then continued up to September 15$^{th}$ . The ADWC for this period reduced to 1.294 $m^3$/day. The saving was 1.459 $m^3$/day. This is equivalent to a 53% reduction in

consumption as compared to the RADWC. On this basis, about 532.5 $m^3$ of water or 213 BD per year can be saved (US $ 82.83, £.304.2).

*Bahrain shopping Mall*

RADWC for Bahrain Mall was determined based on water consumption in the period from 5th to 19th August 2005. It was found to be 14.85 $m^3$/day. The manual mixers were replaced on 20th August with ETs. Daily readings of water meter continued. The ADWC during the period from Aug 20 to September 2nd was estimated at 9.709 $m^3$/day. Water flow through the ETs had a 3 seconds closing time delay. The delay time was cancelled and flow rate was reduced to about 4 l/min on September 2nd. Unfortunately, there was a problem and no saving was observed at flow rate 6l/min.

Based on RADWC of 14.85 $m^3$/day and ADWC of 9.709 $m^3$/day after installing the ETs 5.141 $m^3$/day (34.6%) can be saved. This is equivalent to 1876.5 $m^3$ of water or 750.6 BD per year, (US $ 219.9, £.1,072.2) accordingly the payback period in this case was about six months.

*AlAbraj Restaurant*

Daily recording of water meter readings commenced following the installation of a water meter on July 2nd 2005 to determine the RADWC. This was estimated at a 1.1117 $m^3$/day. The four manual mixers in the washroom for diners were replaced on August 18th with ETs. Monitoring of daily water consumption continued until September 7th 2005. Until September 2nd the ETs had a 3 second closing delay time and ADWC for this period was estimated at 709 $m^3$/day. This represents a saving of 0.408 $m^3$/day (36.5%). The closing time was cancelled on September 2nd. This caused the AWDC to drop to 0.65 $m^3$/day. Accordingly, the daily saving in consumption increased to 0.467 $m^3$/day (42%). This is equivalent to 170.5 $m^3$ of water or 68.2 BD/year (US $ 175.4, £.92.4). The payback period on this basis can be calculated as 3.2 years. Installing electronic taps shows that on average it is possible to make water saving of 37%.

**Table 5.18:** Percentage water saving achieved by installing Electronic Taps

| Location | Reference Average Daily Water Consumption ($m^3$/day) | Average Daily Water Consumption ($m^3$/day) | % Water Saving per location | Water saving ($m^3$/day) | Annual water saving ($m^3$/year) | Annual saving (BD) | Payback period (Year) |
|---|---|---|---|---|---|---|---|
| **Al Seef Mall** | 2.753 | 2.171 @ 6 l/min | 21.1 | 0.582 | 212.4 | 85 | 1.3 |
| | 2.753 | 1.294 @ 4 l/min | 53.0 | 1.459 | 532.5 | 213 | |
| **Bahrain Mall** | 14.85 | 9.709 @ 6 l/min | 34.6 | 5.141 | 1876.5 | 751 | 0.5 |
| **Al Abraj Restaurant** | 1.117 | 0.709 @ 6 l/min | 36.5 | 0.408 | 148.9 | 60 | |
| | 1.117 | 0.65 @ 4 l/min | 41.8 | 0.467 | 170.5 | 68 | 3.2 |

Source: Author's field work, (2007), Note: $US 1= BD 0.378

### *5.4.3 Findings from questionnaire to industries*

The effectiveness of the non-domestic public awareness and education campaign implemented in Bahrain was evaluated through an industrial customer questionnaire survey conducted by the researcher in 2009 on thirty four (34) respondents from eleven (11) different industries as there are only 400 industrial sectors in Bahrain. As indicated in Table 5.19, the result showed that 6.1% of industries were found using groundwater against 93.1% from EWA. One third of respondents were found to be using water conservation devices. About 26% of respondents said that they used one or other form of conservation. The majority of respondents (64%) were found to be interested in using new technology of conservation and using EWA supplied water. Groundwater industrial users upon questioning about their willingness to migrate from groundwater to EWA supply showed less interest due to lack of regulations and enforcement that could force them to migrate.

It is interesting to note that the majority of respondents (88.2%) when asked whether they would like to use treated wastewater in places of groundwater for their industrial use their reply was definitive NO. They were not sure that the quality of treated wastewater would be maintained due to the lack of or nearly absent regulations in this area.

At the same time none of the respondents would like to see any increase in water tariff even to the extent of production cost.

The argument against having the tariff increased was that a low existing tariff is industrially friendly and reasonable and that any upward change will result in an increase in cost of production.

Also it was understood from the respondents most of them (76.5%), discharge their factory waste water into the discharge system and a very small percentage of users either reuse it in one form or another.

It can be concluded from the above that the respondents have the knowledge of conservation & wish to migrate to EWA supplied water/treated waste water only when guaranteed supply can be deemed to be reliable. The reliability of supply can only be guaranteed when EWA comes with firm bylaws which are not in place at present. The absence of bylaws leaves the industrial sector with this apprehension.

**Table 5.19:** Industrial questionnaire results regarding water issues

| Question | | Percent | Total Respondent |
|---|---|---|---|
| What is your source of water? | Groundwater (GW) | 6.1 | 34 |
| | Electricity & Water (EWA) | 93.9 | |
| Do you use water conservation technology? | Yes | 32.4 | 34 |
| | No | 67.6 | |
| What technology are you using? | Sensor | 22.2 | 9 |
| | Air cooling | 22.2 | |
| | Aerator | 55.6 | |
| In case you are not using new technology, do you agree to use them? | No | 36.0 | 25 |
| | Yes | 64.0 | |
| If you are using Groundwater, do you agree to change to EWA water? | No | 33.0 | 3 |
| | Yes | 67.0 | |
| If you disagree to change to EWA, what is the reason? | Need to change the network | 34.0 | 3 |
| | No regulation s there that enforce the use of EWA water | 66.0 | |
| If you are using Groundwater, do you agree to change to treated wastewater? | Yes | 11.8 | 33 |
| | No | 88.2 | |
| If you disagree to change to wastewater, what is the reason? | Water quality may changed | 100.0 | 29 |
| Do you agree to increase water tariff to cover production cost? | Yes | 0.0 | 34 |
| | No | 100.0 | |
| Why do you disagree to increase tariff? | Current tariff reasonable | 55.7 | 34 |
| | To keep production costs down | 3.1 | |
| | To encourage industries | 41.2 | |
| Where do you discharge factory waste water? | Water garden | 3.0 | 33 |
| | Collect outside factory | 6.1 | |
| | Reuse | 12.1 | |
| | Drainage system | 78.8 | |
| What type of pollution comes out from factory? | Nothing | 12.0 | 33 |
| | Oil and grease | 6.1 | |
| | Chemical | 36.4 | |
| | Heat | 45.5 | |
| Where do you prefer to treat industrial waste? | Inside factory | 94.1 | 33 |
| | main collection point for all factories | 2.9 | |
| Do you agree to penalise industry who dump their waste without treatment | Yes | 63.6 | 33 |
| | No | 36.4 | |
| If you agree on penalty? How it should be? | Based on pollution load | 95.2 | 21 |
| | Based on concentration of pollution | 4.8 | |
| If you disagree of introducing penalty, what is the reason? | Encourage industry development | 25 | 22 |
| | Pollution is limited | 75 | |

Source: Researcher's questionnaires, (2009)

### *5.4.4 Selected core studies from official documents and other Secondary sources*

**a. Bahrain Airport Service (BAS) Model**

Bahrain Airport Company (BAS) conducted a water conservation pilot study with the aim of reducing water consumption costs as the company uses water in its process operations. One of the BAS Engineers from the Maintenance Section designed a system in 1996 to collect evaporated water from Air Conditioning (AC) units in the airport buildings, and then reused (after condensing that water) that water for several different purposes excluding drinking.

BAS has a 1500 ton AC capacity and initially the water produced from condensation was measured to be within the range of 6-29 $m^3$/day (1 litre per 3-5 seconds depending on operation, temperature, humidity and wind speed). Depending on the tourist season, passengers' movements, and climate conditions, it was found that this quantity (6-29 $m^3$/day) could be utilised to irrigate the gardens of the company buildings near the Airport.

Evaluation of the pilot study indicated that the company made significant cost savings in excess of BD 60,000 (US$158,730) per year (Zubari, 2007).

This type of project could be introduced to all companies in Bahrain and they should be encouraged to apply the same principle to their building design, as Bahrain is currently an area attracting tourists and it has more than 100 hotels/furnished apartments with AC systems. EWA with coordination policies should encourage the companies to apply this principle as it will save their water use and reduce their water bills. The author suggests that EWA should put some regulation in their electricity and Water law forcing to private sectors to apply this principal in their building design, as it will reduce the use of potable water for non drinking purpose and it would save water for other sectors.

In addition, a lot of commercial centres and tourist attractions which consume a lot of their water quantities from blended water may adopt this principle as most of it is used for other purposes than drinking (toilet, floor washing, and landscape irrigation). Most of these hotels and commercial centres have Air Conditioning (AC) similar to that used in Bahrain Airport Services (BAS) Company.

**b. Wastewater reuse from ablutions at mosques**

This pilot test was carried out by Water Conservation department. Wastewater from the ablutions of worshippers is collected and pumped to a rooftop storage system, where it is filtered and reused to irrigate some fairly extensive areas of ornamental plants in the grounds of Al Mehzaa mosque in Arad. The system was installed around five years ago (in about 2005), and has resulted in a significant saving on the mosque's water bills. In fact, the capital costs for the installation of the system were recovered within the first year of operation. Since the water used for ablutions is of a relatively good quality to begin with, there are no adverse effects whatsoever on the plants (Mahfood, 2007).

**c. Wastewater reuse from Arad Health Centre therapy swimming pool**

Wastewater from a health centre therapy swimming pool is collected and reused for irrigating the health centre's gardens. From the study it was estimated that the payback period was seven months (Mahfood, 2007).

Arad Health Centre is one of the largest governmental primary care health centres in Bahrain. It includes physiotherapy treatment clinic and its consumption is estimated at between 8 $m^3$/day and 11.5 $m^3$/day for domestic use and 3.5 $m^3$/day for irrigation.

Due to technical problems with the existing irrigation system and its underground pipes, it was decided to abandon the system and replace it with a new irrigation system that consists of visible irrigation pipes and connected to several timers distributed equally on the irrigation area, and to cancel the storage tank connected to the old irrigation system.

It was also decided to utilise the swimming pool water for irrigating the gardens surrounding the health centre as follows:

- 50% of the swimming pool water should be drained and pumped twice a week to roof tanks at the centre roof where it is diluted before using. So no harm on plants.
- From these tanks water is to be distributed to irrigation taps fixed around the centre which are already connected to the irrigation system via controller timers.
- Water drained from the swimming pool should be replaced by fresh water twice a week.

The proposed expenditure of the project was as follow:

- Average consumption including leakage during the study period was 37 $m^3$, and monthly billed consumption was 1110 $m^3$/month with paid bills = 207 BD/month.
- Monthly consumption after modification was estimated at 360 $m^3$, billed value = 57 BD/month
- Expected saving = 150 BD/month, total project expenditure = 1050 BD, and the payback period was 7 months.

There are several advantages for implementing such projects such as: overcoming the problems in finding invisible leaks in irrigation systems, reuse of swimming water for irrigation instead of draining the whole water in sewerage system, a reduction in Health Centre's monthly water bill by 1/3, and also it reduces water losses by distributing it to other consumers.

## 5.5 Measures at government policy level

This section addresses the research question: "How can WDM measures taken at the government policy level contribute to providing a sustainable water supply to Bahrain?"

The objectives were to document and understand the existing government policy level that promote WDM; to study the effects of putting water bylaws in place and development of proper water tariff on sustainable water supply for Bahrain. The analysis includes evaluation of existing water tariffs and the role of the policy level in approving water tariff reform and water bylaws. The section evaluates if the existing government policies promotes WDM.

### *5.5.1 Official documents regarding implementation of bylaws and supportive tariff reform*

The role of EWA laws is to implement and enforce policy, and to provide effective administrative and regulatory mechanisms at appropriate levels. The water laws are powerful to support WDM.

It was not possible to conduct interviews with policy makers regarding approval of EWA laws. EWA and Shura Council only forwarded some materials regarding the process of

approving its law. Figure 5.10 describes the approval process and the various institutions involved.

Water tariff revision is a policy decision in Bahrain. Policy decisions have impact on social sectors. EWA do not have a process regulation of tariff revision, last revision was 1986 for non domestic and 1992 was for domestic.

From Figure 5.10 it can be seen that the process to approve the law is lengthy. It has to go through various institutions before it gets approved.

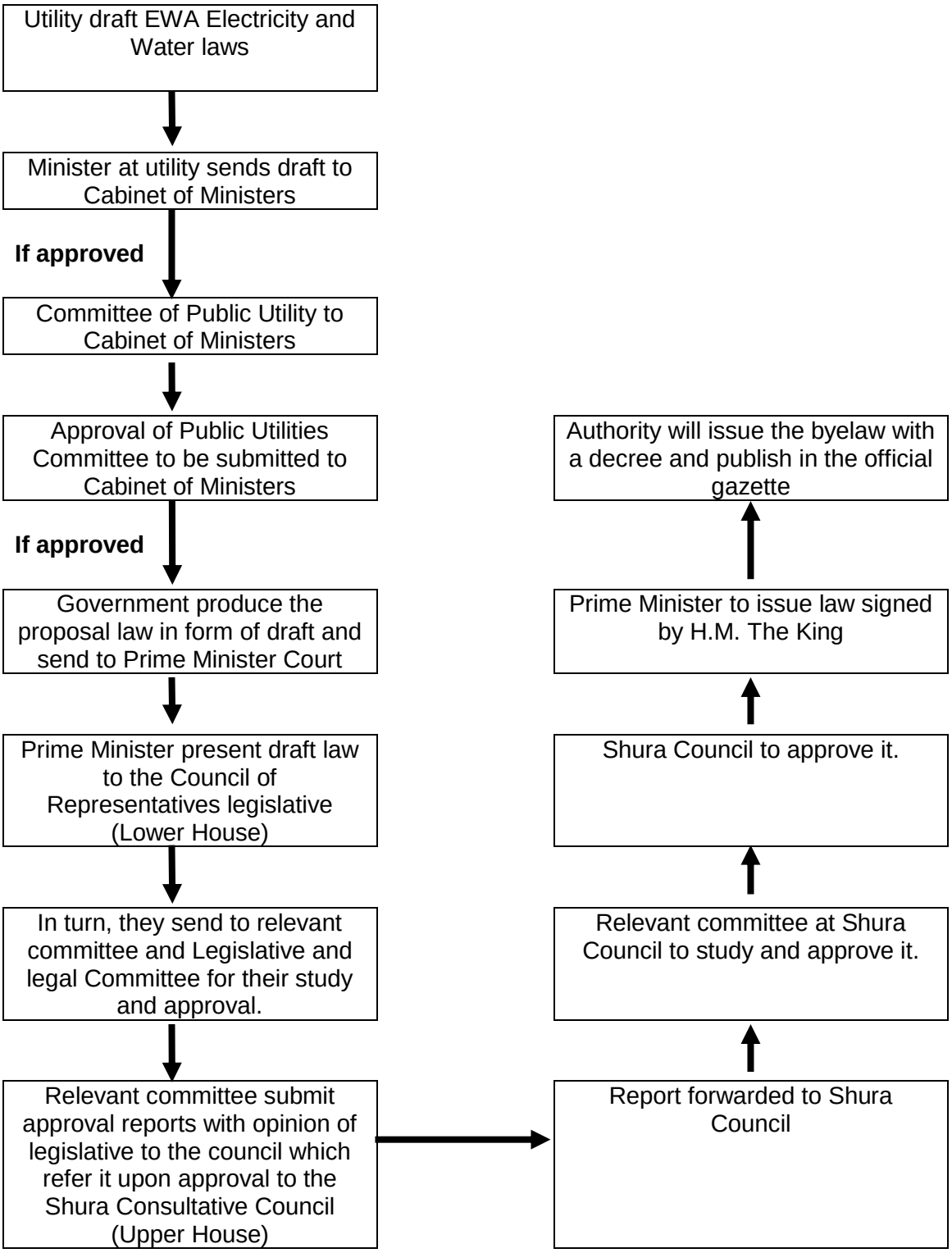


**Figure 5.10:** The Electricity and Water Laws process of approval, and the various institutions involved. Source: Al-Maskati (2008)

**Policies and water legislation environment in Bahrain**

Water scarcity problems have been addressed in Bahrain for a long time, but mostly by increasing supply, not by reducing demand. Water legislation is still governed by sharia (Islamic law) principles and traditional practices, which say that water should be provided to all people. Water is essential for life. It is vital to every civilization and to any process of development. Both economic and non-economic approaches to water demand management is within the context of Islam. Water has occurred in the Holy Quran in over 50 "Verses" and 40 "Suras", which emphasise the importance of regulatory water use, along with the conservation and rational exploitation of its resources. Water is not only vital, but every living creature owes its life to water: "We made from water every living thing" (Sura Anbiyaa, Verse 30).

Faruqi (2001), states that Quran makes two clear statements regarding water that support water demand management. First, the supply of water is fixed, and second, it should not be wasted "And we send down water from the sky in fixed measures". Then Quran tells humans that they may use God's gifts for their sustenance in moderation, provided that they commit no excess therein: "O Children of Adam!... Eat and drink: But waste not be excess, for God loveth not the wasters" (Sura A'araf, Verse, 31). The hadith are even more explicit. The Prophet forbade waste even in conditions of plenty when he said "Do not waste Water even if performing ablution on the bank of fast-flowing (large) river". The Islamic Sharia is one of the fundamental sources of water legislation in the Islamic world, as it embodies many principles, which are listed summarily and in part as follows:

- Water is the common property of all. There should be no obstruction to its use and exploitation though its ownership is allowed, especially when it comes to groundwater.
- The use of water by man and animals for drinking has priority over other uses even if it is meant to perform acts of worship. Therefore, nobody is allowed to prevent supplying man and animals with drinking water.

From an economic perspective, the Prophet (PBUH) said that, like fire and pasture, water is a common right for all Muslims. Moreover, according to modern legislation water is owned by society, i.e. the State.

There are many Sharia provisions that address the issue of water usage and which could be referred to as an authority in terms of water legislation, as one could hardly oversee these provisions in Muslim countries (ISSESC, 2004). Faruqi (2001), argues that given these examples, unfortunately, they are not used more widely to promote water conservation in predominantly Muslim countries.

**Review of the evolution of water legislation and institutional arrangement in Bahrain**

Bahrain recognised the need to improve its institutional arrangement. Groundwater development has largely been regulated by permits or licences but most of them are not metered. However, these methods are not very effective; a more comprehensive, modern and relevant to present day requirements based code need to be framed with the stress on WDM.

Recently, all government agencies, including water-related agencies, are being instructed by the Crown Prince to prepare their water strategies in light of general strategic goals of "The Bahrain 2030 Vision" prepared by the Bahrain Economic Development Board (EDB). It is expected that these strategies are finished before the end of 2010.

Owing to the nature of water management strategies and practices in Bahrain, which are concentrated around supply management and augmentation schemes of water resources more than on demand management schemes, the environmental aspects of these schemes has not taken much attention. For example, expanding desalination plants capacity is looked at as the only solution to meet the spiralling domestic water demands, despite their negative impacts on the surrounding environment, which include air pollution by emitted oxides and seawater and marine life pollution by rejected hot brines and residual treatment chemicals and trace element.

Recently, Royal Decree No. 36/2009 concerning the amendments of some items of Decree 7/1982 on the Establishment of the Water Resources Council was issued. The objective of the law is to reactivate the previously formed High Water Council in 1982, seen as the most suitable organizational framework to ensure efficient levels of water resources management in the Kingdom. The stated Water Resources Council responsibilities are: i) Formulation of the overall water resources policies and strategies for the country, including the setting up of

appropriate institutional and legislative frameworks; ii) Coordination of government water policies and ensuring integration of these policies; and iii) Following up the implementation of water policies and plans and setting up priorities for the implementation of the developed strategies and programmes.

It is expected that this institutional reform, manifested by the Water Resources Council, will have a key role in addressing the water sector challenges in Bahrain, and lead the formulation of a clear comprehensive, integrated, national water policy and strategy based on IWRM principles in the Kingdom of Bahrain. This is considered to be the first step forward in the long intricate path to sustainable water management in the Kingdom.

On the level of EWA, Qamber (2009; 2001) stated that EWA's mission is to reduce wastage technically after customer metering by introducing water bylaws, because there is no control over all the types of appliances and their standard of workmanship.

For example, a toilet cistern may use 9 litres per flush while there are other types with a capacity of less than 6 litres per flush. Al Ansari, 2004 state controlling the size of the cistern can avoid a large proportion of a household's wastage of water flows (33%). In March 1999 a Ministerial Decree was introduced imposing 6 litres as the maximum size of cistern allowed in the Kingdom of Bahrain. This was one step towards the introduction of water bylaws. In eleven years (1999- 2010) it was estimated that a total saving of 9,606 $m^3$for eleven (11) years (873.3 $m^3$/year) was achieved by installing toilet cisterns which use 6 litres per flush (author, 2011). It is the plan to change all the existing not standard ones out since there is only 6l/flush and dual flush cisterns in the market.

The first edition of Technical Guidelines for Internal plumbing water system was published in 2010. Copies of the guidelines are distributed to customers during conferences, exhibitions and workshops.

EWA is in the process of publishing water bylaws to prevent water wastage, undue consumption, misuse and contamination. The intention is to enhance the quality of material,

workmanship, plumbing standards, and storage capacity and to set controls over the appliance rate of flow to serve water conservation.

*Standards for water bylaws*

The water bylaws are stated in a set of standards which broadly cover the standards intended for the following:

- Prevention of water contamination from contact with unsuitable materials or substances.
- Prevention of water contamination by back siphonage, back flow or cross connection.
- Prevention of contamination of stored water by contact with waste.
- Prevention of wastage of water from damage to water fittings resulting from causes other than corrosion.
- Prevention of waste from, or contamination by, unsuitable or improperly installed water fittings.
- Standards for water closets and urinals.
- Prevention of waste, misuse and contamination of water from draw-off taps, baths, basins, sinks and other fittings.
- Prevention of waste or contamination of water from any water system.
- Conservation.

*Compliance*

Water bylaws compliance will serve the broad long-term demand management strategy in terms of waste reduction from appliances in households and public areas. To implement the water bylaws requirements, a reference list of international standard approved materials and fittings that will be allowed to enter the Kingdom will be produced and enforced by the Ministry of Commerce (all appliances are imported to Bahrain, no local manufactures). It is necessary, but is yet to be enforced, and this is another handicap.

"The Bahrain 2030 Vision" prepared by the Bahrain Economic Development Board. It is not adequately discussed on water side, as government did not give attention to water scarcity

and its limited resources, there is nothing regarding water regulation, water bylaws that take care of water demand management.

**Current Water tariff applied in Bahrain**

Setting an appropriate tariff structure for water supply is one of the most adaptable tools of demand management strategy and is increasingly being promoted to send out proper signals, especially in areas with shortage and scarcity of water. Low water tariffs discourage water conservation.

From Customer Services Department documents and reports it was found that Bahrain has applied an increasing block tariff on both blended water use for domestic and non-domestic uses (industrial and commercial) based on volume of water consumed from 1985. The water tariff has been modified several times. The last modification for domestic use was 20 years ago in 1992 under Ministerial Resolution No. 2 (1992), which is currently in force. These modifications were done when the tariff was reduced and extra block tiers were introduced in order to reduce the cost to customers. In the case of non-domestic use, the water tariff was revised by Ministerial Resolution No. 19 (1986) and was reduced for both categories. This was done in order to encourage the industrial and commercial sectors. This tariff is still in use in 2010 and has not changed. This is just a reduction in tariff without adequate analysis and will defeat the water conservation efforts. Relevant details regarding each tariff structure are shown in Figures 5.11 & 5.12.

The cost of water in Bahrain depends on the processes and availability of plant in operation (Al Ansari, 2004; Al-Masri, 2008b). As indicated in Table 2.16, Chapter 2, the unit cost of water production in year 2007 rose to BD 0.312/ $m^3$, due to increase in the cost of chemicals and spare parts. It shows that the water tariff is substantially lower than the actual production costs, and the government heavily subsidises the domestic and, to a certain extent, the industrial supply. Comparing production costs with tariffs it is clearly shows that there is a huge gap between the cost of production and tariffs, which indicates that the current water tariff is not effective in returning the cost of providing drinking water to customers.

The section below discusses the effect of low tariff and subsidies on WDM.

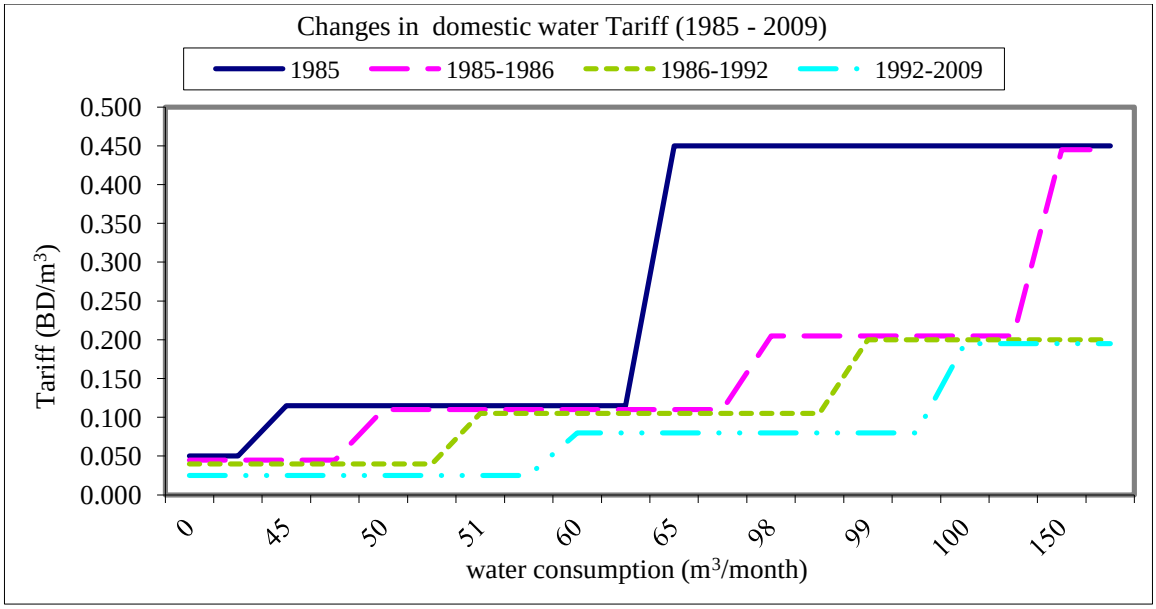


**Figure 5.11:** Changes in domestic water tariff, Source: Al Jamri (2007)

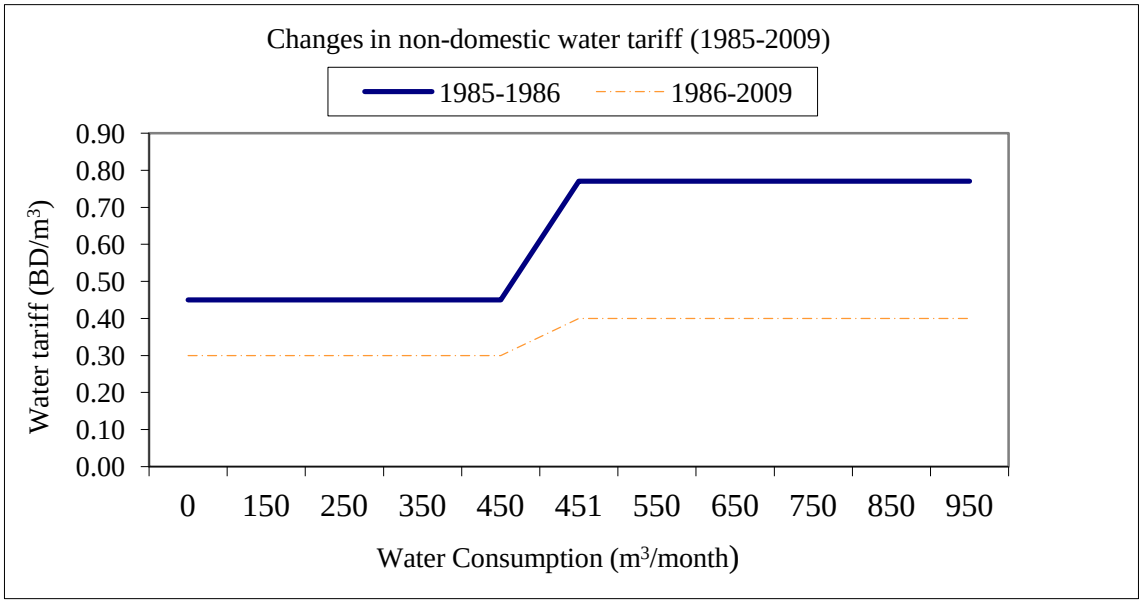


**Figure 5.12:** Changes in non-domestic water tariff, Source: Al Jamri (2007)

**Effect of low tariff and subsidies**

As indicated earlier, a reduction in tariff without proper analysis will defeat the water conservation efforts. Low water tariffs encourage wasteful practices. At the present domestic sector tariff is highly subsidized (80%) compared to the cost of production that in turn affects water allocation to other sectors in the economy. This subsidy has to be reduced

similar to other subsidies across the GCC where they have been reduced or removed such as Dubai if this were to happen then the increasing block tariff will have an effect.

Also operation and maintenance cost recovery is as low as 20%. Government spending on capital investments may be divorced from management of water resources, as government is facing deficit in taking loans to bridge the gap. Also the cost for projects to desalinate and distribute water is increasing, this cost is very wide, and indicates no value for water.

Also specialised banks do not play significant role (due to ignorance & lack of interest related to water problems). This lack of investment is perhaps because EWA is far away from recovering 80% of its production costs.

In the absence of a proper tariff for water, revenue generated from the water is very small. Thus to run the Authority, it is the Government's responsibility to pay the remaining of the Authority's budget. It may be noted that Bahrain is not facing significant inflation and it will have very to nil effects on tariff, a rising inflation is not putting pressure on either the cost of operation or the cost of capital being reflected in the cost of water being produced or distributed, so therefore making the subsidy even greater.

This low charge for water implies lack of incentives to encourage efficient water use in the face of escalating water scarcity. The vast socio-political policy in favour of low prices has no economic viability as studies (Abu Qdais and Al Nassay, 2001) have shown that an increase in the price of water will have a positive impact on productivity and lead to more efficient and economic use of water.

Tariffs need to be revised upwards and in to several tiers blocks. Each block tariff should increase in a non-linear manner. The number of consumers per connection also needs to be considered. That means per capita high domestic consumers should be made to pay high bills. Having applied this, it may result in water conservation.

To summarise, revising the tariff upwards and devising several tariff tiers blocks (depending on per capita consumption of water use per domestic connection) and also some socio-

economic consideration, will help water conservation. In addition schemes like encouraging people with rewards for saving water need to be devised. Also the right tariff which somewhere represents cost of production, distribution and maintenance would result in efficient use of water and hence result in conservation.

Also domestic water consumption accounts for more than 50% of total sold water from EWA as indicated in Table 5.14. Table 2.20 below (which shows the water consumption in each tariff block during the period 2001–2010) indicates that the percentage of water consumption in the first block (01-60 $m^3$/ month, BD 0.025) ranges from 51% to 59%, the percentage of consumption in the second block (61- 100 $m^3$/ month, BD 0.08) ranges of 11% to 15%, while the percentage of consumption for the third block (>100 $m^3$/ month, BD 0.2) is from 27% to 35%. This information indicates that the increase in consumption in the third block is based on the subsidy of the first and second blocks.

**Table 5.20:** Domestic Water consumption per block tariff in $Mm^3$, 2001–2010

| Year | Water consumption per block | | | | | | Total Domestic |
|---|---|---|---|---|---|---|---|
| | 01-60 $m^3$/month BD.025 | % | 61-100 $m^3$/ month BD.08 | % | >100 $m^3$/ month BD.2 | % | |
| **2001** | 48,637,421 | 59 | 12,078,238 | 15 | 21,924,038 | 27 | 82,639,697 |
| **2002** | 49,798,906 | 58 | 12,775,768 | 15 | 23,828,733 | 28 | 86,403,407 |
| **2003** | 51,824,045 | 57 | 12,872,440 | 14 | 25,948,954 | 29 | 90,645,439 |
| **2004** | 51,554,759 | 57 | 10,531,253 | 12 | 27,859,599 | 31 | 89,945,611 |
| **2005** | 53,088,525 | 56 | 10,222,871 | 11 | 32,070,109 | 34 | 95,381,505 |
| **2006** | 54,953,698 | 54 | 11,160,617 | 11 | 36,027,533 | 35 | 102,141,848 |
| **2007** | 53,316,184 | 51 | 12,105,354 | 11 | 40,046,788 | 38 | 105,468,326 |
| **2008** | 64,635,559 | 57 | 13,456,078 | 12 | 34,756,140 | 31 | 112,937,777 |
| **2009** | 65,430,814 | 65 | 12,561,101 | 12 | 22,760,460 | 23 | 100,752,375 |
| **2010** | 71,454,997 | 62 | 14,419,190 | 12 | 30,062,572 | 26 | 115,936,759 |

Source: Customer Services Directorate, Electricity and Water Authority, (2011)

The percentage increase in domestic consumption in the first block indicates that the quantity of water in this block (60 $m^3$/ month), does not actually reflect the basic human needs. If it is assumed that the domestic per capita water consumption is 150 l/c/d according to World Health Organization (WHO) Standards, and we assume the average Bahraini family size is 6.23 people, then monthly water consumption for the family will be about 28 $m^3$/ month while the recorded consumption from billing is about 49 $m^3$/ month. Al-Masri

(2009) reported that the total per capita water consumption was 92 $m^3$/ month in year 2008. Therefore the first block tariff does not serve the goal from it which is to provide the basic human needs with reduced prices to avoid obstacles ton getting water.

With regard to the third block tariff, the increase in percentage consumption to 35% in this block indicates that the tariff does not represent a constraint to reducing water consumption due to increase in average family income and low tariff with regard to production cost. Also this means that high income customers with high consumption gain more benefits than others from the government subsidy provided for drinking water sectors.

Based on average consumption, we can divide Bahrain into three categories: according to the study carried out by EWA (Ali, 2008):

- Category 1 whose consumption is limited to and less than 60 $m^3$/ month. The majority of this population are Bahraini and non-Bahraini nationals because of the small size of the building units where they reside, and without garden or housemaid. This average consumption is 240 l/c/d.
- Category 2 whose consumption is of 61 - 100 $m^3$/month and belongs mostly to the flats and small houses occupied by Bahrainis and non Bahraini nationals. This average consumption between 290 to 410 l/c/d.
- Category 3 whose consumption is high, more than 100 $m^3$/ month, and belongs in the majority to Bahrainis who live in big villas and houses. The consumption of this division is not clear but it is expected to be at low level of 500 l/c/d.

In general, proper water tariffs have a major effect on the implementation of WDM measures in Bahrain. Studies state that poor consumers can only afford to use a small amount of water (the basic), and any increase in tariffs will have little effect because they cannot do with less water. For large consumers (the ones that irrigate their gardens, own cars that need to be washed) the ability to pay is such that the need to save money on water is limited. Therefore water tariff should be set in such away where all people of all income can afford sufficient quantity of water for their basic needs and lifeline tariff should be within 3-5 % of household income as suggested in literature. A low water tariff has a negative impact on the implementation of the following WDM measures water loss management, installation of

efficient devices, and recycling as discussed below: Awareness campaigns, regulation, policing, leak detection, renewal of appliances, etc. are more effective than the price mechanism per sector.

**On water loss management**

Low water tariff has negative effect on the water loss management. A low tariff will not encourage householders to repair their leaks in side their premises since the water tariff is low and highly subsidies by the government. They will only think about it when their water bills and consumption become high. This has negative impact on the environment as water production cost is high and water resources are limited, and it is easily wasted. On the other hand, it has an effect on the building foundation and may cause settlement.

Tariffs should give a signal to customer to conserve water and try to save every drop.

**On installation of efficient devices**

Low water tariffs will not encourage customers to use efficient devices to reduce their water usage (inside premise/ outside), which in turns reduces their water bills as the current water bill is low and does not affect customer in paying their water bills.

On **recycling**

Low water tariff discourage both householders and non-domestic users to use recycled water. Recycled water requires another system to be installed with certain standards and specification and is more costly than the available potable water which is highly subsidised by the government. Thus customer will prefer using blended water and pay for their water use since there is no regulation that enforces them. This also has negative impact on the environment as wastewater will increase and will need more wastewater treatment plants.

**Water Metering**

Low tariffs will not encourage customer to complain about their defective water meter as they are paying less than 25%. Therefore a metering policy of fitting GSM based E-Meters to all households has to be think of so WDD know when a meter is failing or has stopped.

Also utility will not take its priority to replace aged meters, but it will look for replacing stopped meters and installing meters for illegal connections.

**Public acceptance**

It is accepted that to use lots of water is normal, even though it is costly. EWA and Ministry of Education should work together and educate public about the water and its scarcity and need to conserve water.

Illegal connections need to be treated as theft against the state and punished.

**Non Revenue Water**

A low water tariff has a negative impact on reducing NRW, as discussed above. Apparent losses in Bahrain will be high because of factors associated with the low water tariff. There is no programme for replacing old water meters that under-register water flows and, as meters become older, the recorded flows will reduce further. The low tariff also means that customers will not repair interior house leaks, because there is no incentive to do so. All of these factors combine to increase the level of NRW.

**Comparison of water tariff in Bahrain and other GCC countries**

Länderfourm, (2010) argues that the citizens of GCC states are used to pay very little, if any for their water supply, low tariff encourage wasteful practice and the GCC states rank among the countries with the highest per capita usage in the world, despite being a severely arid region. The Water tariff in Bahrain is the lowest compared to other GCC countries, as water is sold in the lowest block (1-60 $m^3$) at BD 0.025 (US$ 0.065/$m^3$). It should be noted that in Bahrain groundwater is blended with desalinated water using a ratio of about 1:3, respectively, for drinking use. In the GCC countries, production costs range between US$ 1.1/$m^3$ and US$ 2.0/$m^3$. More importantly, the gap between production costs (including production, transmission, and distribution) and revenues is quite large in all GCC countries, resulting in large subsidies of between US$ 0.48/$m^3$ and US$ 1.79/$m^3$ as indicated in Table 5.21 (Smith and Al-Maskati, 2007 cited in ESCWA, 2005).

**Table 5.21:** Estimates of Current Production Costs and Subsidies for Freshwater in the GCC Countries

| Country | Cost ((US$/m$^3$) | Average revenue (US$/m$^3$) | Subsidy (US$/m$^3$) |
|---|---|---|---|
| Bahrain | 0.65 | 0.17 | 0.48 |
| Kuwait | 1.98 | 0.19 | 1.79 |
| Oman | 1.34 | 0.84 | 0.5 |
| Qatar | 1.31 | 0.42 | 0.89 |
| Saudi Arabia | 1.35 | 0.08 | 1.27 |
| UAE Abu Dhabi | 1.16 | 0.13 | 1.03 |

Source: ESCWA, (2005)

Although Bahrain has employed a progressive tariff system since 1990, per capita consumption is high but the tariff is very low, and the majority of the customers fall in the first two blocks where water charges are minimal.

In the past some of the GCC countries have introduced block tariffs, where a sliding scale ensures customers are incentivised to conserve water. The effectiveness of a block tariff depends on the level at which it is set. If it is too low, it will fail to act as an incentive to conserve water. Bahrain, Oman and Saudi Arabia have adopted a progressive block tariff system and Kuwait, the UAE and Qatar have retained a flat rate system. Qatar and the UAE exempt their national citizens from municipal water charges; therefore, the cost recovery is very low relative to production costs. Figure 5.13 below shows Tariffs for water in GCC countries.

Bahrain and GCC countries need to look at restructuring water tariffs and introducing disincentives to help reduce consumption. Tariff structure should be sufficient to cover O&M costs, and development plans while at the same time providing a low lifeline rate for low consumption and penalty rate for higher consumption. In other countries where increasing block tariffs are used, the lifeline consumption benefiting from lower tariff levels is typically set at 20 m$^3$/ month or less.

Water tariff in Bahrain needs to be reformed and to be given more incentives to encourage consumers to conserve water. Even so, there is general political resistance to tariff increase and in maintaining tariff levels in real terms.

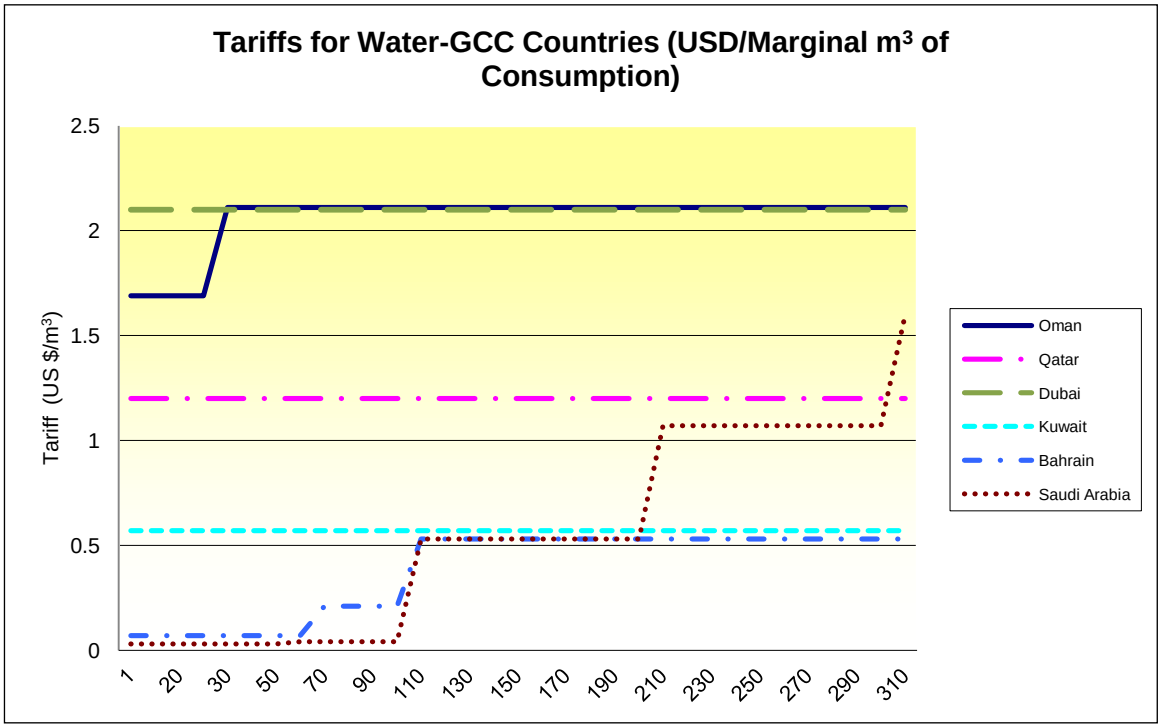


**Figure 5.13:** Block tariff for water, GCC Countries, Source: Smith and Al-Maskati (2007)

## 5.6 Chapter Summary

The various analyses and data presented in this chapter were geared towards answering the primary research questions as outlined in Section 1.4 of Chapter 1 of the thesis. Various aspects of WDM measures have been examined to help identify the suitable measures to be obtained for the case of Bahrain.

The information in this chapter covered the water demand management measures at four different levels (utility level, household level, non-domestic level and government policy-makers level). Some important characteristics about utility units and their problems in carrying out their duties which had an effect on WDM implementations have been examined. Also presented in this chapter was analysis of households' intention to pay for improved services, evaluation of using aerators, and electronic taps as water saving devices,

wastewater reuse and grey water at industrial sectors. In summary, the following key points emerged from the analysis presented in this chapter:

- Major problem issues associated with utility units were:
  - *shortage of budget*
  - *capacity building*
  - *public awareness*
  - *policy & standards*
- Implementation of ILI was tested to evaluate its suitability for Bahrain as a performance indicator for leakage management.
- In order to reduce apparent losses caused by meter under-registration, a pilot study was carried out to evaluate the implementation of a Low Flow Controller (LFC) device to take care of low flow rate and hence of meter under-registration. Results showed there was an increase in average water consumption recorded by 36%, and the payback period for installing one LFC is 3.8 months.
- The majority of household were against the increase of water tariff to cover the true cost of water.
- The current tariff is heavily subsidised by the utility and does not encourage conservation.
- Waste water reuse is not implemented at household level nor at non-domestic level.
- Electricity and Water Bylaws have still not been approved, and it takes a long time to approve them. Also water tariff is heavily s subsidised by the government and the last time was it was modified goes back to 1992 for domestic and 1986 for non domestic consumers.
- Grey water from ablution at mosques and grey water from a health centre swimming pool could be used for irrigating the surrounded garden areas and could be generated to health clubs, hotels, villas and schools which have swimming pools.
- Grey water from AC at BAS could be generated to other hotels, institutions and commercial buildings
- Most of the industries are not using any saving devices, but they are willing to do so.
- Most of the industries were against the use of wastewater as they thought the quality might change and there were no regulations to force them to use wastewater.

- Most of the industries were against increasing water tariffs to cover the true cost.
- Saving devices are distributed to the public during summer campaigns or to students on voluntary basis, and economic incentives are given to customer who reduces his/her water bills by 5% or more than previous months after installing saving devices.
- In general, proper water tariffs have a major effect on the implementation of WDM measures in Bahrain. A low water tariff has a negative impact on the implementation of the following WDM measures water loss management, installation of efficient devices, and recycling.
- A low tariff will not encourage householders to repair their leaks in side their premises since the water tariff is low and highly subsidies by the government, also it will not encourage customers to use efficient devices to reduce their water usage (inside premise/ outside),
- Tariff structure should be sufficient to cover O&M costs, and development plans while at the same time providing a low lifeline rate for low consumption and penalty rate for higher consumption.

The research questions were analysed by the use of multiple methods. This chapter presented the results without discussing the findings. The next chapter deals with the discussion and conclusions about the findings pertaining to the research objectives and questions.

# CHAPTER 6: Potential for Water Demand Management in Bahrain: Discussion of findings

## 6.1 Introduction

This chapter discusses the key findings from the analysis carried out in the previous chapter and explores the potential for water demand management applicable to the various sectors of the country. These findings are discussed based on the analysis of various measures in Bahrain, the literature review (Chapter 3) and the research background (Chapter 2). In this chapter, an address to key issues and answer the primary research questions, and major components of the strategy are highlighted. This chapter attempts to be comprehensive in its scope in terms of discussing the research findings. Most of the individual measures have been field tested and found to be successful in specific areas. In some cases their more general applicability requires further investigation.

In order to achieve the aim of the research, the four research questions which were developed and outlined in Chapter 1, Section 1.4 are discussed in the following sections:

6.2 How can WDM measures taken at the **utility level** contribute in providing a sustainable water supply for Bahrain?

6.3 How can WDM measures taken at the **household level** contribute in providing a sustainable water supply for Bahrain?

6.4 How can WDM measures taken at the **non-domestic consumers level** contribute in providing a sustainable water supply for Bahrain?

6.5 How can WDM measures taken at the **government policy level** contribute in providing a sustainable water supply for Bahrain?

## 6.2 How can WDM measures taken at the utility level contribute in providing a sustainable water supply for Bahrain?

From the field survey carried out in Chapter 5 it was found that several departments and units in EWA are currently practising various forms of WDM measures as part of their operational policies. For example the Waste Control Unit is responsible for detecting and repairing leaks and reducing NRW; the Metering Workshop Unit puts substantial effort into

replacing aged and non-functional meters. The Water Conservation Department is responsible for public awareness and education about water conservation and installation and adoption of various water saving techniques; and the Customer Services Department is responsible for generating water consumption reports and collecting water revenue. As was explained in the previous chapter, although these units work hard to achieve their policies and strategies, nevertheless they are currently experiencing various constraints to fully realize the ideal WDM measures at utility level. In the following subsections, the deficiencies, constraints and specific measures identified from the research related to WDM at utility level are identified and addressed.

### *6.2.1 Measuring and reducing system losses*

The first step in measuring system loss is to conduct a water balance (using a recognised method) for assessing non revenue water. It should be measured in cubic metres or litres per year. The water balance can help to identify and aid the reduction in actual water losses, such as those from leaking pipes, along with apparent losses resulting from metering, billing or accounting errors. The accuracy of water loss volumes depends on the accuracy and the quality of data used in the calculation. The next step is to assess leakage through a comprehensive and intensive leak detection programme. However, before carrying out leak detection, preliminary activities should be conducted to identify zones where significant real losses are occurring and to prioritise those zones for leak detection exercises.

The following subsections discuss the steps carried out in measuring and reducing system loss.

**a) Non Revenue Water (NRW)**

The accuracy of the assessment of the impact of non-revenue water (NRW) provides a vital role in the overall WDM strategies, especially when the result is to be used for monitoring improvement in performance. Based on observation and the process of calculating NRW in Bahrain a high trend of NRW has been observed since 2000 with no substantial improvement in reducing NRW over this period, as shown in Table 2.12 in Chapter 2.

The present units of measure used for NRW and leakage within WDD in Bahrain are currently expressed as percentages of water distributed. This is not an appropriate measure as it can be

misleading, and loss volumes are of greater importance from a technical perspective. Thus WDD needs to express these in terms of cubic metres or litres per customer per day.

One of the reasons that NRW in Bahrain is considered to be high is due to estimated values for apparent loss where meter under-registration is one major factor. Rothenberger, (2011) also found that NRW was not significantly reduced in Madaba, Jordan, despite the major investment in reducing NRW. This was due to inaccurate meter reading, billing/ cost collection, illegal connection and meter under-registration. Johnson (2011) found that in Australia NRW is influenced by errors in calculation of apparent losses through meter-under registration. It is important that management of the apparent loss component of NRW must take into account the various types of meter-measured error and their effects on the water balance.

Considering NRW, IWA Water Balance was calculated for EWA. Table 2.11 indicates the various factors that contribute to overall NRW values. Reference is made to Water Balance (Chapter 2, Table 2.11) for the year 2010, which showed that NRW was 38% and water loss, consisting of apparent losses and real losses, was 32% (estimated apparent loss was 5% and estimated real loss was 27% from the water distribution system). These estimates are based on an historical study to estimate quantity of water losses as discussed in Chapter 2. This personal historical study has to be updated by revising all the factors that contribute to calculating the NRW.

The estimated figures for real and apparent losses used within the EWA have been used for many years by engineers who assumed them to be correct. A review by the researcher revealed that the figures were inaccurate. The real losses from the water distribution system (27%) are the most significant factor, and the most expensive and time consuming to eliminate. Thus figures should be reviewed periodically to ensure that the current values are used. This is in line with Seago et al., (2005) that careful management must be applied when dealing with scarce resources, especially water lost from potable distribution systems.

**b) Real Losses Performance indicators**

From the research background chapter (Chapter 2) it was found that WDD in Bahrain relies on water balance as a guideline for assessment of real losses, which are part of total water losses. Water losses are often expressed as a percentage of the water from supply, or water into the distribution system. From the literature (Trow, 2007; Liemberger et al, 2007) it was

found that percentages were not good technical measures because they are affected by other factors such as customer demand, and their use must take into account actual customer use, and also level of intermittency of service which does not apply to Bahrain where is continuous supply. Owing to the disadvantage of percentage, American Water Works Association (AWWA) recommends use of the term Non-revenue Water and the array of performance indicators included in the IWA/AWWA Water Audit Method. Thus, real losses should be assessed by an additional method which is currently recognised as a performance indicator. Performance indicators can be calculated to measure the level and volume of water losses in the distribution system (EPA, 2010). Previous performance indicators then serve as benchmarks to gauge improvement during the next scheduled audit.

Nowadays, a well-known international water loss indicator is the Infrastructure Leakage Index (ILI), which is presented by the International Water Association (IWA) to perform benchmarking of utility leakage status, allowing easy comparisons to be made between different countries. It is the ratio of the Current Annual Real Loss (CARL) to the Unavoidable Annual Real Losses (UARL). CARL is always tending to increase, as the distribution networks grow older.

$$ILI = CARL/UARL \qquad \text{[Equation 1, Lambert 2005]}$$

ILI measures how well the system is being managed for the control of real losses, at the current operating pressure. It also measures how effectively the three infrastructure activities - speed and quality of repairs, Active Leakage Control (ALC) and pipe materials - are being managed, at the current operating pressure.

Another indicator, the French Linear Leakage Index (LLI), is calculated by dividing the volume of leakage by the length of mains; this is only used in parts of France and in French Outer territories.

ILI and LLI indicators could be used to calculate real losses and to prioritise waste zones for leak detection exercises. These applications are consistent with those recommended by Winarni (2009) and G2C, (2006). These indicators measure how effective a utility is at managing real losses.

From analysis of technical data (this is explained in Section 5.2.3, Table 5.5) the calculated ILIs for Bahrain for the years 2005, 2006 and 2010 were 57.5, 59.0, and 102.2 respectively. With reference to the World Bank table (Table 3.3, Chapter 3) it was found that Bahrain was in the 'Bad' band. ILI was calculated to be higher than 16 which places Bahrain in category D for developing countries. This indicates an inefficient use of resources; a reduction programme therefore becomes imperative and a high priority. The ILI values calculated for Bahrain are in line with McKenzie, et.al, (2007) that for many developing countries, ILIs for some systems are usually found to be in excess of 10; in some cases even in excess of 100, so a very low ILI can be considered almost an impossible target for such systems. It was also mentioned (Liemberger and McKenzie, 2007) that pressure management affects both CARL and UARL, but ILI is effectively independent of supply pressure.

Thus measures must be taken to reduce leakage by reducing ILI to below 16 as a starting point for EWA. Nevertheless this ILI tends to be helpful for the comparison between waste zones in other parts of the country, and can assist in the prioritisation of the programme of night exercises for waste.

The researcher calculated the French Linear Index (LLI) for Bahrain for the period 2005 to 2010 which showed that the LLI is increasing and in the range 0.84 -1.40 $m^3$/hr/km, as indicated in Table 5.7, Chapter 5. All LLI values calculated for Bahrain were in the range corresponding to 'poor network'.

From the literature (G2C, 2006) it was found that the LLI has the advantage that it can be applied locally, enabling comparisons between different areas of the same network. The disadvantage is that it does not allow true international comparison as ILI claims; it requires coordinated readings of customer meters and bulk meters, which are not accurate in the case of Bahrain.

In general it is clear that, regardless of the methods used for calculating the performance indicators and network evaluation, both indicators (ILI, and LLI) were high and exceeding accepted international values. The 2005 indicators for Bahrain were better than for the period 2008-2010, which implies that the performance of the distribution network in Bahrain

is deteriorating significantly. This is not the case, but is because data are becoming more accurate. The researcher prefers using ILI as it was developed by an IWA task force and is internationally used, while LLI is only used in France and French territories, although it is easy to apply. Winarni (2009) states that ILI could be used by operators to measure their attempts at water loss reduction, and reducing ILI to below 16 would be the first step for utilities. Therefore EWA could reduce real losses by prioritising leak detection exercises in waste zones based on ILI values as indicated and supported by the literature review (Radivojević, et.al (2007).

### *6.2.2 Improving leak detection and repair programme*

Interviews with the Waste Control Unit staff and general observation of their work have been used to evaluate the staff and the equipment involved in detecting leaks (Section 5.2.1 and Section 5.2.2). It was found that the Unit suffered from shortages of staff, training needs, leak detection equipment, and lack of capacity in terms of number of staff and updated network drawings. On top of that the water tariff in Bahrain is low so that calculations of Economic Leakage Level (ELL) are meaningless because leakage reduction is not economic.

The low tariff levels also lead to insufficient budget allocation, inadequate numbers and skill levels of staff; inadequate resources for active leakage management. Because of these constraints the Waste Control Unit showed an overall low performance as indicated from the achievement during the year 2009-2010 (Table 5.10). Tay et al (2008) found that the number of leaks in Singapore was low compared to many other countries in the world. This was attributed to the ability of the Public Utility Board (PUB) which also manages the water supply network, to undertake active detection of underground leaks, and respond quickly to customers who report leaks.

Shortage of equipment has led to the number of unreported leaks increasing, leak detection exercises being abandoned and inability to follow the policy that waste zone leak detection exercises should be completed once every 2 years. The researcher finds the interval between leak detection exercises is too long and not in line with the BABE (Burst and Background Estimation) concept. According to the BABE concept, the shorter the interval between leak detection exercises, the fewer un-reported leaks remain undetected. Reynolds and Preston

(2004) state that the IWA recommends a maximum of 6 month intervals between leak detection exercises. Unfortunately this all depends on budget availability and sufficient trained staff; however the low water tariff does not allow EWA to generate revenues. Thus to reduce NRW level in Bahrain factors affecting NRW should be evaluated.

### *6.2.3 Improving water metering accuracy*

Existing literature (Tate, 1990; Shawky, 2001, Biswas et al., 2008) highlighted that water metering is essential for a successful WDM programme, as water metering makes the link between consumption and price. Without accurate metering, any attempt at demand-based pricing and demand management will be ineffective.

**a) Meter maintenance /replacement**

From interviews and reviews of selected literature (as indicated in Section 5.2.1 & 5.2.5), it was found that domestic meters are not necessarily replaced in line with Water Distribution Directorate (WDD's) policy to replace meters every six years to take account of deterioration in accuracy with age. This is because of shortage of budget allocated and unavailability of new meters. A policy was started in 2009 to replace all meters installed before 2003. In 2010 the number of meter units planned for replacement was around 13,000. The total number of units replaced was 9,594 i.e. 26% of the meters were not replaced due to shortage of budget. This resulted in customer dissatisfaction and revenue loss. Priority is given to replacement of stopped meters, and replacement of meters on the basis of age has low priority. In addition there was no plan to calibrate or replace bulk meters.

Weak policy in replacing aged meters has an effect on apparent loss, and in turn increases the level of NRW, as a considerable proportion of apparent losses are due to metering errors, as is the case of Bahrain as explained earlier. Thus all meters should be in good working condition (Biswas et al., 2008).

From the analysis chapter (Section 5.2.5) and based on a pilot test study carried out by WDD it was found that domestic meters tend to under-register by 15% after six years of service as indicated in Table 5.1, Chapter 5. This is in agreement with literature (White, 1998; Egbars,

2010; Rotherberger, 2011) that the accuracy of meters deteriorates with usage and affects mostly the low flow range, especially in domestic meters.

White (1998) found the cumulative potential error from under-registration of customers' meters may be up to 10% of all water delivered, depending on the type and age of meter, the water quality and other factors. Thus it is essential that EWA has a programme to measure and calibrate the performance of various types of domestic water meters, and that meters are regularly maintained and replaced. This is in line with Al Senafy et al., (2008) who called for a comprehensive review of metering policy with regard to meter selection, and meter replacement programmes, in order to resolve the issue related to metering and to arrive at a reliable estimation of water utilisation and network leakage. EPD (2007) refers to AWWA manual M6 which suggests a planned meter replacement programme to be implemented over a number of years, with a percentage of meters being replaced each year. As stated earlier in this section, EWA′s priority was to replace stopped meters only, due to shortage of budget and lack of meter stock.

As documented by Yaniv (2009) and Fantozzi et.al (2011), a Low Flow Controller (LFC) device is used to enable low flow to be measured at low flow rate. From observations as part of a pilot test performed by the researcher and the WDD team, it was noted that, on average, 36% of the water that passed through a meter during low flows was not registered by the meter. Thus LFC is useful for implementation in Bahrain as it has an effect on reducing NRW apparent loss.

Another NRW exercise was performed in Bahrain, Muharraq-zone 234. After installing LFC it was found that NRW was reduced from 22% to 7% (Section 5.2.2, Table 5.3). These figures are consistent with (or better than) the ranges indicated in the literature review as shown in Table 6.1 below for similar sized properties in other countries.

**Table 6.1:** NRW reduction after installing LFC in different countries

| Author | % reduction mentioned | Country |
|---|---|---|
| Researcher (2011) | 15 (22% - 7%) | Bahrain- Muharraq |
| Christodoulides (2008) | 7. 57 (16.38% - 8.81%) | Cyprus- Larnaca |
| Davidesko (2007) | 9.9 (16 % - 6.1%) | Israel- Ein Karem |
| Yaniv (2009) | 6 (18.1% - 12.1%) | Malta |
| Fantozzi et al (2011) | 9.15 | Italy- Palermo |

Source: Researcher's field work, (2011) compared with the work of others in the same field

**b) Meter reading and bill distribution**

It was found from interviews (section 5.2.1) that the Customer Services Department is responsible for taking monthly water meter readings, generating water bills and collecting revenue, and also for coordinating with the Metering Unit in cases where the meter has stopped to arrange for replacement or repair.

*Meter reading*

From interviews with Customer services staff (Section 5.2.2) it was found that meters are read manually by an EWA reader. This raw data is then entered into a billing system. Water meters should be read on a monthly basis. Unfortunately there are problems in taking meter readings due to difficulties in accessing some of the areas, as well as a shortage of meter readers and limited overtime hours compared to the expansion of the distribution network; all of this has an impact on the actual consumption reports. This has led to deficiencies in the meter reader performance, such as ignoring visible leaks in the meters and false recording or missing recordings of the readings giving rise to inaccuracy in the meter reading.

*Bill distribution*

From interviews with the Customer Services Department (Section 5.2.1) it was found that the water bills are generated on a monthly basis. From the documents (WDD, 2008), the Water Distribution Directorate NRW studies indicated that, on some occasions, the estimated readings account for 25-40% of the actual meter readings. This, by itself, means that the actual level of NRW is not known with any accuracy.

Additionally, based on interviews with the Customer Services Department it was found that Very Important Customers (VICs) are billed on the basis of actual meter reading on specified dates of each month. However, if the meters cannot be accessed due to their location, or for any other reason, then an estimated consumption rate of 60 $m^3$ of water per month is given. This figure is not an accurate representation of actual consumption rates of VICs. VICs include important individuals, industries, companies and projects. It was also found that there is weak enforcement of policy against customers who do not pay their water bills.

As a result, a significant portion of apparent losses are due to errors in meter readings and billings, not only because of data handling errors which results in a high level of NRW. The researcher is in agreement with Rothenberger, (2011) that meter reading outsourcing is one of the solutions for tackling this issue, as was done in Madaba in Jordan where outsourcing of certain business processes was done in operation of water services in order to improve billing and revenue collection. This will provide a true measure of actual consumption. Another solution as recommended by EPA, (2010) is Automatic Meter Reading **(AMR)** systems which provide many advantages over manually read meters. AMR is a technology that automatically collects data from the meter and transfers it to a central database for analyzing and billing.

### *6.2.4 Public education and awareness of utility staff about water conservation*

The effectiveness of the public awareness and education campaigns implemented in Bahrain was evaluated through a household questionnaire survey conducted by the researcher in 2006 on 545 respondents. The results (as shown in Table 5. 8, Section 5.2.4) indicate that 54.2% of respondents were aware of water conservation, and that was through different media, mainly TV. This obviously indicates that EWA is doing well through TV and newspapers but is not particularly effective at raising awareness through its staff. Due to inadequate campaigns for passing information and encouraging the public to use water in an efficient way, results achieved are not very encouraging. Awareness programmes should be concentrated during summer time when the peak water demand occurs. Through local TV and Radio stations EWA can approach huge numbers of citizens and residents especially

when the awareness programme is translated into different languages and broadcast at the correct times. The researcher believes that there is an important window which is not being used efficiently due to shortage of budget allocation. The current public awareness campaign implemented by Water Conservation Department is being practised but is **NOT** adequate for water demand management.

There is a need to train & educate the EWA staff through intensive education, capacity development and training in order for them to educate the public directly. This supports the view of Emoabino and Alayande (2006) and Hani et al., (2011) that creating awareness and improving people's understanding of WDM is the first step towards implementation of WDM, and all stakeholders should be made to see themselves as working towards the same goal and be ready to share information.

The researcher sent a letter to the President of the University of Bahrain (dated 20 April, 2009) proposing the introduction of modules in WDM for the Civil engineering master's degree and also some material to be introduced in the undergraduate curriculum. Another letter was sent to Director of Water Research, Bahrain Centre for Studies and Research to run short courses in the field of water demand management (Refer to Appendix 6). A reply was received from the Director of Water Research, Bahrain Centre for Studies and Research that they would take into consideration the idea to run short courses in WDM. It is worth mentioning that conservation has been identified as an important means for saving water and has evolved from what was a small section some time back to a fully-fledged directorate.

The Government of Bahrain is showing a very keen interest and attaching high priority importance to conservation by allocating higher budget and exploring new ways of conservation (EDB, 2010). Unfortunately no action or interest has taken place regarding water tariff reform which is the main measure for successful WDM as it plays the major role in other measures as indicated in Chapter 5, Section 5.5.1.

This is in line with Emoabino and Alayande (2006) who argued that the technical and management skills required at the different levels of utilities /stakeholders must be identified and their capacities developed in a more integrated manner. Mulwafu, et al (2002) state that

efforts must be made to train staff in water utilities in WDM and this should emphasise the significance of WDM in sustainable water resources and must also promote a change in people's cultural attitudes towards water resources. As documented by Hani et al (2011) highly qualified professionals are required to effectively manage and operate facilities that contribute to efficient water use. Therefore, an overall vision and strategy for water education, awareness raising at all levels need to be formulated in Bahrain as an important part of sustainable water resources management in the Kingdom.

### *6.2.5 Institutional arrangement for water supply*

From the study area background (Chapter 2, Section 2.8) it was found that, in addition to EWA, two other ministries manage water supply in Bahrain: the Ministry of Works, and the Ministry of Municipalities Affairs and Agriculture. These institutions are making efforts to achieve their mandate goals. Although the current structure has inter-linkage/communication, unfortunately there is a gap in this linkage mainly due to coordination of activities which has resulted in conflicts in the way institutions implement their activities. Also public participation is considered to be at a low level with no specific participation mechanism (AlMansoor, 1999; AlNoami, 2004; Es'haqi, 2009; Al-Masri, 2010). Thus, formulated policies cannot be considered as national water policies but rather as sectoral water policies. The participation of each institute and other stakeholders in the developed policies of other ministries is minor.

Therefore, the existing policy framework in Bahrain is fundamentally inefficient and non conducive towards achieving the ultimate implementation of WDM.

To the extent that laws, policies and strategies do not explicitly provide for WDM, the policy and legal environment also does not provide the required support for WDM in the country. It was found that there is a water bylaw that exists but it does not efficiently support any regulations that enforce the management of water use, promote conservation and impose adoption of water conservation regulation; as indicated in Table 2.15 most of the water governances and orders in Bahrain are supply oriented. Since the importance of water conservation in the implementation of WDM has been recognised by the government, its role has been identified in the Bahrain Economic Development Board's vision 2030.

Managing demand for water implies taking into account the value of water in relation to its cost of provision, and instituting measures that require consumers to relate their consumption more closely to that cost. It is worth mentioning that tariff has a role to play in all of these measures.

## 6.3 How can WDM measures taken at the household level contribute in providing a sustainable water supply for Bahrain?

From the analysis of Chapter 5 (Section 5.3) some WDM measures are currently in practice at household level in Bahrain while others are being pilot tested. Nevertheless they are currently experiencing various constraints to fully achieve the ideal WDM measures at household level. In the following subsection, the specific measures identified from the research related to WDM at household level are identified; their constraints and deficiencies are addressed.

### *6.3.1 Behavioural change in water consumption in response to tariff and public education*

From the research background Chapter 2, Section 2.9 it was found that the unit cost of water production in Bahrain rose from BD 0.312/ $m^3$ in 2007 and continued to increase until it reached BD 0.380/ $m^3$ in 2010. This is due to an increase in the cost of chemicals and spare parts; however the average unit price of water to the consumer remained at BD 0.06 /$m^3$. This shows that the water tariff is highly subsidized by the government. It is not effective in recovering the cost of providing water to the customer, and will not encourage customers to use water more efficiently. From the household questionnaire survey conducted by the researcher (Section 5.3.3, Table 5.13) it was found that the majority of respondents (87.7%) were opposed to increasing the water tariff and was of the opinion that cost recovery is the responsibility of EWA. This shows that EWA should educate the public about water issues and the cost of water supply and importance of using water efficiently. Respondents who agreed to an increased water tariff stated that the tariff should be charged on an incremental use of water.

In the case of water bills ( expenditure on water), the majority of respondents reported that they were in the range BD 1.500-10.000 per month, which means that customers with a higher income tend to consume more water by enjoying luxuries such as a swimming pool or garden etc. due to the present low water tariff.

From EWA documents (Section 5.5.1) it was found that EWA is using increasing structural tariffs comprising tiers for domestic users and non-domestic users that were last modified in 1992. The current domestic tariff is generally low, which is normal for low income groups, but at the same time it was observed that even the higher income groups who also happen to consume more are benefiting as well.

Present tariffs represent on average of no more than 20% of actual cost, which implies a lack of incentives to encourage efficient water use in the face of escalating water scarcity. This is in agreement with Abu Qdais and Al Nassay, (2001) that an increase in the price of water will have a positive impact on productivity and lead to more efficient and economic use of water. Länderfourm, (2010) argues that low tariffs encourage wasteful practices and the GCC states rank among the countries with the highest per capita usage in the world, despite being a severely arid region. It should also be noted that wasteful use of water increases with per capita income and GCC is among the highest in the world. He also states that the effectiveness of a block tariff depends on the level at which it is set. If it is too low, it will fail to act as an incentive to conserve water and per capita consumption will not reduce in the short term, as is witnessed in Bahrain.

The relevant literature states that realistic water pricing is one of the most fundamental keys to water demand management (Biswas et al., 2008). Raising tariffs is politically difficult; however, there may be political capital to be earned by elected officials who can demonstrate the cost effectiveness advantages of the price-based approach (Olmstead and Stavins, 2008). The literature (Foster et al, 2002) states that there is a new concept called ‘Direct Subsidy’ and this means that the subsidy is directed towards a certain portion of society i.e the poor. The researcher agrees with Foster et al, (2002) and a revised water tariff is needed to take care of poor customers. Faroqui, (2001) adds that recovering the cost of water is allowable in Islam.

The statement that "There is no effective implementation of WDM measures without a proper economic policy" (Al-Masri, 2011), is true for the Bahraini case and explains all shortcomings of other implementation measures such as low awareness level, insufficient use of conservation devices, grey water, etc.

In relation to public education, interviews with staff from the Water Conservation Department (Section 5.3.1) revealed that awareness campaigns are already organised regularly by the department in coordination with the Ministry of Education and Health centres.

The results from the household questionnaire conducted by the researcher regarding customer awareness on water conservation (Table 5.8) show that only 54.2% of respondents had heard about the term 'water conservation'. This implies that media on water conservation do not fully contribute to raising the level of public awareness regarding water management, and currently the most effective media are TV (67.3%), while EWA is significantly less effective (28.9%). Thus there is a need for EWA to strengthen its effort to increase public awareness about water demand management and conservation.

From the questionnaire results regarding household opinions about current per capita consumption (125 g/c/d; 568 l/c/d) in Bahrain (Section 5.3.3, Table 5.13) it was shown that the majority (87.7%) of respondents (middle income customers with monthly earning of BD 300- 599) think that the current per capita consumption is unreasonable, which implies that consumers are wasteful. They also offered suggestions for reducing water consumption in the home which indicates that respondents have an idea about how to conserve water. This is a good opportunity to convince customers to change their behaviour about the water consumption concept and the use of saving devices. It was also found that members of the public with different income and education levels need to have greater awareness about water issues in order to encourage them to reduce their water consumption and inform them about the social environmental benefits from saving water.

It was found from questionnaire surveys (Table 5.15) that there is a strong relation between household income (especially middle income) and their involvement in decision making

about water related issues. Thus it is necessary to involve the households in decision making. Even those water users who are currently implementing WDM measures in their operations do not actually know that they are carrying out WDM activities. This neutral public view is generally created by the fact that most water users in the country are not aware of the importance and benefits of WDM. The level of public awareness of WDM and its benefit is low in Bahrain. Therefore households, irrespective of income bracket and background, need to be educated and made aware about the water situation and ways of saving water, as public participation in decision making will encourage them to apply rules and regulations based on the decisions taken by them.

From analysis (Section 5.3.4) it was found that the Water Conservation Department participates in special events by drawing attention to the objectives of water conservation campaigns. One example would be celebrating World Water Day 22 March, when lectures about water issues are given to various public sectors and particularly at schools. Unfortunately these campaigns are not continuous and less effective for that reason. The research findings support the view of Es'haqi (2009) who stated that there is a deficiency in water related educational programmes in Bahrain, both in curricula and activities. This has a negative impact on society, especially for the young, with regards to water conservation behaviour and attitude. Atallah et al (2001) reported that in order for public awareness activities to be effective, water authorities should plan continuous, long term awareness activities in close collaboration and coordination with the ministries of Education and Islamic affairs.

The research finding is supported by literature (Emoabino and Alayande, 2006) which indicates that public awareness and education are important in every water conservation plan and are considered as basic tools needed to guarantee the participation and involvement of the public in water conservation. Public awareness is the key to getting public support for the utility's water conservation efforts (Al Senafy et al, 2008). The information and education programme should explain to water users all the costs involved in supplying drinking water, and demonstrate how water conservation practices will provide water users with long-term saving. Furthermore Imams can educate the public in general at mosques as

indicated by Attalla, (2001) and Alrubiai (2005). Thus there is a need to educate Imams in Bahrain about water issues in order for them to educate the public during Friday speech.

### *6.3.2 Use of water saving devices*

From interviews with staff from the Water Conservation Department (Section 5.3.1) it was found that there was limited use of water saving devices; most devices (aerators, toilet bags, garden timers and drip irrigation items) were distributed to the public free of charge (to be installed at their premises) either during public campaigns or to school students. Thus not all customers are involved in the campaign. In Bahrain, based on Water Conservation Department experiences, tap aerators can reduce water usage by 12% of total consumption while still maintaining a strong flow. In 2008 11,354 premises were issued with aerators during a national campaign and 500 extra premises per year are planned to be covered (EDB, 2009). Following the campaign in 2008 the daily saving was calculated to be 3,040 $m^3$ which is equivalent to BD 1,216 (US $3,127, £1,737) of savings.

From the pilot test campaign (Section 5.3.2), it was found that aerators were used in Bahrain at household level on a voluntary basis. Unfortunately the aerators cannot be installed on old buildings constructed before 1999, leaving a significant percentage of premises without any water saving measures. Therefore, there is a need to enforce the change in plumbing codes and encourage owners of old buildings to upgrade the existing plumbing systems and use the more efficient appliances. Conservation is also aided by controlling the size of the WC cistern capacity, as a large proportion of a household's wastage of water could be avoided by implementing this measure. Since the installation of toilet cisterns which use 6 litres per flush, from year 1999 up to year 2010 it is estimated by the researcher that a total saving of 9,606 $m^3$ for eleven (11) years (873.3 $m^3$/year) has been achieved.

Irrigation timers also affect conservation. From official documents (Section 5.3.4) it was found that installation of devices in customers' gardens reduced consumption by 22.3%, i.e., from 6.37 to 4.95 $m^3$/premises/day. These timers were installed in 288 locations.

This is in agreement with Al-Senafy et. al (2008). Significant water conservation by residential users can be achieved through the use of efficient indoor plumbing fixtures and

equipment such as Low-flow plumbing fixtures and retrofit programmes which are permanent, one-time conservation measures with little or no additional cost over their life-times (Jensen, 1991). Plumbing programmes usually include the use of low flush toilets, low-flow showerheads, faucet aerators and pressure management. Also it is suggested that in new construction and building rehabilitation or remodelling there is a great potential to reduce water consumption by installing low-flush toilets. Even in existing residences, replacement of conventional toilets with low-flush toilets is a practical and economical alternative. Unfortunately there are no regulations requiring customers to use water more efficiently or use saving devices.

It is worth mentioning that installation of efficient devices will not be successful with the current low water tariff as there is no incentive for customers to install saving devices to reduce their usage and in turn reduce their water bills. The current tariff will not affect customers in paying their water bills. Even though EWA established and published a handbook for technical guidance it is not effective or enforced.

### *6.3.3 Improving wastewater use and grey water reuse at household level*

From interviews with the Water Conservation Department (Section 5.3.1) it was revealed that currently neither grey water nor wastewater is in use at household level as there is no regulation that enforces the use of wastewater or grey water within households. There is a need to encourage and promote the installation of units to separate, treat and re-use 'grey water' in homes for secondary uses where low quality water is acceptable i.e local onsite dual systems. This is in agreement with Iacovides, (2004) where he argues that the basic objective of the water policy of Cyprus was to make water supply meet the demand. The government policy has effectively encouraged and adopted various water demand measures and efforts were made to utilise the latest technological devices to efficiently protect water resources. A legislation process should follow to enforce the use of grey water and for new systems to be installed for collecting grey water. Bahrain can use grey water for flushing in a similar way to Saudi Arabia's usage as per the studies (Abderrahman, 2001) that indicate that grey water is being used for flushing toilets at the two Holy Mosques at Makka and Al-Medina Al-Monawwarah, Saudi Arabia. Also it was stated that Islam allows the use of such

type of water for purposes other than drinking. Relevant literature (Tate, 1990; Strauss, 1991; Al Alawi and AlKindi, 2005; Vairavamoorthy and Mansoor, 2006; Bukhari and Al-Harazin, 2010) state that the use of recycled or treated water is the most significant of demand management strategies because it reduces the demand on available water resources by supplying reused water for activities which would otherwise use potable water from the distribution system.

A study was carried out at the University of Bahrain for utilising grey water for flushing toilets (AlAyam Newspaper, 2007) and the results of this study are awaited.

From the above findings it can be noted that a WDM strategy at household level is still in need of additional efforts, especially in areas such as using grey water in watering gardens and toilet flushing, WDM is taking a step in the right direction but this work should be further enhanced.

The low tariff discourages household users from using recycled water (grey water/ wastewater). Recycled water usually requires a secondary system to be installed with specific standards and it is more costly than the current blended water which is highly subsidized by the government. Thus customers will prefer using the blended water at low cost since there is no regulation that forces them to change. This is also having a negative impact on the environment as wastewater will increase and as a result, the country will need more waste water treatment plants.

### *6.3.4 Mandatory requirements for water supply*

EWA regulates the use of the potable water by issuing regulations which contribute to conserving and protecting water from waste, contamination and misuse. In 2010 EWA issued comprehensive water regulations which contain rules, procedures and detailed measurements for domestic plumbing systems. A considerable amount of legislation has been developed in order to optimise water use and effluent reuse as a new source of water supply. Through the Water Conservation Department, EWA produced a handbook of technical guidelines for internal plumbing water systems which summarises the most

important points that are involved in the water regulations. Even though the regulations have been made some are not being followed strictly.

## 6.4 How can WDM measures taken at the non-domestic consumers level contribute in providing a sustainable water supply for Bahrain?

From the analysis of Chapter 5 (Section 5.4) some WDM measures are currently in practice or being pilot tested at non-domestic customer level in Bahrain. Nevertheless they are currently experiencing various constraints to fully achieve the ideal WDM measures at non-domestic level. In the following subsection, the specific measures identified from the research related to WDM at non-domestic level are identified; their constraints and deficiencies are addressed.

Most of the household activities which were discussed in Section 6.3 are considered to be applicable at the non-domestic level and have almost similar constraints.

### *6.4.1 Behavioural change in water consumption in response to tariff*

From the industrial questionnaire (Section 5.4.3) results, all industrial owners who responded raised strong objections with regard to increasing the water tariff to cover the full cost of water production and supply. Their main reason was that increasing the tariff would result in an increase in their respective production costs and would discourage industrial development.

According to Arlosoroff (2002), increasing the tariff in the non-domestic sector (agriculture and industrial sub-sectors) was one useful measure of water demand management in Israel. Thus, according to Arlosoroff (2002) Bahrain can consider increasing the non-domestic tariff to encourage WDM.

### *6.4.2 Public education and awareness about water conservation*

From interviews (Section 5.4.1) and questionnaire surveys (Section 5.4.3) it was found that the Water Conservation Department does not give sufficient lectures or presentations to industrial companies, commercial establishments, institutional organisations or hospitals

about how to conserve water or use water saving devices. It was found that public awareness addressed to non-domestic was not sufficient and only done when celebrating the World Water Day 22nd March when lectures to various sectors of public were conducted. This means that water conservation campaigns are not particularly effective in educating non-domestic users in using water efficiently. Thus more attention should be given to public education and targeting all non-domestic customers. This is in line with Atallah et al (2001) who reported that in order for public awareness activities to be effective water authorities should plan continuous, long term awareness activities.

With the current level of public awareness, the non-domestic consumers are not fully aware about the current water situation and the importance of using water more efficiently.
Thus as with household findings, public awareness and education are important in every water conservation plan and are basic tools required to guarantee the participation and involvement of the public in water conservation and the key to getting public support .

### *6.4.3 Use of water saving devices*

From the industrial questionnaire results (Section 5.4.3, Table 5.19) it was found that one third of industries are using some kind of water conservation device. However the majority of the respondents were of the opinion that there should be some kind of new technology for saving water. This indicates that respondents have the knowledge of conservation and wish to use potable water as well as waste/grey water in a phased manner instead of an abrupt switch over. This can only be guaranteed when EWA publishes strong enforceable bylaws.
The use of a variety of water-saving devices at non-domestic premises was studied in Bahrain as indicated in Sections 5.4.2 and 5.4.4. From the observation, the assessment of installation of electronic taps in toilets in commercial buildings in Bahrain was evaluated and resulted in a 42–53% water saving. Based on the results it is recommended that all non-domestic premises are covered with similar devices.

### *6.4.4 Improving wastewater use and grey water reuse at non-domestic level*

From the research background (Chapter 2) it was found that grey water is currently not in use at non-domestic level with only 20% of treated water being used for public park

irrigation and landscaping. From interviews with Water Conservation staff (Section 5.4.1) and selected core studies review (5.4.4), it was found that the reuse of grey water from ablutions at a mosque has resulted in a significant cost saving to the mosque's water bills and this water can be used for irrigating the mosque's garden. It was also found from another study (Section 5.4.4) that using grey water from a health centre swimming pool to irrigate the garden of the health centre resulted in a pay-back period of less than seven months. Reports also show that grey water from air conditioning systems has been collected for non-domestic uses such as for cleaning floors and washing aircraft at Bahrain Airport Services (BAS) premises; and it was found that a reduction in their water bills was achieved (BD. 60,000).

From industrial questionnaires (Section 5.4.3, Table 5.19) it was found that the majority (88.2%) of industries are not willing to use wastewater as it may affect the quality of their products. Also there is no regulation that forces them to use grey water.

### *6.4.5 Mandatory requirements for water supply*

As observed with household consumers in Section 6.3.1, from official documents (Section 5.5.1) it was revealed that in 1999, low capacity flushing cisterns that use dual system (10 litres/ 6 litres per flush) were installed in all new and ongoing commercial buildings, hotels, and other industrial establishments (Qamber, 2009). Unfortunately old buildings cannot be covered due to their old plumbing systems. Regulations are required in order to encourage the efficient use of water for commercial properties and must be enforced with vigour. Penalties should be imposed for deliberate water wastage. This is in agreement with UN-HABITAT, 2006 which recommends the use of low-volume devices for new developments, and regulation for importing materials from outside the country.

## 6.5 How can WDM measures taken at the government policy level contribute in providing a sustainable water supply for Bahrain?

From the analysis of Chapter 5 (Section 5.4) some WDM measures are currently in practice at government policy level in Bahrain while others are pilot tested. Nevertheless they are currently experiencing various constraints to fully achieve the ideal WDM measures at government policy level. In the following subsection, the specific measures identified from

the research related to WDM at government policy level are identified; their constraints and deficiencies are addressed.

- Tariff reforms to promote water demand management
- Development and implementation of water bylaws that can reinforce WDM measures and produce more efficient water demand management system.

### *6.5.1 Tariff reforms to promote water demand management*

The analysis results indicate that there is no dedicated policy related to calculation of water tariffs by the Electricity and Water Authority (EWA). There is also a clear subsidy policy in place. Tariff is highly subsidized by the government. It was last modified 2 decades ago when the tariff was reduced and extra tiers were introduced. Unfortunately tariff reform is a political issue and it needs government approval. It takes a lengthy procedure to get approved. It involves different government parties until it becomes approved by the King. It may take more than two years to get approved.

The literature indicates that a reduction in tariff without proper analysis will defeat the water conservation efforts. Low water tariffs encourage wasteful practices.
One of the constraints to implementation of water demand management in Bahrain is the extremely low water tariff. The vast majority of domestic and non-domestic-users enjoy highly subsidised water. Low priced water, purchased below its market values, is likely to be wasted. As a result of the low tariff EWA does not obtain sufficient revenue to cover the cost of providing water services to their customers.

This low charge for water implies a lack of incentives to encourage efficient water use in the face of escalating water scarcity. The vast socio-political policy in favour of low prices has no economic viability and, as studies (Abu Qdais and Al Nassay, 2001) have shown, an increase in the price of water will have a positive impact on productivity and lead to more efficient and economic use of water.

In general, proper water tariffs would directly have a major impact on the implementation of WDM measures in Bahrain. Studies state that poor consumers can only afford to use a small amount of water (the basic level), and any increase in tariffs will not have much effect because they cannot do with less water. For large and affluent consumers (the ones that irrigate their gardens and own cars that need to be washed) the ability to pay is such that the need to save money on water is limited. A low water tariff has a negative impact on the implementation of the following WDM measures: water loss management; installation of efficient devices; recycling; water metering; public acceptance and Non Revenue Water.

Current government policies of heavily subsidising the water sector will create problems in the future. Heavy reliance on subsidies will not only worsen the rapidly rising water demand, but will also place an intolerable burden on national budgets. A substantial amount of water will have to be supplied by costly desalination plants. Therefore reform in demand management of municipal water through the introduction of increased tariff rates is essential for water conservation and for achieving financial sustainability in water resources. Politics has a significant influence on how tariffs are designed, developed and implemented. The political influence can be intense in a country like Bahrain, which does not have freshwater reservoirs. Therefore, all key stakeholders, such as the policy makers and customer representatives, need to be involved in the process of water tariff reform. There will be need for creating awareness for moving towards a water-conserving tariff, in a stepwise manner, which also takes the interests of high-, middle- and low-income customers. The gradual tariff reform could be phased over a period of about three to five years, so as to maximise acceptance and willingness to pay from all categories of customers. There is need for positive engagement with policy makers, starting with the Shura Council, who would enact a law that would pave way for water tariff reforms.

One of the commonly used tariff structures that can optimise the objectives of water conservation and social equity is the Increasing Block Tariffs (IBTs) (Kayaga 2011a). For a BRT to work effectively, all the customers' premises should be fitted with meters, so that their consumptions are accurately recorded. IBTs provide two or more prices for water used, with consumers falling in low-consumption brackets paying at lower prices. IBTs assume that low-income households will use less water per period of time (e.g. per month), and

therefore pay at a lower price, than high-income households and commercial/industrial entities. Some scholars (e.g. Boland and Wittington, 2003) have pointed to limitations of IBTs in developing countries, where many low-income households are not connected onto the water supply network, and therefore end up collecting water from group connections. As a result, these group connections end up falling in the high consumption bracket. In Bahrain, this anomaly does not apply, as all households are connected on the water supply network, and are charges based on a volumetric basis. Although the current tariff structure is in the form of IBT, it is nowhere near water conserving. There is a strong need to carry out out econometric studies (e.g. to determine the price of elasticity of demand, and willingness to pay studies) so as to come up with an effective water-conserving increasing block tariff, which is also socially equitable.

### *6.5.2 Development and implementation of water bylaws that can reinforce WDM measures and produce more efficient water demand management system*

Water scarcity problems have been addressed in Bahrain for a long time. From the research area background chapter (Section 2.11) for the last few decades, Bahrain has focused its strategies solely on increasing water supplies through costly sea-water desalination for municipal and industrial water use but not by reducing demand (supply-side management not demand-side management). From the case study background (Chapter 2) it was found that Bahrain does not have a clear policy on water use and management. The overall management of water resources is on an ad-hoc basis through several uncoordinated pieces of legislation spread amongst several ministries and other non government institutions. It was also revealed that the majority of policies and legislation address the problem of water supply and distribution and do not make any attempt to address issues of WDM.

Bahrain developed its first water law in 1993, providing a basis for issuing licences for the drilling of groundwater wells. Many laws have been developed since that time. Unfortunately most of these laws faced major difficulties during implementation due to a lack of institutional capacity and insufficient awareness. Thus provincial or national legislation is required to back-up the local legislation and must be promoted at a national level in support with UN-HABITAT, (2006). Therefore, a major shift is needed in order to

put more emphasis on WDM to catch up with the ever-increasing water demand and provide water in a more efficient and sustainable manner. Water legislation is still governed by Sharia (Islamic law) principles and traditional practices, which say that water should be provided to all people. Therefore, Bylaws must be strongly enforced by introducing regulation that is comprehensive, modern and relevant to the present day requirements. There is need for legislation reform and influence of the Bahrain government on wealthy and influential customers in paying their water bills and engaging them in taking decision regarding water issues such as water tariff reform, using water saving devices and impose adoption of water conservation regulations. This is in line with Kayaga (2011a) that there is a need to update the legislation to include corporate demand management tools. There needs to be a conducive legal and institutional framework for these tools to function effectively.
Faruqui, (2001), states that the Quran makes two clear statements regarding water that support water demand management. First, the supply of water is fixed, and second, it should not be wasted

On the level of EWA, Qamber (2009; 2001) stated that the EWA's mission is to reduce wastage beyond the customer meter by introducing water bylaws, because there is no control over all the types of appliances and their standard of workmanship.
It was found that The "Bahrain 2030 Vision" prepared by the Bahrain Economic Development Board is addressing water issues, as the government has started giving attention to water scarcity and its limited resources. Unfortunately there is no reference to water regulation or water bylaws that focus on water demand management.

## 6.6 Summary of key activities and responsibilities for improving Water Demand Management in Bahrain

To overcome the constraints that prevent the implementation of WDM measures in Bahrain and improve Water Demand Management in Bahrain, the researcher prepared an activity/ responsibility matrix.

Figure 6.1 presents a matrix of the allocation of key roles and responsibilities. The matrix shows that the main Governmental bodies are responsible for evaluating and making recommendation about tariff reform to assist in reaching a decision on tariff setting revision

for achieving full cost recovery. Approving the laws lies with the Parliament Council (Lower House) and Shura Council (Upper House) while EWA is only involved in drafting water laws. The Ministry of Justice is involved in cases related to penalties raised by EWA against customers who are then transferred to the courts.

The Human Resource and Finance Directorate at the EWA utility allocates budgets for all departments based on their requirements and is also responsible for human resource management. Unfortunately all departments suffers from budget shortages and this results in staff not receiving adequate training that would have enabled them to do their task well, thus their productivity is less and morale is low. There is a need to train & educate the EWA staff in WDM, and education should emphasise the significance of WDM for sustainable management of water resources and must also promote a change in people's cultural attitudes towards water resources. This has to be done in order for them to educate the public directly by creating awareness and improving people's understanding of WDM; and is the first step towards implementation of WDM. All stakeholders should be made to see themselves as working towards the same goal and be ready to share information. It is the responsibility of the Human Resource and Finance Directorate at the EWA to identify staff and all technical and management skills required for training staff at the different levels of the utility, and ensure that their capacities are developed in a more integrated manner. This requires the involvement of the Ministry of Education in conducting courses for EWA staff at local universities or arranging for staff to study at overseas universities for degrees in the field of water resources.

| key activities | Key organization | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Government | | | | | | | | | Electricity and Water Authority | | | | | | |
| | Parliament Council (Lower House) | Shura Council (Upper House) | Ministry of Finance | Minister in charge of EWA | Cabinet of Ministers | Prime Minister | Ministry of Works | Ministry of Education | Ministry of Justice | Human Resources and Finance Department | Metering unit | Waste Control unit | Water Conservation Department | Customer services Department | Mass Media (Radio, TV, Public Clubs) | End-user (domestic and non-domestic) |
| Water tariff reform towards full cost recovery | I | I | I | I | I | R | A | I | I | I | A | A | A | I | I | I |
| Legislation to enforce bylaws | I | I | I | I | I | R | | | I | I | I | I | I | I | I | A |
| Institutional strengthening agency to clarify responsibility | | | | I | | R | I | I | I | I | I | I | I | I | A | |
| Increasing budget allocated to each department/ unit in EWA | | | R | I | | | | | | I | I | I | I | I | | |
| Capacity building increasing staff numbers | | | | I | | | | | | R | I | I | I | I | | |
| Capacity building Human Resources Development towards WDM | | | | I | | | | | | R | I | I | I | I | | |
| NRW reduction | | | | I | | | | I | | I | I | R | I | I | I | A |
| Public education and awareness in WDM | I | I | I | I | | | | I | | I | | | R | | A | I |
| Installation of water saving devices | I | I | I | I | I | | | | | I | | | R | A | I | A |
| Implementing wastewater use/ grey water reuse | I | I | I | I | I | | I | I | | I | | | R | | A | I |
| | | | | | | | | | | | | | | | | |
| Legend | R | Responsible | | I | Involved | | | A | Aware | | | | | | | |

**Figure 6.1:** Activity/responsibility matrix for overcoming constraints in implementing WDM in Bahrain

The level of NRW is currently high and it is the responsibility of the Waste Control Unit at the EWA to reduce the real losses as component of NRW, while the Metering unit, Customer Services Department and Water Conservation Departments are involved in assisting to reduce apparent losses. These departments are supported by the Human Resources and Finance Directorate in allocating budgets to each department to carry out its tasks to help reduce overall NRW. Involvement of the Ministry of Education and mass media is also essential to educate the end-user and raise their awareness of policies for reducing the level of NRW.

Institutional strengthening, to clarify responsibility among ministries and the water utility involved in water resources management, is the responsibility of the Government. The Government has responsibility for approving all the proposed legislation for all ministries authorities involved in water resource management. For legislation, all ministries, organizations and departments are involved in recommendations to establish new legislation to integrate the work of each organization responsible for water resources and to implement the legislations. Legislation is required to support the process of WDM and to encourage water use efficiency in the Kingdom of Bahrain. The legislative measures should be reviewed continuously to keep abreast of latest developments in the area of water conservation. All these policies should be introduced in a legislative form at national and sectoral levels, defining the responsibilities of each organisation in order to avoid or address any weaknesses and constraints in implementing the policies or action plans. End-users and customers should be involved in framing new laws to facilitate their acceptance, approval, and implementation.

Installation of water saving devices is the responsibility of the Water Conservation Department at EWA, while the government is involved in issuing regulations to require the use of such water saving devices. The media should also be involved in publicising the water saving devices and water conservation measures through radio, TV and, newspapers. The Customer Services Department should be aware of these installations when customers submit applications for water services in order to make sure that the applicant (end-user) is aware of conservation measures and feels responsible for water conservation.

Implementation of wastewater/ grey water reuse is the responsibility of the Water Conservation Department. The government should also have involvement as a regulator to issue regulations enforcing the use of wastewater and ensuring its quality. The Ministry of Works is involved in treating wastewater to the prescribed standards. In addition, end-users should be educated and involved in accepting the use of these types of water for gardening and/or toilet flushing. Treated wastewater or grey water should also be used for industrial operations and processes whenever possible.

Regulation should enforce the use of saving device, use of grey water and waste-water wherever possible, and research into utilisation of treated wastewater or grey water should be carried out. Projects similar to the one at Bahrain Airport Services (BAS) could be implemented in hotels, commercial buildings, and shopping malls, while ablution water from mosques can also be used to water gardens. Similar use of washing water could also be implemented at shopping malls and clubs. As at health centre pools, projects can be generated by schools, clubs and villas that have swimming pools to use the grey water for floor washing. The Media plays an important role in producing programmes & broadcasting the importance of using the wastewater and grey water, and their involvement is therefore important.

EWA has the responsibility for raising the awareness of WDM and changing the attitudes of household and non-domestic water users. This requires the involvement of the Ministry of Education in updating topics about water shortages and water conservation at school level within subjects such as religion, Arabic, science, and geography. This would be in addition to cooperation between the EWA and the existing research institutes in the country (Bahrain Centre for Studies and Research, University of Bahrain, and the regional Arabian Gulf University) in running short courses and seminars for EWA staff in the field of WDM.

## 6.7 Conclusions

This chapter has discussed the key findings of the analysis carried out in the previous chapter. These findings were discussed within the context of the research questions and are related to the literature reviewed in Chapter 3. The discussion covered WDM at utility level,

end-user level, and government policy making level. The chapter ended by summarising the key activities and responsibilities for improving the water demand management in Bahrain. The researcher proposes six areas to be investigated in greater detail to achieve more efficient use of water:

(a) Obtaining government and political support to implement WDM;

(b) Water tariff reform to recover full water production and supply costs;

(c) Institutional reform through activating and enforcing Water Resources Council roles;

(d) Prompting public awareness about WDM and its benefits;

(e) Reducing non revenue water;

(f) Applying a positive economic sliding scale of incentives for customers who succeed in reducing their water consumption;

(g) Enhancing public participation at all water planning and management stages.

# Chapter 7: Validation of the Research Findings and Conclusions

## 7.1 Introduction

The validation of the WDM measures focused on evaluation of the findings and conclusions of the research. Furthermore, it was important to evaluate how the research findings had met the aim and questions of the research. The objective of the validation process was to verify, validate and evaluate WDM measures at utility level, household level, non-domestic level and government policy level; to obtain feedback for improvement of the findings, to highlight any disagreements with the findings and finally to formulate suggestions that would provide future directions for research, as suggested by Yin, (2003, 2009) and Bryman and Bell (2003).

This chapter presents the results of the evaluation of the findings and conclusions of the research which was carried out in July 2010, using the validity measurements used in the literature. Other processes of validation of the research and the chain of thought during the conduct of the research, data collection and analysis until arrival to the conclusions were discussed in Chapter 4, Section 4.5. It was also an opportunity to provide feedback on the findings to key stakeholders.

Yin (2009; 2003) states that the third tactic to be used for constructing validity is to have the case study report reviewed by key informants. He encourages the participants and informants to review the draft case report and comment on it. Bryman and Bell (2003) agree with Yin and add that respondent validation is the process by which the researcher provides the participants in the research with an account of the findings. The aim of this process is to check agreement or disagreement with the account of the research and should be improved in the light of the subjects' reactions (Silverman, 2005). This has become popular in qualitative research as a measure of the fit between the research findings and the perspective and experience of the participants. In this research it was decided to use 'non-participants' to evaluate the findings because they are more objective in their assessment of the findings. Silverman, (2005) questions whether participants in a study can really 'validate' the findings

and suggests that other 'non-participants' should be provided with the opportunity to 'refute' the findings?

## 7.2 Feedback Required for Validation

Due to resource constraints it was found that open discussion via a telephone conversation followed by an email summary of findings highlighting the main focus of concern was an appropriate method for evaluating the research findings. From the previous section it was decided to use 'non-participants' in the research study to evaluate the findings. The participants in the evaluation included one key informant and others who were provided through acquaintances.

They all had similar experience in water management in Bahrain. A total of 25 evaluators with experience in the water situation in Bahrain were invited to participate in the evaluation process, and a high response rate of 21 responses was received. There were 9 from EWA utility and 12 from the professional sector with experience in water resources and the current situation. A list of descriptive questions seeking agreement/ disagreement and reasons behind selected answers was required. Subjects such as reduction of NRW, government and political support to efficiently implement WDM, initiation of policies, legislation and institutional measures all required more detailed comments. The main questions asked in the validation of findings were as follows

1. Water tariff is a major measure in implementing Water Demand Management (WDM). Currently the water tariff in Bahrain is highly subsidized by the government. Do you agree that water tariff has to be reformed to cover the full cost of water supply? Please justify.

2. Does public awareness about WDM and public participation at all planning and managing stages need promoting? Please justify.

3. Do you agree with institutional reform through activating Water Council role and water bylaws? Please justify.

4. The current Non Revenue Water (NRW) level in Bahrain is considered high. In your opinion what is the recommended approach to reduce that to a reasonable level?

5. Do you agree on customer incentives for reducing their water consumption during the summer period? Please justify.

6. Do you agree with using treated wastewater/ grey water at the non-domestic level? Please justify where and why?

7. Do you agree with using treated wastewater/ grey water at the domestic level for purposes other than drinking? Please justify where and why?

8. In the view of the researcher it is essential to obtain both government and political support to implement the WDM strategies efficiently in Bahrain? Please comment.

9. There is a shortage in policies, legislation and institutional measures related to WDM in Bahrain. What is your opinion on such the importance of such initiates?

Feedback was gathered on the extent to which respondents agreed with the conclusions and findings regarding the following topics:

- Obtaining government and political support to persuade and change opinion to implement WDM
- Water tariff reform to cover full cost of water supply
- Policy, legislative and institutional measures
- Non Revenue Water (NRW) reduction
- Raising public awareness about WDM
- Implementation Incentives
- Wastewater/ grey water reuse

The results are shown in Table 7.1 below. The feedback received from evaluators was encouraging as most of them agreed with the researcher's findings.

**Table 7.1:** Evaluators' feedback regarding research findings and conclusions

| Research findings | Agree with research findings | | Total | Disagree with research findings | | Total |
|---|---|---|---|---|---|---|
| | EWA | Expert | | EWA | Expert | |
| Obtaining both government and political support to implement WDM efficiently in Bahrain | 9 | 12 | 21 | 0 | 0 | 0 |
| Tariff reform as major WDM measure to cover full cost of water supply | 7 | 9 | 16 | 2 | 3 | 5 |
| Raising Public awareness about WDM and involvement of public in all planning and managing stages | 9 | 12 | 21 | 0 | 0 | 0 |
| Policy & Institutional reform through activating water Council role and water bylaws | 8 | 12 | 20 | 1 | 0 | 1 |
| Approach to reduce NRW level in Bahrain | 9 | 12 | 21 | | 0 | 0 |
| Economic incentive for reducing water consumption in Summer | 7 | 12 | 19 | 2 | 0 | 2 |
| Using waste water/grey reuse at household and non-domestic levels | 6 | 11 | 17 | 3 | 1 | 4 |

Note: the questionnaire was directed to two categories of expert: EWA and experts from other organization (i.e. water specialist, university lecturer and consultants).

### *7.2.1 Government support and water bylaws*

All of the evaluators were in agreement with the researcher that government and political support is essential in order to successfully implement the WDM strategies in Bahrain. There is nothing stronger and more effective than the support of the government and politicians. It needs integration between social and political plus human resources interventions in order for customer acceptance with any changes or suggested procedures. This support will reduce efforts and will make for a faster accomplishment of objectives. Governmental and political support could be in many forms such as political speeches, information discussion, setting an example and issuing laws.

One evaluator stated that as long as EWA stays as a government body it is essential to have support from the government. If it is converted as an autonomous body it will also require support from the government to execute its strategy effectively. Public awareness and water literacy should be instilled into the minds of the people and their mindset be changed to a water saving mentality.

### 7.2.2 Water tariff reform to cover the full cost of water supply

Most of the evaluators (16) agreed with the researcher's findings and conclusions that reform has a beneficial effect on reducing water consumption. They also suggested that reform should be done in stages, and that some 'relief' would have to be given to poorer families to assist them as water projects should also be economically feasible. However, the public attitude that water is a free commodity needs to be challenged and gradually addressed by suitable education. Reform evaluation should target all sectors (domestic, industrial and commercial) and respondents also stated that tariff reform should stop wastage of water. Additionally, customers will look after their house maintenance work in case of water leakages from WC or swimming pool, etc. The cost of production, transmission and distribution should be borne by the user. This will make the user concerned about use and utilities accountable for the money spent and the whole system will be forced to be effective.

One of the evaluators said that costs should be recovered in full from rich people. Another evaluator stated that he agrees that tariff reform is needed, not to recover the full cost, but maybe just the operational and maintenance costs initially.

Those who disagreed with tariff reform stated that customers earning wage in the range of BD 300 or less cannot bear the expenses. Others stated that tariff reform may be applicable for industrial and commercial consumers.

### 7.2.3 Raising public awareness about WDM and their participation at all planning and management stages

All evaluators agreed with the researcher's findings and conclusions. One of them suggested that more promotion should be carried out at all levels and in all sectors to enable the beneficiaries to have some idea of the cost and technical difficulties. People need to be more involved in order to appreciate the value of water and the only way to do that is to promote public awareness. It will encourage a change in mindset towards saving water. One evaluator said "*In fact, I cannot find a form of public participation in Bahrain. Also, Public awareness should emphasize action, not only knowing*".

### 7.2.4 Institutional reform through activating the Water Council's role and water bylaws

All of the evaluators agreed with activating the Water Council's role and water bylaws as regulator, especially for strategic planning and decisions due to the lack of effective norms and authority/power of water utility staff which makes the situation embarrassing. They also added that institutional reform will enable the adoption of a rational policy to all similar types of customers, and customers will have to follow the rules. One of the EWA staff said that activating water bylaws (regulations) will reduce water loss due to bad workmanship/ illegal connections, though results will take a longer time to appear. Another EWA staff member stated that existing laws are not effective to implement WDM as they supply-oriented, concentrate mainly on water supply. He also stated that clear rules and policies are required to be implemented and customer awareness is necessary. In fact, there are policies, and to some extent legislation, but the main issue is enforcement and effective implementation of the policies and legislation. Rationalized policy should be formulated on water production, transmission and distribution. It should be promulgated and enforced.

Thus there is a need to develop these in a special project that hires consultants with considerable experience. Water experts (from outside EWA) stated that institutional reform is feasible economically and would save loss of water. One evaluator from EWA was opposed to institutional reform as, according to him; reform takes time to reach to its goals.

### 7.2.5 Recommended approach for Reducing NRW level in Bahrain

EWA staff commented that it is EWA's mission to reduce the NRW level. As one of the EWA staff stated, saving water means saving costs as well as more supply being provided for customers rather than going for extra production. One expert stated that the level of NRW is unacceptable and any investment to alleviate NRW is worthwhile and will pay back its cost very quickly. Another expert added that to reduce NRW it was worth searching for new technologies and techniques.

All evaluators suggested that work should be in all directions (i.e. technical and social), starting from the most cost effective measures. Apparent losses should be minimized

through various actions. One of the evaluators stated that: "*In my opinion the priority should be: Very Important Customers (VIC), under registration, then Leakage reduction*".

The evaluators were also invited to provide comments and suggestions. Below is a list of the suggested activities to reduce level of NRW as suggested by the water expert evaluators:

- Activate the meter replacement programme.
- Control the water consumption specially the premises being supplied with water through large sized connections.
- Minimise the estimated readings.
- Enable the concerned staff to read the meters either through handheld or through Global System for mobile Communication (GSM), or by outsourcing reader, through Automatic Meter Reading (AMR) system.
- Replace all the stopped meters as soon as WDD receives the defect notices.
- Adequate stock of available meters
- Check all the illegal connections
- Implement the law against crimes
- Increase EWA site staff team and support them with the latest equipment to detect the leakages.

### *7.2.6 Wastewater use and grey water reuse at household / non-domestic level*

Most of the evaluators agreed about using wastewater and grey water at the non-domestic level and that should only be used by industry. One expert stated that the culture in which we live is uneasy about the use of grey water, and he is unsure how successful any attempt to introduce grey water would be. Another expert was in favour of using grey water as, according to him, it sounded economical and he hoped it would be politically acceptable. One of the EWA staff added that grey water reuse should be used and restricted to limited purposes according to the environment and laws as it will reduce some water usage from the water distribution network.

One evaluator from EWA said "*grey water should be used in factories where water can be used for cleaning or cooling or may be mixed with other material such as in paint manufacturing, use*". All evaluators agreed on using wastewater/ grey water at the domestic level for uses other than drinking and cooking provided that it does not cause any harm to the health of people, and that it should be used mainly for flushing toilets and watering gardens. One evaluator from EWA said "*A time will come when people are forced to use grey water. Let us adapt to the situation early*".

### *7.2.7 Implication of economic incentive*

The majority of evaluators were in favour of applying incentives for reducing customer water consumption during the summer period and the need for it to be promoted to help reduce consumption. This will get additional benefits on saving, and customers will always favour incentives and have control over the way they are using water. One expert stated that higher management within EWA tried hard to convince the public and many proposals have been submitted for implementation. One evaluator from EWA agreed on customer incentives only if the rate paid for water is the full cost of supply. Two from EWA staff were against the applying of incentives and their reason was that customers usually travel during the summer so the reduction in use is not necessarily due to conservation methods. Additionally, they added that water saving is everyone's responsibility. So there should not be a need for incentives for something under one's responsibility.

## 7.3 Conclusions

The responses of the evaluators validating the research findings largely confirmed the research conclusions on WDM in Bahrain; this also suggested that such findings could be applied to other countries.

The evaluators added comments on reduction of NRW methods and benefits of tariff reform. The following chapter presents how the research has achieved its aim and objectives and provides the conclusions, limitations, contributions and recommendations for future work.

# Chapter 8: Conclusions and Implications

## 8.1 Introduction

Chapter 6 discussed the key findings of the implementation of WDM measures in Bahrain. Chapter 7 validated research findings and conclusions of the thesis.

This Chapter concludes the thesis by highlighting the most important findings that have arisen from the case study in relation to the overall research process and outcome. It links the contribution of the thesis to existing knowledge, and suggests areas for further research. This chapter shows that the research questions were answered and the aim of the research was achieved.

## 8.2 Conclusions about aim and research questions

The aim and research questions of this research were presented in Chapter 1 of this thesis.
To recap the aim of this research was to: "**evaluate the effect of Water Demand Management (WDM) measures in achieving a sustainable water supply for Bahrain".** In order to answer the research questions (which are listed later in this section), the following issues were investigated:

1. Current practices of water resources management in Bahrain.
2. Reviewing international experience in the field of WDM, in order to identify what WDM measures can be applied in Bahrain.
3. Identification of WDM activities and associated problems in Bahrain.
4. Evaluation of the public awareness at household and industrial levels with regard to usage of water saving devices, need for water tariff reform to recover supply cost, and water conservation, through surveys.
5. Investigating the willingness of corporations to use recycled water in industry.

It is believed that the work and analysis of this thesis were sufficient to achieve the aim and questions of this research. This chapter will examine the implications towards WDM in Bahrain.

The research was guided by the research question "How can WDM measures contribute in achieving a sustainable water supply for Bahrain? The main purpose of this research was to find how WDM measures can be effectively used to improve the management of water demand in arid regions and especially in the case of Bahrain. In order to achieve the research objectives, the following questions were developed:

**Research Question 1:** How can WDM measures taken at the utility level contribute in providing a sustainable water supply for Bahrain?

**Research Question 2:** How can WDM measures taken at the household level contribute in providing a sustainable water supply for Bahrain?

**Research Question 3:** How can WDM measures taken at the non-domestic consumers level contribute in providing a sustainable water supply for Bahrain?

**Research Question 4:** How can WDM measures at government policy level contribute in providing a sustainable water supply for Bahrain?

A case study research methodology was used to answer the research questions. Data were collected through a review of documents, and fieldwork comprising semi-structured interviews, observation, questionnaire survey and pilot tests. Triangulation was used at two levels; data were collected using different methods and from different sources. In addition methodological triangulation was used in data analysis by applying both quantitative and qualitative approach methods.

Bahrain has already initiated some of the steps needed for better management of its available water resources, with emphasis on conservation, and is considering implementing other steps in the near future. It is hoped that positive outcomes from these steps will soon be realised. For example in 2010 EWA issued comprehensive water regulations on rules, procedures and detailed measurements for domestic plumbing systems, the Water Conservation Summer campaign, and Bahrain Vision 2030 strategies. This research has identified issues that need to be further addressed in order to provide sustainable water services. The main conclusions drawn from the research are briefly described under each research question in the proceeding paragraphs.

***Research Question 1: How can WDM measures taken at the utility level contribute in providing a sustainable water supply for Bahrain?***

a. Shortage of budget allocated to departments within the water utility

It was found that because of low water tariff, all departments within the EWA suffered from an insufficient budget; inadequate numbers and under-skilled levels of staff; inadequate resources for active leakage management; underfunding for research and development. All of these factors affected their productivity. Human Resources and Finance Department at EWA utility allocates budgets for all departments based on their requirements and is also responsible for human resource management.

The Metering unit suffered from shortage of equipment which prevented replacing aged meters, and increased the estimated meter readings. This resulted in customer dissatisfaction and revenue loss. It is the responsibility of the Human Resources and Finance Department at EWA to allocate the budget for providing material to replace stopped and aged meters in order to reduce level of apparent losses through meter errors.

Difficulties in accessing meters in some areas, as well as a shortage of meter readers and limited overtime hours compared to the expansion of the distribution network all has an impact on the actual consumption reports, as meters are not read. Human Resources and Finance Department at EWA has to allocate budget to the Customer Services Department in order to increase overtime hours to take more meter readings and to outsource meter reading. In case of inaccessible areas it is recommended to go for Automatic Meter Reading (AMR). This will reduce apparent losses.

The Leak Detection unit suffered to the extent that the leak detection operation had to be abandoned due to shortage of equipment and stopped meters which made the interval between leak detection exercises long, and increased the number of un-reported and undetected leaks. Increasing the budget allocated to the Waste Control unit and replacing defective or stopped meters as well as providing equipment

required will allow the leak detection exercise to be completed within a shorter time and reduce the number of undetected leaks in the system.

In 2010 EWA issued comprehensive water regulations on rules, procedures and detailed measurements for domestic plumbing systems. Even though the regulations have been set, some are not being followed strictly.

b. High level of NRW in the water distribution network

The above obstacles described in sub-section (a) above have resulted in an increased number of un-reported leaks and high percentage of estimated meter readings leading to a high NRW figure which is currently 38%. The estimated figures for real and apparent losses used in EWA have been used for many years by engineers who assumed them to be correct. These figures should be reviewed periodically to ensure that the current values are used. It is the responsibility of the Waste Control Unit at EWA to reduce the real losses as a component of NRW, while the Water Conservation Department is responsible for conducting public awareness by encouraging customers to coordinate with EWA staff to reduce leakage (before and after meter); explaining to them the benefit of reducing leakage.

c. Lack of public awareness and understanding of the WDM benefits among professionals and water supply providers

It was found that most of EWA staff and professionals are not aware about WDM and its benefits, which prevents them from passing on information and educating the public about WDM and ways to conserve water. Therefore EWA needs to conduct in-house training about WDM to its professionals and other water supply providers or coordinate with other universities to conduct short training course in WDM. EWA should identify staff technical and management skills as well as capacities required development in an integrated manner.

There is need for EWA to strengthen its effort to increase public awareness about WDM and conservation since public awareness and education are important for getting public support for utility water conservation implementation as well as to guarantee the participation and involvement of public in water issues. Due to

inadequate campaigns for passing information and encouraging the public in using water in an efficient way, results achieved are not very encouraging.

***Research Question 2: How can WDM measures taken at the household level contribute in providing a sustainable water supply for Bahrain?***

***Research Question 3: How can WDM measures taken at the non-domestic consumers level contribute in providing a sustainable water supply for Bahrain?***

Even though the subsidised water tariff has been identified as a main obstacle in implementing WDM, the researcher found the following factors that contribute to uneconomic use of water:

a. Water Saving devices at both household and non-domestic levels

   There is limited use of the water saving devices which are mostly distributed to the public free of charge (to be installed at their premises), such as aerators, toilet bags, garden timers and drip irrigation items, either during public campaigns or school visits. Installation of efficient devices will not be successful with the current low water tariff as it does not encourage customers to install such saving devices or efficient appliances to reduce their water bills. The current tariff will not affect customers in paying their water bills as they are paying a very low portion from their income so it does not encourage them to reduce their water usage. It is the responsibility of the Water Conservation Department at EWA to promote the installation of water saving devices. EWA should implement policies that encourage customers to install water saving devices indoors/outdoors, in existing premises, and update new connection codes which enforce the installation of water saving devices in newly constructed premises.

b. Limited use of wastewater, grey water reuse, at both household and non-domestic levels

   Currently neither grey water nor wastewater is in use at household level or non-domestic level as there is no regulation that enforces the use of wastewater or grey

water within households. The low tariff discourages household users from using recycled water (grey water/ wastewater). Thus customers will prefer using the blended water at low cost since there is no regulation that forces them to change.

c. Lack of public awareness and understanding of the WDM benefits among all levels of society

This unresponsive public view is generally created by the fact that most water users in the country are not aware of the importance and benefits of WDM. The level of public awareness of WDM and its benefit is low in Bahrain. The researcher believes that there is an important window which is not being used efficiently due to budget allocation. The current public awareness campaign implemented by the Water Conservation Department is being practised but is not adequate for water demand management, as these campaigns are not continuous and less effective for that reason.

***Research Question 4: How can WDM measures at government policy level contribute in providing a sustainable water supply for Bahrain?***

a. Low water tariff and high subsidy by the government

The current water tariff is 80% subsidised by the government which implies a lack of incentives to encourage efficient water use in the face of escalating water scarcity in Bahrain. Bahrain needs to have the pricing policies for water usage to reflect at least the cost of operating and maintenance of the desalination plants. Thus the effectiveness of the increasing block tariff depends on the level at which it is set. The increase of water tariff will hopefully lead the households to believe that it is necessary to save water and it will improve the awareness of saving water, and prompt the customers to conserve water. It is mainly the central government's responsibility to evaluate and make recommendation about tariff reform that will lead to revising the tariff for achieving full cost recovery. Politics has a significant influence on how tariffs are designed, developed and implemented. There is a strong need to carry out econometric studies so as to come up with effective water-conserving increasing block tariff, which is socially equitable.

b. No strategy for integrated water resources development to clarify responsibility

Due to lack of coordination between different ministries and EWA in managing water resources, the existing regulations do not support WDM. Most of the policies are supply-oriented. There are requirements to improve coordination and organisation between EWA departments and other ministries and institutions. There is need for political and social support to implement strategies. Currently WRC is the only institution that includes members from all institutes involved in water resources. It is the responsibility of the government for approving all the proposed legislation for all ministries and authorities involved in water resource management. For legislation, all organizations are involved in recommendations to establish new legislation to integrate the work of each organization responsible for water resources and to implement the legislation. The legislation should be introduced at national and sectoral level, defining the responsibilities of each organization. End-users and customers should be involved in framing new laws to facilitate their acceptance, approval and implementation.

There is a need for regulation to enforce the use of wastewater or grey water in home or non-domestic premises to irrigate green surfaces. Legislation should be followed to enforce the use of grey water. There is a need for water laws that encourage customers to use grey water for irrigating gardens. This should go hand-in-hand with public education and raising public awareness. It is the responsibility of the Water Conservation department to give advice and technical support to customers to select appropriate systems and locations to reuse grey water. Amendments should be made to the new installation code to encourage the use of, and provide grey water collection and treatment system for new connections. The government should also be involved as a regulator to provide incentives for the use of wastewater and ensuring its quality. The Ministry of Works is involved in testing wastewater to the prescribed standards.

Public awareness could also be raised through the involvement of the Ministry of Education in updating topics about water shortages and water conservation at school level within subjects such as religion, Arabic, science, and geography. As well as

Ministry of Justice, Islamic Affair where training are given to Imams in order for them to give speech at Friday prayer at mosques.

## 8.3 Implication for theory and knowledge

This research contributes new knowledge on WDM measures in theory and knowledge in the following aspects.

a. The Literature Review revealed that few published research studies about Bahrain concerned WDM, and none addressed blended water supply. No studies reviewed integrated WDM measures at utility, end-user and government policy levels in GCC countries. This research thesis provides data on customers related to the urban water utility in Bahrain. The findings add to the existing knowledge by extending generalisations from the Kingdom of Bahrain and to other GCC countries.

b. The analytical framework (with actors at different levels) used in this research may provide a good tool for practitioners and researchers in future analysis of WDM strategies. This framework is four (4) fold: WDM measures at utility level, WDM measures at household level, WDM measures at non domestic level and WDM measures at government policy level.

c. This is one of the few studies that have empirically examined the use of Low Flow Control (LFC) devices in assessing meter under-registration at low flow rates in GCC.

## 8.4 Implication for policy and practice

The following are the key contributions to the research in the field of policy and practice for informing and directing the government's strategy to implement WDM measures:

a. It is important for scarcity countries with limited water resources, high per capita consumption, and highly subsidised water supply to reform their water tariff to recover operation and maintenance cost. For the tariff to work effectively as an economic measure for WDM, it should be designed so that it is water conserving. Although

approval of the water tariff in Bahrain largely lies with the government, EWA should be more proactive and make positive engagements with policy makers, to work towards the tariff reform.

b. Due to the low domestic water tariff in Bahrain it is recommended that the existing increasing block tariff is redesigned to make it more water-conserving. In order to reduce the heavy government subsidies, the increase in price levels should be done in an incremental manner, with the full involvement of politicians and policy makers, so as to avoid social backlash. The gradual increase in tariff could be carried out every 2-3 years. The Domestic water tariff should be restructured to reflect the strategic importance and scarcity value of water, while at the same time striving to achieve social equity across various sections of society.

c. It is essential to establish a WDM committee within the Water Resources Council (WRC), as an important tool for integrating various aspects of water resources management, inclusive of WDM.

d. The research shows the importance of application of the use of Infrastructure Leakage Index (ILI) performance indicators in prioritising zones for leakage detection exercises to control leakage in the distribution network. ILI values could be used by operators as a tool for more accurately prioritising leak detection exercises in waste zones.

e. Grey water should be promoted for other household uses which do not require water of a high bacteriological quality. This study demonstrated the use of grey water from mosques and health centre pools as additional sources of water to irrigate surrounding areas and to save potable water for other uses.

f. Increasing public awareness among the public and EWA staff: it should be noted that public awareness is only one of the many factors that influence behavioural change and the mass media will remain the main channel of raising public awareness. People need to be more involved in order to appreciate the value of water. *Public awareness should emphasize action, in addition to knowledge. Furthermore*, the capacity of field staff should be

developed to engage in personal selling as they go about with their duties, as another channel of raising public awareness.

## 8.5 Limitations of the research

This research has made some contribution to our understanding of WDM and provided useful suggestions for policy formulation and service provision. This notwithstanding, the researcher acknowledges a number of limitations with the research findings. Firstly, it was difficult to conduct interviews with staff from Government, so there was no data triangulation for the research question regarding WDM at government level.

Secondly, probability sampling for collecting data was not used in this research. In this case study the researcher used Simple Random Sampling for sending out questionnaires. The limited resources made it impractical to use probability sampling as this requires taking a sample of the population. In addition, all information needed about customers to obtain a sample and such data would come from the water authority, where researcher has no access to customer details.

Despite the limitations of the research, the research findings remain credible. The limitations identified in the above paragraph do not detract from the value of this research, but rather provide a platform for further research.

## 8.6 Suggestions for future research

The following recommendations are made for future research in developing Water Demand Management strategies for Bahrain:

a. This study looked at generic aspects of WDM at the four levels. Further study should be done with households to assess WDM feasible options at the end-user level.
b. There is a need for further study on tariff reform. This requires planners to make certain assumptions (based on the available empirical evidence) about the elasticity of water demand (the responsiveness of water usage to change in price).

This Chapter concludes the thesis by summing up the key points resulting from the research. It demonstrates that the study has successfully achieved the research objectives of identifying and analysing Water Demand Management measures at different levels. Finally, this Chapter highlights the main contributions of the research to the body of knowledge and suggests some recommendations for future research.

Thus EWA should initiate appropriate tariffs in the water sector to reflect the actual cost of supply and the shortage of water; which will lead to more efficient use of water resources. The success of all other WDM measures depends upon water tariffs that cover production costs.

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## Appendices

## Appendix 1: Letter requesting interviews during execution of the research

Date: 18th November, 2008

Subject: Request for participation in research project and interview schedule.

Dear Sir(s):
A PhD research project is embarking regarding Water Demand Management. The research will be performed on a single case study Water Demand Management in Bahrain.. A brief description of the research follows.

**The research aim is:**
To develop a Water Demand Management strategies framework that suits the needs and requirements of Bahrain and provide sustainability water supply to Bahrain.

**The research objectives are:**
• To identify the current water demand management measures practice by utility.
• To evaluate the effectiveness of the current water demand management measures practices in Bahrain
• Develop a water demand management framework that provide sustainable water supply to Bahrain
• To verify and validate the water demand management measures in the case study

To achieve the research aims and objectives, your cooperation is essential, and would be highly appreciated. This cooperation would be in the form of a taped interview lasting between half and one hours. Rich picture diagrams would be sketched during the interviews. The interview and respondent will remain confidential and interviews will be used for research purposes only.
There is no required preparation for the interview on your part.

I am requesting your permission to perform an interview with you at your work place. A proposed preliminary interview schedule is enclosed. If the time of the interview is not convenient for you, please advise the convenient date and time slot for you to my email at H.Al-Maskati@lboro.ac.uk or my mobile 39434322.

Thank you for your cooperation.

Sincerely,
Hana Al-Maskati

## Appendix 2: The schedule of the data collection activities in the fieldworks

### a) the schedule of data collection for interviews

- From 18 January to 2 February, 2009

Location: Meter Workshop office in Salmabad

- 18 February to 12 March, 2009

Location: Water Conservation Department office in Manama

- From 14 April to 6 May, 2009

Location: Waste Control Unit office in Juffair

- From 10 June to 16 June, 2009

Location: Customer Services Directorate office in Manama

### b) the schedule for data collection activities from questionnaire survey

- From November 2006 to December, 2007 development of household questionnaire
- From January 2008 to March, 2008 distribution of questionnaires
- From April 2008 to June, 2008 analysis of household questionnaire
- From June 2009 development of Industrial questionnaire
- From September 2009 to October, 2009 distribution of questionnaires
- November 2009 analysis of industrial questionnaires

### c) the schedule of data collection activities from observation

Location: Waste Control Unit office and field location

a) From February 2005 to April, 2005, Infrastructure Leakage Index (ILI) and Linear Leakage Index (LLI) pilot test. And Direct and non-participant observation in waste control unit activities
b) From February 2007 to May, 2007, Low Flow Control (LFC) pilot test, and Direct and non-participant observation in waste control unit activities

Location: Water Conservation Department office in Manama and Exhibition centre

a) From June 2007 to July 2007 water conservation summer campaign and distribution of aerators to customers.
b) Getting information from earlier research
c) Direct and non-participant observation in Water conservation activities such as installation of electronic taps

# Appendix 3: Pro forma for Individual Interviews
## Water Demand Management- Case study- Bahrain

**Before you start**

a. Inform interviewees of the purpose of the interview and how they were selected.
b. Assure them that their identity will be kept confidential
c. Tell them about the approximate length of time for the interview
d. Make sure the environment is conducive for the interview
e. Find out whether or not the interviewee is comfortable with the interview been recorded. If he is not comfortable, proceed without using the recorder.

Guiding questions for interview

# Appendix 4: Log for Interviews

| No | Date of Interview | Person Contacted | Position | Transcript | Original chart sketch | Field & observation Notes | Other documents | Department/ Unit |
|---|---|---|---|---|---|---|---|---|
| 1 | 18-Jan-09 | √ | Engineer | √ | √ | | | Metering Workshop Unit |
| 2 | 18-Jan-09 | √ | Sr. Technician | √ | √ | | √ | |
| 3 | 25-Jan-09 | √ | Technician | √ | | | √ | |
| 4 | 02-Feb-09 | √ | Mech. Fitter | √ | | √ | | |
| 5 | 02-Feb-09 | √ | Mech. Inspector | √ | | | | |
| 6 | 18-Feb-09 | √ | Sr. Technician | √ | | | | Water Conservation Department |
| 7 | 18-Feb-09 | √ | Inspector 1 | √ | | √ | | |
| 8 | 26-Feb-09 | √ | Sr. Engineer | √ | √ | | √ | |
| 9 | 12-Mar-09 | √ | Inspector 2 | √ | | | √ | |
| 10 | 14-Apr-09 | √ | Engineer | √ | √ | √ | √ | Waste Control Unit |
| 11 | 14-Apr-09 | √ | Technician | √ | | | √ | |
| 12 | 26-Apr-09 | √ | Sr. Technician | √ | √ | √ | | |
| 13 | 26-Apr-09 | √ | Inspector 1 | √ | √ | | | |
| 14 | 06-May-09 | √ | Inspector 2 | √ | | | | |
| 15 | 06-May-09 | √ | Inspector 3 | √ | √ | √ | | |
| 16 | 10-Jun-09 | √ | Meter Reader | √ | | | √ | Customer Services Depaertment |
| 17 | 10-Jun-09 | √ | Chief Accountant | √ | | √ | √ | |
| 18 | 16-Jun-09 | √ | Supervisor | √ | | √ | √ | |

# Appendix 5: Sample of transcripts and interview summary

## Appendix 5-1: Interview summary of Waste Control Unit

1. What are the unit vision, mission and goals?
2. What sorts of field work do you carry out?
3. Do you have enough staff to carryout leak detection exercise?
4. If answer is no, what is your suggestion?
5. What sort of difficulties do you face in carrying out leak detection exercises?
6. What annual saving do you achieve in doing leak detection exercises?
7. Do you have enough equipment to do leak detection exercises?
8. How do you generate your monthly reports?
9. What sort of software are you using in generating your report?
10. What is your coordination with other departments and directorate?
11. Where do you mostly find leaks? what are the causes? explain?
12. What do you suggest to improve the efficiency of the waste detection unit?

**Semi-structured Waste Control Unit key informant interview**

| | |
|---|---|
| **Q1:** | **What are the unit vision, mission and goals?** |
| **Engineer:** | Implementing of leakage control policy in Bahrain, improve the efficiency of water distribution network using latest technology |
| **WD Inspector 1**: | finding cause of losses & NRW |
| **WD Inspector 2**: | Detecting un seen leak, assisting other section in detecting and repairing leaks, and contribute in saving water & reducing NRW |
| **Sr. Technician:** | Minimise leakage level |
| **Technician:** | reduce level of NRW by leak detection exercise |
| | |
| **Q2:** | **What sorts of field work do you carryout?** |
| **Engineer:** | Waste zone monitoring & carrying out of leak detection exercises.<br>2. Establishing of waste zones & districts<br>3. Assisting to locate unseen leaks |
| **WD Inspector 1**: | Pinpoint un seen leak location |
| **WD Inspector 2**: | Leak detection<br>Detecting leaks based on zones<br>Assisting in repair leaks |
| **Sr. Technician:** | Establish waste zones and locate missing fitting, Monitor leakage level in zone |
| **Technician:** | Leak detection night exercise, assess other in locating leaks |
| | |
| **Q3:** | **What sort of coordination between you and other sections/departments?** |
| **Engineer:** | assisting other department in locating leaks and finding missing valves and locate ferrules |

| | |
|---|---|
| **WD Inspector 1** | assisting other department in locating leaks and finding missing valves |
| **WD Inspector 2**: | assisting other department in locating leaks and finding missing valves |
| **Sr. Technician:** | Shortage of qualified technician |
| **Technician:** | No, shortage of inspectors and trade worker |

| | |
|---|---|
| **Q4:** | **Do you have policy to follow in doing night exercise? Explain** |
| **Engineer:** | Yes, leak detection night exercise to be completed with 5 weeks and every 2 years exercise for zone. Steps for carrying leak detection exercise if following IWA task force. Also agreed programme with other departments whenever required |
| **WD Inspector 1** | the policy is to complete zone exercise within 5 weeks |
| **WD Inspector 2**: | Promote trade worker to fulfil inspector job and increase no of trade workers in the section |
| **Sr. Technician:** | Upgrade inspectors |
| **Technician:** | Locate leaks but out sore repair |

| | |
|---|---|
| **Q5:** | **Do you have enough staff to carryout leak detection exercise?** |
| **Engineer:** | Existing staff is not sufficient and also knowledge to be improved, also utilise contractor |
| **WD Inspector 1** | No, shortage Pipe fitter 2 for 13 inspectors |
| **WD Inspector 2**: | No, need to increase staff in unit due to new projects and continuous development. |
| **Sr. Technician:** | Shortage of equipment, no cooperation with other department, Regular meter stop and shortage of meters, shortage of Pipe fitter |
| **Technician:** | Inspector do not have sufficient equipments, shortage of Pipe fitter |

| | |
|---|---|
| **Q6:** | **If answer is no, what is your suggestion?** |
| **Engineer:** | Staff should be double at least & they should have sufficient knowledge of latest technology of leakage control, outsourcing |
| **WD Inspector 1**: | increase no of staff |
| **WD Inspector 2**: | Promote trade worker to fulfil inspector job and increase no of trade workers in the section |
| **Sr. Technician:** | It depend on many issue but it is 1-2% in exercised zone |
| **Technician:** | Depend on the size of leaks found and repair |

| | |
|---|---|
| **Q7:** | **What sort of difficulties do you face in carrying out leak detection exercises?** |
| **Engineer:** | 1.Distributing to waste zones by other parties<br>2. Regular meter defects & time consuming for correction of defects.<br>3. Valve exercising is a difficult activity<br>4. Access to the chambers & valves in the night is difficult task<br>5. No staff encouragements.<br>6. No enough equipment<br>7. No enough budget to do waste zones maintenance/ establish of new waste zones<br>8. Need qualified engineers and technician, also improve coordination |

9. Update drawings not available
10. Technology not fully utilised
11. Training is not effective

**WD Inspector 1:** Unavailability of updated drawing, illegal connection, waking risk, cars, dogs, external effect such as noise, no training is provided, meter stop, difficult to do leak detection in VIP areas

**WD Inspector 2**: difficulties reaching some areas, no training, no enough staff, no enough equipment, no cooperation between customers and WD inspectors, under estimating the work of inspectors, and no enough training in using leak detection equipment

**Sr. Technician:** Essential instrument ok other instrument inspectors have to share which affect their productivity

**Technician:** No inspector sharing some instruments

**Q8:** **How do you generate your monthly reports?**

**Engineer:** Manual method. used some personnel spreadsheet developed in the office. Use old database (Dbase IV) software locally developed for the zone records

**WD Inspector 1:** manually and then Technical do the rest

**WD Inspector 2**: Technician in charge generate reports and list in it achievement f the section that cover no of leak detected and repaired and other jobs carried out by WD staff

**Sr. Technician:** Excel sheet no database

**Technician:** Manually and excel sheet

**Q9:** **What sort of software are you using in generating your report?**

**Engineer:** Used Debase IV locally developed software for zone records along with some spreadsheets

**WD Inspector 1:** software for loading and down loading logger for recording zone flow

**WD Inspector 2**: Does not have PC

**Sr. Technician:** Use excel sheet, special software for loading and down loading loggers for recording flow

**Technician:** Excel sheet, as main report is with information unit

**Q10:** **What is your coordination with other departments and directorate?**

**Engineer:** meter defects- Metering Unit
Network maintenance & exercises – Maintenance Unit.
Data collection – CSD & CSS WTD
Leak inside premises, high consumption- water conservation Directorate
Network planning- P&C DPRT.

**WD Inspector 1:** There is no coordination with them. only some emergency work

**WD Inspector 2**: Receive complaints from different department and sections such as complaint centre and maintenance unit, water transmission and other section and out side utilities

**Sr. Technician:** Ask for shutdown from maintenance unit, locate and repair leaks transfer from maintenance, assess other department in locating missing fitting

**Technician:** Report meter defect to metering workshop
Network maintenance in repairing leaks

**Q11:** **Where do you mostly find leaks? what are the causes? explain?**

**Engineer:** From service mains (poly main)

1. poor workmanship
2. not following specification
3. material defects
4. high pressure
5. damages by other parties abandoned live lines

**WD Inspector 1**: Service main & near meter. due to: no periodic maintenance and old main poor and workmanship

**WD Inspector 2**: Most of leaks are found in service mains that is use at houses 12mm and mainly at bends and ferrules

**Sr. Technician:** From service mains, due to material defect, old main

**Technician:** from service main due to no replacement of old poly

Q12: **What do you suggest to improve the efficiency of the waste detection unit?**

**Engineer:**

**1.** staff training, encouragement & motivation
2. Provide data required
1. training staff & use new software & methods, CSS, GIS, Balance score card program & explain the role of each staff on those
2. Training of new technology & use them. Professionally
5. Supplying of instruments & other facilities required
6. Implementing the real management system to manage staff
7. Developing of staff moral & productivities
8. Other sections should understand the importunacy of leakage control programme & should support actively

**WD Inspector 1:** Train staff, merit step & promotion, create equity environment, and follow development in technology for waste detection instruments

**WD Inspector 2**: more practical training, increase no of staff; Development of unit and increase public awareness about WD nature work

**Sr. Technician:** merit step & promotion, create equity environment, follow development in technology for waste detection instruments

**Technician:** Training of new technology & use them. Professionally developing of staff moral & productivities, supplying of instruments & other facilities required, other sections should understand the importunacy of leakage control programme & should support actively

**Interview transcript**
Simi-structured interviews with Waste Control Unit staff
Inspector1
8:30 – 9:15 am 14$^{tht}$ April 2009

**Inspector 1:** Waste control unit is responsible for finding cause of losses & calculating NRW. This is done by carrying out leak detection night exercise using leak detection equipment and following policy set by waste Detection Unit which state that any waste zone exercise should be completed with 5 weeks and the same zone will be visited after 2 years from last exercise done. The unit also assist other departments and sections in detecting unseen leaks and locating missing valves. Currently there are some constraints in doing leak detection exercise this is because of unavailability of updated drawing which affect inspector times in doing leak survey, also shortage of pipe fitter which delay the repair of leak detected by inspectors, and poor working conditions as inspectors has to go to some VIC areas where security will not allow them/ waste zone chamber is full of water and in bad condition not enough budget to do maintenance, and dogs parking at inspectors who are afraid of dogs. In addition general public do not know the nature of Waste Detection nature of work so inspectors face problems when they are working at night beside, they do not get risk allowance. Also inspectors are not given a training in using new leak detection equipment for example when new loggers were brought selected staff were trained to use them and they were programming the loggers to other inspectors. Inspectors did not get and incentive for several years. All these constraints affect the inspector productivity and unit achievements. There is a need to increase no of staff to fulfil vacant position and increase productivity of the unit.

*VIC areas affecting our productivities, as security not allowing us to work in these areas. One times they pointed at me with their gun and asked me to leave the area*.(Inspetor, Waste Control Unit)

## Appendix 5-2: Interview summary of Meter Workshop Unit

1. How many customer meters do you have in distribution network?
2. What type of meter do we have in the distribution system (for example mechanical, electronic]
3. What type of mechanical meter?
4. Do you face any problem with mechanical meter? what are the problem?
5. Do you face the problem with electronic meter? what are the problem?
6. what are the size of meters and No. of each type of customer meter?
7. At what age of meter do you replace the customer meter?
8. Do you replace the meter according
   a. Age
   b. Customer complaints
   c. others, specify
9. What is the policy to replace customer aged meter?
   a. 6 years
   b. 10 years
   c. 15 years
   d. other, specify
10. What is the policy to replace bulk aged meter?
    a. 6 years
    b. 10 years
    c. 15 years
    d. other, specify
11. Do you calibrate customer meters at workshop?
    a. Yes
    b. No, why?
12. What is your programme to replace customer meter
13. Do you have enough staff to do the replacement of meter?
    a. Yes
    b. No
    c. What do you suggest
14. Do you have enough staff to calibrate aged meter?
    a. Yes
    b. No
    c. What do you suggest
15. How many meters do you replace annually?

**Interview transcript**

Simi-structured interviews with Meter Workshop Unit staff

Technician

8:30 – 9:15 am 25th January 2009

**Technician:** there are 170,000 customer meters in water distribution system in Bahrain. These meters are mechanical meters (volumetric rotary Piston type and Turbine Vane types. There are some problems with these mechanical meters. The volumetric piston has the problem that due to small partial of dust or sand meter stops, while in the case of Turbine type it is difficult to replace or maintain because of brass getting rust and contaminated. Also there are electronic meters in the distribution system which does not give accurate readings for example thread damaged, battery leak. Metering workshop is responsible for replacing aged meters, after six years in service based on the policy. Unfortunately this is not practice due to shortage of budget, shortage of staff, meters and spare parts. Due to these constraints replacement is carried out based on defect reports received from Customer Services Department. The unit is also responsible for calibrating domestic meters, currently it is not done due to test bench is out of service and not been replaced due to shortage of budget. All these constraints affect the Metering Workshop productivity and unit achievements. There is a need to increase no of qualified staff or out sourcing by increasing number of contractor to increase productivity of the unit.

One common problem pointed out was that mechanical meters had problems and are not replaced based on policy, as highlighted by one thus:

> *"Due to small particles of sand (in piston type meters), Pistons get stuck and stop while in Turbine type meters brass parts get corroded and are difficult to replace. Domestic Meters are replaced according to the condition of the meter and not necessarily after 6 years in service as indicated in the policy. This is because of shortage of staff and spare parts*."
>
> (Technician, Metering Workshop Unit)

## Appendix 5-3: Interview summary of Water Conservation Department

1. When was the department established?
2. What is conservation department goals, missions and visions?
3. What are the activities of the department?
4. What are the objectives of the department?
5. What is the educational campaign carried by the WC department?
6. Who is your target group in the educational programme?
7. What are the educational programmes you are using?
8. What is the public awareness you are using?
9. Who is your target group in public awareness?
10. Is there any specific time you do your awareness campaign? when, why?
11. Have you implemented any saving devices in domestic buildings? where? what are these saving devices?
12. Have you implemented any saving devices in non domestic building? where? and what are they?
13. What saving has each of implemented device given? Is it within the recommended range?
14. Do you do any research studies? What are these studies? elaborate
15. Do you have byelaw enforcing the use of saving devices in Buildings? why
16. You did summer campaign, last summer what was the out come?
17. What is your future plan in regards to implementing saving devices and education and public awareness?
18. How success was the campaign?
19. How cooperative were people?
20. How much saving department achieved by installing saving devices?
21. How cooperative with ministry of education?
22. What about domestic, industrial, commercial, hotel, institutional you covered?
23. What instruments you used?
24. What about regulation, byelaw, penalty, code supplier education?

## Appendix 5-4: Interview summary of Customer Services Department

1. What are the vision, mission and goals of Customer Services Directorate?
2. How many water meters do you have in the water distribution network?
3. What are the problems faced by meter reading?
4. What are the customer problems they mostly complain about regarding water meters?
5. What tariff do you apply for water consumption? Elaborate?
6. Do you have any problem in collecting water revenue?
7. Do you have any problem in reading water meters?
8. How often do you take water meter reading? What is the method follow and program?
9. Do you have enough staff to take meter reading?
10. Do they take reading manual? Or use handheld? Explain
11. How do you generate your water consumption report? Do you use special software?
12. What is the problem in generating water consumption report please explain?
13. Do you have special plan (program) to take water meter reading?
14. Do you have any problem with customer in paying their water bills? Explain
15. How many meter stopped case do you find per year?
16. What is your coordination with Metering section at Water Distribution Directorate?
17. Do you have problem in reading VIP customer meters? How do you deal with it
18. If yes what are these problem? And how do you solve them?
19. Does water tariff recover your maintenance costs?
20. How many times have you changed water tariff? and on what bases?
21. Who is responsible for water tariff reform?
22. What is the coordination between you and metering section at Water Distribution Directorate?

## Appendix 6: Letter Suggesting conducting WDM courses in University of Bahrain

Dean
University Of Bahrain

Ms. Hana H. Al-Maskati
PhD Research Student
P.O. Box 24
Manama, Kingdom of Bahrain
Email: H.Al-Maskati@lboro.ac.uk

Date: 9th April, 2009

Dear Sir,
I am a Senior Civil Engineer working for Electricity and Water Authority [EWA] Bahrain.

I am at present in the final phase of PhD research title is "Water Demand Management in Bahrain" at Loughborough University, UK.

During my analysis of water demand management strategies (Combination of measure and instrument) at different levels, I found that Education about water related issues in Bahrain has not reached to the students at Secondary schools and university students in full. Therefore it seems that public education regarding awareness of water issues have not been very effective.

Keeping the above findings in view, I suggest you to please explore possibilities to include some subjects about water demand management issues in the curriculum of undergraduate level of Civil Engineering department, and establishing a Master's degree program in Water Demand Management at University of Bahrain. This master program is a pioneer program that includes a series of highly specialized courses in Water Demand Management to name a few like Best Management Practices, Demand Forecasting and Analysis, Strategic Planning for Water Demand Management; Planning Urban Demand Management Programs, Alternative Water Supply; and Water Demand Management in Agriculture. This program is thought to help to institutionalize the profession of water demand management.

I shall be very pleased to extend any sort of help or assistance in this regards and I am looking forward to hear from you shortly.

Yours faithfully,

Hana H. Al-Maskati

BAHRAIN CENTRE FOR STUDIES & RESEARCH

مركز البحرين للدراسات والبحوث

25th July 2010

**Ms. Hana Al Maskati**
**Senior Engineer**
**Ministry of Electricity & Water**
**Manama,**
**Kingdom of Bahrain**

Dear Ms. Al Maskati,

**Subject: Water Demand Management Courses**

Further to your letter dated 9th April 2009 regarding the above subject, we are pleased to inform you that your suggestion was studied and we are taking into our consideration to run seminars and short course in the field of water demand management.

Regards,

**Dr. Mohammed S. Alansari**
Director, Directorate of Water Research

# Appendix 7: Questionnaires survey

Appendix 7-1 Household Questionnaires

**QUESTIONNAIRE:-**

**MUNICIPAL WATER DEMAND MANAGEMENT SURVEY IN BAHRAIN**

| |
|---|
| Serial No.:……. |
| Address: House/Flat/Building:……. Road:……. Block:……. |
| Area:……. |

Circle appropriate answer ○

**Part I. Background Information**

**100 Water Source, use and expenditures**

**101** Type of premises

| | |
|---|---|
| **1**. House with garden | 01 |
| House Without garden | 02 |
| **2.** Villa with garden | 03 |
| Villa Without garden | 04 |
| Villa With swimming pool | 05 |
| **3.** Building flat with swimming pool | 06 |
| Building flat without swimming pool | 07 |
| 4. Government Housing with garden | 08 |
| Government Housing without garden | 09 |
| 5. Government building. flat with garden | 10 |
| Government building flat without garden | 11 |

**102**. Number of person (users) per premise …….

**103**. What is your source of water?

| | |
|---|---|
| Ministry of Electricity & Water | 1 |
| Private desalination Plan | 2 |
| Private Borehole | 3 |
| Private vendor | 4 |

**104**. What is your average water consumption per month from Ministry of Electricity & Water in $m^3$ [check your recent bills]

1. Summer……..$m^3$
2. Winter……$m^3$

**105.** How much do you pay to Ministry of Electricity & Water for Water per month?

1. Summer BD. ……

2. Winter BD. ……..

**106**. If water is bought from other source what is your average monthly consumption in $m^3$?
1. Summer month of June. …… …$m^3$
[2] Winter month of January ……...$m^3$

**107.** If water is bought from other source how much do you spend per month on the average?
1. Summer BD. …… [2] Winter BD. …….

**108.** Do you have swimming pool

| | |
|---|---|
| Yes | 1 |
| No | 2 |

**109**. If yes what is the size of swimming pool

| | |
|---|---|
| Large | 1 |
| Medium | 2 |
| Small | 3 |

**110.** what is the source for filling your swimming pool

| | |
|---|---|
| Borehole | 1 |
| ministry of Electricity & Water | 2 |
| others, specify……. | 3 |

**111.** How many times do you change swimming pool water in week……. 1
Month 2
Year 3

**112**. Do you have:

| | yes | no |
|---|---|---|
| 1. Ground storage tank | 1 | 2 |
| 2. Roof tank | 1 | 2 |

**113.** How would you rate the availability of water in your household (please tick one)

| | |
|---|---|
| Always available (24hr) | 1 |
| Usually available (16hr) | 2 |
| Sometimes available (8hr) | 3 |
| [4] Not available (have to buy from vendors) | 4 |

**114.** How would you rate the quality of water in your household (please tick one)
Highly acceptable (water can be drunk straight from tap) 1
Moderately acceptable (water can be used for cooking, cleaning but not for drinking) 2
Acceptable only (water can be used for cleaning but not for cooking or

drinking) 3
Not acceptable 4

**115.** What do you think is the main cause of water supply shortages?
Burst pipe 1
Illegal connections 2
Insufficient water during the summer season 3
Misuse of water 4
Others, please specify…… 5

**116.** What are the negative effects of poor or limited water supply to your household? [You may select more than one]
Health problem 1
Higher expenditures for water (buying water) 2
Delay in doing household task 3
Personal hygiene is affected 4
Others, please specify…… 5

---

## 200. Awareness about Water Demand Management

**201**. Water conservation is something that individuals, and utilities, can practice to reduce water use. Have you heard of these terms?
Yes 1
No 2 go to question 203

**202**. ***If "Yes" where did you hear about it***
Newspaper 1
Radio 2
TV 3
Relative 4
Ministry of Electricity and water 5

**203.** Water Demand Management includes measures that utilities can practice to control how much water people use. Have you heard of these terms?
Yes 1
No 2 go to question 205

If "Yes" where did you hear about it
Newspaper 1
Radio 2
TV 3
Relative 4
Ministry of Electricity and water 5

**204.** Presently the total quantity of water consumed per person in Bahrain is on average 370 litres per day of water (130 g/c/day). Do you feel that this consumption is appropriate?
Yes 1
No, consumers in Bahrain are wasteful in their use of water 2

No, people are not wasteful, but there are many leaks in the system 3

**205.** Which of the following do you think should be used to reduce the volume of water supplied?

Customers should use less water 1
The utility should discourage wasteful use of water 2
The utility should repair leaks in the distribution network system 3
Put the correct tariff for water i.e. sell water at true price 4

**206.** What action are you taking to conserve water?

1……
2. ……
3……
4……
5.

**207.** How do you rate the importance of managing and protecting water resources to ensure a stable supply in Bahrain?

Important 1 go to question 209
Not important 2 go to question 210
I don't know 3 go to question 211

**208.** Why it is important

to ensure better quality 1
convenience 2
continuity and quantity 3
more reliable supply 4

**209.** Why it is not important

it doesn't affect me 1
it's someone else's problem 2
there are more important priorities 3
we can afford to use other sources 4

**210.** Do you have leaks in your home/ domestic plumbing?

Yes 1
No 2 go to question 301
Don't know 3 go to question 301

**211**. how many leaks per year

1 – 3 1
3 – 5 2
>5 3

**212**. Who repairs the leaks?

Yourself/ owner 1
Plumber 2
Water Supply Emergency 3
Nobody 4

Don't know 5

---

**Part II Assessment of Willingness to Pay for Improved water supply through Water Demand Management WDM**

**301.** The lowest tariff is 25 fils/$m^3$. Production costs are about 400 fils/$m^3$. Would you be willing to pay the true cost for your water? (True cost is approximately 16 times what you pay at present)

Yes 1 go to question 303
No 2
Yes, but if services improve 3 go to question 303

**302.** If No, how much you will be willing to pay?

2 times what you are paying now 1
4 times what you are paying now 2
6 times. what you are paying now 3
8 times what you are paying now 4
Others _____times what you are paying now 5

**303.** Do you accept a gradual annual incremental increase of tariff over a period of 5 years to meet the actual costs of water supply?

[1] Yes 1
[2] Yes, but over a period of _____ years 2
[3] No, I do not want to pay more. 3

**304.** Do you agree that the water tariff should be increased to the full production costs?

Yes 1 go to question 305
No 2 go to question 306
No comments 3 go to question 307

**305.** Why do you agree to increase tariff to cover production cost (you may select more than one answer)

This will result in a better quality of service 1
The present tariff is too low 2
The increased tariff is not a significant drain on my income 3
Other reason (please specify) ……. 4
……..……
……
……
……
You may select more than one reason

**306**. Why do you do not agree to increase tariff to cover production cost (you may select more than one answer) because

I just do not want a price increase 1
Previous increase did not improve the water service 2
It would affect my lifestyle without a corresponding salary increase 3

Other reason (please specify) …… 4

**307.** What is your monthly income (BD):……

0-99 1
100-299 2
300-599 3
600 -999 4
More than 1000 5

**308.** What is your monthly water bill (BD)

[1] <1.500 1
[2] 1.500-10.000 2
[3] BD 10-50 3
[4] BD 50-100 4
[5] BD 100-200 5
[6]Other,(please specify)……. 6

**309.** How do you perceive your expenditure on water?

Low 1
Reasonable [ 2
High 3

**310.** What are you willing to pay per month as (a multiple of what you pay at present i.e 2 times what you pay or 1.5 what you pay)?

| Season | Multiplying factor |
|---|---|
| Summer | |
| Winter | |

**311.** What do you think should be the basis of charging the water price?

Volume of water used 1
Income 2
Number of members in the household 3
Season (changes vary during the year) 4
Other, please specify, …… 5

**312.** What is your opinion about the involvement of the public in making decisions about water supply issues?

Necessary 1
Unnecessary 2
Don't know 3

**313**. What is your opinion on the current water supply services?

Very good 1
Good 2
Poor 3
Very poor 4

**314.** Do you think there is a noticeable change in water services?

1. During past 10 years

| | |
|---|---|
| Great Improvement | 1 |
| Less improvement | 2 |
| No change | 3 |
| Deterioration | 4 |

2. During past 20 years

| | |
|---|---|
| Great Improvement | 1 |
| Less improvement | 2 |
| No change | 3 |
| Deterioration | 4 |

Thank you for your cooperation.

Filled by (Name):…… Date:……..

**Have you heard of "water conservation" term? * What is your monthly income? Cross tabulation**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Have you heard of "water conservation" term? | Yes | 7 | 62 | 141 | 51 | 35 | 296 |
| | No | 16 | 57 | 114 | 53 | 5 | 245 |
| Total | | 23 | 119 | 255 | 104 | 40 | 541 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 24.539[a] | 4 | .000 |
| Likelihood Ratio | 27.226 | 4 | .000 |
| Linear-by-Linear Association | 10.170 | 1 | .001 |
| N of Valid Cases | 541 | | |

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.42.

**Have you heard of "water demand management" term? * What is your monthly income? Cross tabulation**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Have you heard of "water demand management" term? | Yes | 1 | 10 | 52 | 21 | 14 | 98 |
| | No | 22 | 109 | 203 | 83 | 26 | 443 |
| Total | | 23 | 119 | 255 | 104 | 40 | 541 |

**Case Processing Summary**

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| Rate of the importance of managing and protecting water resources * What is your monthly income? | 541 | 99.3% | 4 | .7% | 545 | 100.0% |

**Rate of the importance of managing and protecting water resources * What is your monthly income? Cross tabulation**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Rate of the importance of managing and protecting water resources | Important | 13 | 79 | 219 | 87 | 37 | 435 |
| | Not important | 0 | 7 | 6 | 5 | 1 | 19 |
| | Don't know | 10 | 33 | 30 | 12 | 2 | 87 |
| Total | | 23 | 119 | 255 | 104 | 40 | 541 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 38.778[a] | 8 | .000 |
| Likelihood Ratio | 36.012 | 8 | .000 |
| Linear-by-Linear Association | 24.915 | 1 | .000 |
| N of Valid Cases | 541 | | |

a. 5 cells (33.3%) have expected count less than 5. The minimum expected count is .81.

**Your opinion about involvement of the public in making decisions about water supply issues * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Your opinion about involvement of the public in making decisions about water supply issues | Necessary | 15 | 72 | 194 | 82 | 24 | 387 |
| | Unnecessary | 0 | 5 | 36 | 14 | 12 | 67 |
| | Don't know | 8 | 41 | 25 | 8 | 4 | 86 |
| Total | | 23 | 118 | 255 | 104 | 40 | 540 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 66.763[a] | 8 | .000 |
| Likelihood Ratio | 63.182 | 8 | .000 |
| Linear-by-Linear Association | 12.489 | 1 | .000 |
| N of Valid Cases | 540 | | |

a. 3 cells (20.0%) have expected count less than 5. The minimum expected count is 2.85.

**Your opinion about involvement of the public in making decisions about water supply issues * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | Total |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | |
| Your opinion about involvement of the public in making decisions about water supplu issues | Necessary | 67 | 298 | 21 | 2 | 388 |
| | Unnecessary | 1 | 59 | 6 | 1 | 67 |
| | Don't know | 24 | 51 | 11 | 0 | 86 |
| Total | | 92 | 408 | 38 | 3 | 541 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 27.400[a] | 6 | .000 |
| Likelihood Ratio | 32.448 | 6 | .000 |
| Linear-by-Linear Association | .062 | 1 | .803 |
| N of Valid Cases | 541 | | |

a. 4 cells (33.3%) have expected count less than 5. The minimum expected count is .37.

**Why do you agree to increase tariff to cover production cost? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | Total |
|---|---|---|---|---|---|---|
| | | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Why do you agree to increase tariff to cover production cost? | Will result in a better quality of service | 4 | 17 | 14 | 22 | 57 |
| | The present tariff is too low | 0 | 0 | 1 | 0 | 1 |
| | The increased tariff is not a significant drain on my income | 0 | 1 | 0 | 2 | 3 |
| Total | | 4 | 18 | 15 | 24 | 61 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 4.614[a] | 6 | .594 |
| Likelihood Ratio | 5.187 | 6 | .520 |
| Linear-by-Linear Association | .422 | 1 | .516 |
| N of Valid Cases | 61 | | |

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .07.

**Why do you agree to increase tariff to cover production cost? * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | Total |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | |
| Why do you agree to increase tariff to cover production cost? | Will result in a better quality of service | 6 | 44 | 6 | 1 | 57 |
| | The present tariff is too low | 0 | 1 | 0 | 0 | 1 |
| | The increased tariff is not a significant drain on my income | 0 | 2 | 1 | 0 | 3 |
| Total | | 6 | 47 | 7 | 1 | 61 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 2.010[a] | 6 | .919 |
| Likelihood Ratio | 2.153 | 6 | .905 |
| Linear-by-Linear Association | .800 | 1 | .371 |
| N of Valid Cases | 61 | | |

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .02.

**Why do you agree to increase tariff to cover production cost? * How do you perceive your expenditure on water?**

**Crosstab**

Count

| | | How do you perceive your expenditure on water? | | | |
|---|---|---|---|---|---|
| | | Low | Reasonable | High | Total |
| Why do you agree to increase tariff to cover production cost? | Will result in a better quality of service | 1 | 54 | 2 | 57 |
| | The present tariff is too low | 0 | 1 | 0 | 1 |
| | The increased tariff is not a significant drain on my income | 0 | 3 | 0 | 3 |
| Total | | 1 | 58 | 2 | 61 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .221[a] | 4 | .994 |
| Likelihood Ratio | .418 | 4 | .981 |
| Linear-by-Linear Association | .022 | 1 | .883 |
| N of Valid Cases | 61 | | |

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .02.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Why don't you agree to increase tariff to cover production cost? | I just don't want a price increase | 13 | 94 | 212 | 76 | 10 | 405 |
| | No | 0 | 6 | 8 | 3 | 5 | 22 |
| Total | | 13 | 100 | 220 | 79 | 15 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 26.562[a] | 4 | .000 |
| Likelihood Ratio | 14.608 | 4 | .006 |
| Linear-by-Linear Association | 4.362 | 1 | .037 |
| N of Valid Cases | 427 | | |

a. 3 cells (30.0%) have expected count less than 5. The minimum expected count is .67.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | Total |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | |
| Why don't you agree to increase tariff to cover production cost? | I just don't want a price increase | 67 | 308 | 29 | 1 | 405 |
| | No | 7 | 13 | 1 | 1 | 22 |
| Total | | 74 | 321 | 30 | 2 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 12.042[a] | 3 | .007 |
| Likelihood Ratio | 6.633 | 3 | .085 |
| Linear-by-Linear Association | .709 | 1 | .400 |
| N of Valid Cases | 427 | | |

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .10.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Why don't you agree to increase tariff to cover production cost? | Previous increase didn't improve the water service | 0 | 1 | 1 | 3 | 5 | 10 |
| | No | 13 | 99 | 219 | 76 | 10 | 417 |
| Total | | 13 | 100 | 220 | 79 | 15 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 68.251[a] | 4 | .000 |
| Likelihood Ratio | 26.260 | 4 | .000 |
| Linear-by-Linear Association | 23.096 | 1 | .000 |
| N of Valid Cases | 427 | | |

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is .30.

**Why don't you agree to increase tariff to cover production cost? * How do you perceive your expenditure on water?**

**Crosstab**

Count

| | | How do you perceive your expenditure on water? | | | |
|---|---|---|---|---|---|
| | | Low | Reasonable | High | Total |
| Why don't you agree to increase tariff to cover production cost? | Previous increase didn't improve the water service | 1 | 8 | 1 | 10 |
| | No | 43 | 331 | 43 | 417 |
| Total | | 44 | 339 | 44 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .002[a] | 2 | .999 |
| Likelihood Ratio | .002 | 2 | .999 |
| Linear-by-Linear Association | .000 | 1 | 1.000 |
| N of Valid Cases | 427 | | |

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.03.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | Total |
| Why don't you agree to increase tariff to cover production cost? | Affect my lifestyle without a corresponding salary increase | 1 | 16 | 22 | 1 | 0 | 40 |
| | No | 12 | 84 | 198 | 78 | 15 | 387 |
| Total | | 13 | 100 | 220 | 79 | 15 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 12.986[a] | 4 | .011 |
| Likelihood Ratio | 16.815 | 4 | .002 |
| Linear-by-Linear Association | 9.608 | 1 | .002 |
| N of Valid Cases | 427 | | |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 12.986[a] | 4 | .011 |
| Likelihood Ratio | 16.815 | 4 | .002 |
| Linear-by-Linear Association | 9.608 | 1 | .002 |
| N of Valid Cases | 427 | | |

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is 1.22.

**Why don't you agree to increase tariff to cover production cost? * How do you perceive your expenditure on water?**

**Crosstab**

Count

| | | How do you perceive your expenditure on water? | | | |
|---|---|---|---|---|---|
| | | Low | Reasonable | High | Total |
| Why don't you agree to increase tariff to cover production cost? | Affect my lifestyle without a corresponding salary increase | 2 | 35 | 3 | 40 |
| | No | 42 | 304 | 41 | 387 |
| Total | | 44 | 339 | 44 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 1.908[a] | 2 | .385 |
| Likelihood Ratio | 2.186 | 2 | .335 |
| Linear-by-Linear Association | .134 | 1 | .715 |
| N of Valid Cases | 427 | | |

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 4.12.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| Why don't you agree to increase tariff to cover production cost? | financial status of the others | 0 | 0 | 0 | 0 | 1 | 1 |
| | No | 13 | 100 | 220 | 79 | 14 | 426 |
| Total | | 13 | 100 | 220 | 79 | 15 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 27.531[a] | 4 | .000 |
| Likelihood Ratio | 6.763 | 4 | .149 |
| Linear-by-Linear Association | 6.120 | 1 | .013 |
| N of Valid Cases | 427 | | |

a. 5 cells (50.0%) have expected count less than 5. The minimum expected count is .03.

**Why don't you agree to increase tariff to cover production cost? * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | Total |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | |
| Why don't you agree to increase tariff to cover production cost? | financial status of the others | 0 | 1 | 0 | 0 | 1 |
| | No | 74 | 320 | 30 | 2 | 426 |
| Total | | 74 | 321 | 30 | 2 | 427 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .331[a] | 3 | .954 |
| Likelihood Ratio | .571 | 3 | .903 |
| Linear-by-Linear Association | .035 | 1 | .852 |
| N of Valid Cases | 427 | | |

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .00.

**What do you think should be the basis of charging the water price? * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | Total |
| What do you think should be the basis of charging the water price? | Volume of water used | 69 | 333 | 31 | 2 | 435 |
| | No | 20 | 61 | 6 | 1 | 88 |
| Total | | 89 | 394 | 37 | 3 | 523 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 3.129[a] | 3 | .372 |
| Likelihood Ratio | 2.885 | 3 | .410 |
| Linear-by-Linear Association | .966 | 1 | .326 |
| N of Valid Cases | 523 | | |

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is .50.

**What do you think should be the basis of charging the water price? * How do you perceive your expenditure on water?**

**Crosstab**

Count

| | | How do you perceive your expenditure on water? | | | |
|---|---|---|---|---|---|
| | | Low | Reasonable | High | Total |
| What do you think should be the basis of charging the water price? | Volume of water used | 44 | 354 | 37 | 435 |
| | No | 2 | 76 | 10 | 88 |
| Total | | 46 | 430 | 47 | 523 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 6.004[a] | 2 | .050 |
| Likelihood Ratio | 7.730 | 2 | .021 |
| Linear-by-Linear Association | 4.704 | 1 | .030 |
| N of Valid Cases | 523 | | |

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.74.

**What do you think should be the basis of charging the water price? * What is your monthly water bill?**

**Crosstab**

Count

| | | What is your monthly water bill? | | | | |
|---|---|---|---|---|---|---|
| | | <1.5 | 1.5 - 10 | 10 - 50 | 50 - 100 | Total |
| What do you think should be the basis of charging the water price? | Income | 18 | 69 | 9 | 1 | 97 |
| | No | 71 | 325 | 28 | 2 | 426 |
| Total | | 89 | 394 | 37 | 3 | 523 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 1.696[a] | 3 | .638 |
| Likelihood Ratio | 1.578 | 3 | .664 |
| Linear-by-Linear Association | .116 | 1 | .734 |
| N of Valid Cases | 523 | | |

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is .56.

**What do you think should be the basis of charging the water price? * How do you perceive your expenditure on water?**

**Crosstab**

Count

| | | How do you perceive your expenditure on water? | | | Total |
|---|---|---|---|---|---|
| | | Low | Reasonable | High | |
| What do you think should be the basis of charging the water price? | Income | 9 | 78 | 10 | 97 |
| | No | 37 | 352 | 37 | 426 |
| Total | | 46 | 430 | 47 | 523 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .311[a] | 2 | .856 |
| Likelihood Ratio | .302 | 2 | .860 |
| Linear-by-Linear Association | .047 | 1 | .828 |
| N of Valid Cases | 523 | | |

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.53.

**What do you think should be the basis of charging the water price? * What is your monthly income?**

**Crosstab**

Count

| | | What is your monthly income? | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0 - 99 | 100 - 299 | 300 - 599 | 600 - 999 | >=1000 | |
| What do you think should be the basis of charging the water price? | Quality | 2 | 19 | 36 | 15 | 14 | 86 |
| | No | 16 | 96 | 213 | 87 | 25 | 437 |
| Total | | 18 | 115 | 249 | 102 | 39 | 523 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 12.054[a] | 4 | .017 |
| Likelihood Ratio | 9.991 | 4 | .041 |
| Linear-by-Linear Association | 3.801 | 1 | .051 |
| N of Valid Cases | 523 | | |

a. 1 cells (10.0%) have expected count less than 5. The minimum expected count is 2.96.

**Appendix 7-2 Industrial Questionnaires**

**QUESTIONNAIRE:-**
**Industrial WATER DEMAND MANAGEMENT SURVEY IN BAHRAIN**

| |
|---|
| Serial No.:……. |
| Address: /Building:……. Road:……. Block:……Phone No…. |
| Date:……Time……. |

**1 -General Information**

1-1 Address:
1-2 The name of the factory:
1-3 Nature of work:
1-4 The capacity of production:
1-5 The number of workers:

| | | | | |
|---|---|---|---|---|
| 1-6 Do you use water in the factory? | 1) Yes | 2) No | | |
| 1-7 For what do you use water? | 1) Production | 2) cooling | 3) human use | 4) Garden Irrigation |

| | | | |
|---|---|---|---|
| **2 Water Resources** | | | |
| 2-1 What is the source of water used | 1) underground water | 2) Government Network | 3) wastewater treatment |
| | 4) Desalinated Sea water | 5) Desalinated underground water, | |

| | | | | |
|---|---|---|---|---|
| **In the case of the use of groundwater** | | | | |
| 2-2 Would you mind to replace the groundwater water Government Network | 1) Yes | 2) No | 3) Do not know | |
| 2-3 If accept, what are the reasons for acceptance | 1) to preserve the groundwater | 2) better water quality t | 3) the cost of desalination of groundwater is high | 4) Other |
| 2-4 In case of rejection, what are the reasons for rejection | 1) High cost | 2) require amendments to change production lines | 3) There are no obligatory laws | 4) Other |
| 2-5 Do you mind the replacement of groundwater with sewage treatment | 1) Yes | 2) No | 3) Do not know | |
| 2-6 If accept, what are the reasons for acceptance | 1) to | 2) for the | 3) the cost | 4) Other |

| | | | | |
|---|---|---|---|---|
| | preserve the groundwater | abundance of treated wastewater | of desalination of groundwater is high | |
| 2-7 In case of rejection, what are the reasons for rejection | 1) I am afraid of water quality | 2) require amendments to change production lines | 3) There are no binding laws | 4) Other |

**If you use water-governmental network (EWA)**

| | | | | |
|---|---|---|---|---|
| 2-8 What is the amount of water used? | (Cubic meters / month) | | | |
| 2-9 How much do you pay for the use of water? | (BD / month) | | | |
| 2-10 Government subsidize 75% of the cost of water, do you agree to increase the water tariffs gradually and bring it to the actual cost? | 1) Yes | 2) No | | |
| 2-11 If agree, what is the reason | 1) to improve service | 2) to reduce government support | 3) Tariff already low | 4) do not affect the profit increase |
| 2-12 What is the percentage that you suggest to increase water tariff | 1) 0-10%<br>5) 40-50%<br>9) 80-90% | 2) 10-20%<br>6) 50-60% -<br>10) 90-100% | 3) 20-30%<br>7) 60-70% - | 4) 30-40%<br>8) 70-80% |
| 2-13 What is the percentage increase in water tariff that would have an effect on water consumption pattern | 1) 0-10%<br>5) 40-50%<br>9) 80-90% | 2) 10-20%<br>6) 50-60%<br>10) 90-100% | 3) 20-30%<br>7) 60 -70% | 4) 30-40%<br>8) 70-80% |
| 2-15 In case of rejection, what are the reasons for rejection | 1) to reduce production costs | 2) to encourage industry | 3) the current price appropriate | 4) Other |
| 2-16 Would you mind to replace the water network governmental sewage treatment | 1) Yes | 2) No | 3) Do not know | |
| 2-17 If approved, what are the reasons for acceptance | 1) to reduce the consumption of desalinated water | 2) for the abundance of treated wastewater | 3) high costs of desalination | 4) Other |
| 2-18 In case of rejection, what are the reasons for rejection | 1) I am | 2) require | 3) There are | 4) Other |

| | | | | |
|---|---|---|---|---|
| | | afraid of water quality | amendments to change production lines | no binding laws |
| **If you use treated sewage water** | | | | |
| 2-19 What are the uses of treated wastewater | 1) in the cooling | 2) landscaping | 3) Other | |
| 2-20 What is the monthly consumption | (Cubic meters / month) | | | |
| 2-21 In the case of landscaping, the irrigation method is used | 1) Rey Classic - Alhoz | 2) modern irrigation (drip) | 3) modern irrigation (sprinkler) | |
| 2-22 In the case of flood irrigation, do you agree to use the modern methods instead of immersion | 1) Yes | 2) No | | |
| 2-26 In case of acceptance, what are the reasons for acceptance | 1) the provision of water | 2) other reasons | | |
| 2-27 In case of rejection, what are the reasons for rejection | 1) I use a limited | 2) high costs | 3) need knowledge and expertise in using modern methods | 4) Other |
| **In the case of the use of desalinated sea water or groundwater desalination** | | | | |
| 2-28 What is the monthly cost of desalination? | (BD / month) | | | |
| 2-29 What is the quantity used per month? | ( Cubic meters / month) | | | |
| 20-30 What is the method used for desalination? | 1) Reverse Osmosis | 2) evaporation of pulsed | 3) multi-stage evaporation | 4) Other (.....) |
| 2-31 Do you accept to use treated sewage water | 1) Yes | 2) No | 3) Do not know | |
| 2-32 If accept, what are the reasons for | 1) to reduce | 2) for the | 3) high costs of | 4) Other |

| | | | | |
|---|---|---|---|---|
| acceptance | the consumption of groundwater | abundance of treated wastewater | desalination | |
| 2-33 In case of rejection, what are the reasons for rejection | 1) I am afraid of water quality | 2) require amendments to change production lines | 3) There are no binding laws | 4) Other |

**3 - Use of modern technologies**

| | | | | |
|---|---|---|---|---|
| 3-1 Are you using the modern technologies of water-saving in the factory? | 1) Yes | 2) No | | |
| 3-2 What is the technology used? | 1) Sensor | 2) Aerators | 3) Dual Flushing | 4) Air Cooling |
| | 5) Water Recycle | 6) Water Reuse | 7) Other (.....) | |
| 3-3 In the case of the use of modern technologies, how do you evaluate percentage saving achieved? | 1) 10% - 20% | 2) 20% - 30% | 3) 30% -40% | 4) Other (.....) |
| 3-4 if not in use, do you agree to use modern technology? | 1) Yes | 2) No | | |
| 3-5 In case of rejection, what are the reasons for rejection | 1) my use is limited | 2) high cost | 3) require substantial modifications | 4) Other |

**4 - Pollutant discharge of industrial**

| | | | | |
|---|---|---|---|---|
| 4-1 Where do you discharge your wastewater? | | | | |
| 4-2 What is the nature of the pollutants | 1) chemical pollutants | 2) Oils and greases | 3) high temperature | 4) Other |
| 4-3 Are the water treated before discharge? | 1) Yes | 2) No | | |
| 4-4 Do you prefer to address industrial pollutants | 1) within the plant | 2) a central place for all plants | 3) Other | |
| 4-5 Do you agree to impose a fine on | 1) Yes | 2) No | | |

| | | | | |
|---|---|---|---|---|
| the factories that do not treat their waste before discharge in the sea | | | | |
| 4-6, if approved, how can the appreciation of fine | 1) a fixed number | 2) According to the pollution loads | 3) according to the concentration of pollutants | |
| 4-7 in case of rejection, what are the reasons for rejection | 1) to encourage industry | 2) the volume of pollutants limited | 2) to avoid the escape of investments | 4) Other |

**Thank you for**
**Cooperation with us,**
**For the benefit of our dear country and for all our children**

**2-1 What is the source of water used**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Groundwater | 2 | 5.9 | 6.1 | 6.1 |
| | Government Network | 31 | 91.2 | 93.9 | 100.0 |
| | Total | 33 | 97.1 | 100.0 | |
| Missing | System | (1) | 2.9 | | |
| | Total | 34 | 100.0 | | |

**2-6 Do you mind replacing groundwater with water from the Government Network**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 3 | 8.8 | 75.0 | 75.0 |
| | I do not know | (1) | 2.9 | 25.0 | 100.0 |
| | Total | 4 | 11.8 | 100.0 | |
| Missing | System | 30 | 88.2 | | |
| | Total | 34 | 100.0 | | |

**2-8 in case of rejection, what are the reasons for rejection**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | ) Requires amendments to change production lines | (1) | 2.9 | 33.3 | 33.3 |
| | There are no laws binding | 2 | 5.9 | 66.7 | 100.0 |
| | Total | 3 | 8.8 | 100.0 | |
| Missing | System | 31 | 91.2 | | |
| | Total | 34 | 100.0 | | |

**2-9 Do you mind replacing groundwater with treated sewage**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 4 | 11.8 | 100.0 | 100.0 |
| Missing | System | 30 | 88.2 | | |
| | Total | 34 | 100.0 | | |

**2-11 in the case of rejection, what are the reasons for rejection**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | I'm afraid of water quality | 3 | 8.8 | 75.0 | 75.0 |
| | Other | (1) | 2.9 | 25.0 | 100.0 |
| | Total | 4 | 11.8 | 100.0 | |
| Missing | System | 30 | 88.2 | | |
| Total | | 34 | 100.0 | | |

**2-14 Governmental subsidies account for 75% of the cost of water, do you agree to raise water tariffs gradually and bring it to the real cost**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | No | 33 | 97.1 | 100.0 | 100.0 |
| Missing | System | (1) | 2.9 | | |
| Total | | 34 | 100.0 | | |

**2-18 in the case of rejection, what are the reasons for rejection**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | To reduce production costs | (1) | 2.9 | 3.1 | 3.1 |
| | To encourage industry | 14 | 41.2 | 43.8 | 46.9 |
| | Current price suitable | 17 | 50.0 | 53.1 | 100.0 |
| | Total | 32 | 94.1 | 100.0 | |
| Missing | System | 2 | 5.9 | | |
| Total | | 34 | 100.0 | | |

**2-19 Do you mind replacing water from the governmental network with treated sewage**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 29 | 85.3 | 87.9 | 87.9 |
| | No | 2 | 5.9 | 6.1 | 93.9 |
| | I do not know | 2 | 5.9 | 6.1 | 100.0 |
| | Total | 33 | 97.1 | 100.0 | |
| Missing | System | (1) | 2.9 | | |
| Total | | 34 | 100.0 | | |

**2-20 in the case of approval, what are the reasons for acceptance**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | To reduce the consumption of desalinated water | (1) | 2.9 | 50.0 | 50.0 |
| | High costs of desalination | (1) | 2.9 | 50.0 | 100.0 |
| | Total | 2 | 5.9 | 100.0 | |
| Missing | System | 32 | 94.1 | | |
| | Total | 34 | 100.0 | | |

**2-21 in the case of rejection, what are the reasons for rejection**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | I'm afraid of water quality | 29 | 85.3 | 100.0 | 100.0 |
| Missing | System | 5 | 14.7 | | |
| | Total | 34 | 100.0 | | |

**2-31 Do you object to the use of treated sewage water**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 5 | 14.7 | 71.4 | 71.4 |
| | No | 2 | 5.9 | 28.6 | 100.0 |
| | Total | 7 | 20.6 | 100.0 | |
| Missing | System | 27. | 79.4 | | |
| | Total | 34 | 100.0 | | |

**3-4 If not in use, would you agree to use if you are asked to**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 16 | 47.1 | 64.0 | 64.0 |
| | No | 9 | 26.5 | 36.0 | 100.0 |
| | Total | 25 | 73.5 | 100.0 | |
| Missing | System | 9 | 26.5 | | |
| | Total | 34 | 100.0 | | |

**3-5 in case of rejection, what are the reasons for rejection**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| **Valid** | **I use a limited** | **6** | **17.6** | **100.0** | **100.0** |
| **Missing** | **System** | **28** | **82.4** | | |
| Total | | 34 | 100.0 | | |

## Appendix 8 Published Papers

## List of papers published, presented in conference or workshop

This section provides list of papers published, presented in conference or workshop.

The following papers were published

1. Al-Maskati, H and AlShaikh, S. (2005) "Water Losses and Leakage Control in Distribution Network-New Approach", Arab Water World, March 2005, Vol. XXIX- Issue 2, p36-39, Chatila Publishing House, www.cph.com.lb.

2. Smith, M. and Al-Maskati, H. (2007) "The effect of tariff on water demand management: implications for Bahrain", Water science Technology: Water Supply Vol 7 No. 4 pp 118 – 126, IWA Publishing 2007.

3. Kayaga, S., Smout, I. and Al-Maskati, H. (2007) "Water demand management-shifting urban water management towards sustainability", Water Science Technology: Water Supply Vol 7 No. 4 pp 49 – 56, IWA Publishing 2007.

The following papers were presented in conference or workshop

1. Al-Maskati, H. (2005) "Conservation and Water Demand Management" presented in Water Conservation workshop held in Oman; March, 2005.

2. Al-Maskati, H. (2006), "Case Study: Integrating Demand-Side Management within the Integrated Resource Planning Process in the Kingdom of Bahrain" proceedings of Middle East Water congress, Marcus Evans Dubai, UAE, 12-13 June, 2006. Audience were interested in the topic, especially in the case of ground water recharge, they gave their feedback and were willing to assess in providing information regarding artificial recharge case studies carried in their countries.

3. Smith, M. and Al-Maskati, H. (2007), "The effect of tariff on water demand" Proceeding for the Efficient 2007 conference, Seoul, Korea, 4th IWA organization committee Jeju, Korea, 20-23 May, 2007. Audience were interested to know about water tariff structure applied in Bahrain and how it is been subsidised by the government, and the need to reform the tariff in Bahrain.

4. Al-Maskati, H. and Smith, M. (2007) "Potential for Implementation of Water Demand Management in Bahrain" proceeding for International Conference on Water Environment, Energy and Society (WEES) 2007, Roorkee, Organised by National Institute of energy India and Texas A &M University, USA. 18-21 December 2007.