EVALUATING THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF WATER SUBSIDIES IN KUWAIT

A Thesis

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Abstract

Kuwait and the other Gulf Cooperation Council (GCC) states have experienced rapid growth in population coupled with a rise in the standards of living and acceleration in social, agricultural, and industrial growths, which greatly increased the demand for water supplies. Due to the scarcity of water resources in the region, non-conventional water supplies such as seawater desalination are and have been the main water resource. Kuwait has so far been able to meet demand by using its access to both the sea and abundant oil needed in the desalination plants. The quantity of water consumed per capita in Kuwait is higher than in countries with abundant water resources. There are several reasons for such demand, but one of the main reasons is the fact that the price of water is heavily subsidized in Kuwait; consumers currently pay $0.60 USD/$m^3$, while the cost of desalinated water production is currently is above $5 USD/$m^3$ (based on 2007 oil prices). The main objective of this study is to evaluate the water price as a cost effective tool to reduce water over consumption by identifying the economic and the environmental benefits of water conservation using water models in the literature. Two scenarios were evaluated based on a 5-year (2008-2012) water plant using economic indicators (cost of fuels, cost of water projects), and environmental indicators (water production, CO_2, NO_2, and SO_2 emissions). Scenario A was the current price schedule used in Kuwait (uniform rate of $0.6 USD/$m^3$). Scenario B was the price proposal by Milutinovic ($1 USD/$m^3$ price of water, after 150L/capita/ day allowance). A cost-effectiveness analysis was then used to determine the overall effectiveness of each scenario using the above indicators. The results of this study suggest that adopting scenario B will cut the water demand by 113.3 billion imperial gallons in 5 years. Thus, adopting scenario B would postpone the need for new water projects to the year 2020. Under scenario A, water demand would outstrip water production capacity by the year

2012. Implementing the new price schedule (Scenario B) starting in year 2008 will reduce energy consumption for water desalination by around 16.2%. This is equivalent to 4.32 million barrels of Crude Oil, 172 thousand barrels of Gas Oil, 10.12 million barrels of heavy fuel oil (HFO), and 21,421 million SCF of Natural gas. This translates into net fuel savings of 1.5 billion USDs and 16.2% emissions reduction in 5 years. Liquid fuel analysis suggests that HFO and crude oil emit 397 and 360 kg CO_2/bbl, respectively. Also, HFO emits two times more NO_2 and SO_2 than crude oil. Emission factors were also calculated per unit of water produced, 12.81 kg/m^3 of CO_2, .044 kg/m^3 of NO_2, and .253 kg/m^3 of SO_2.

Chapter 1: Domestic Water Resources and Demand in Kuwait

1. 1 Introduction

Kuwait is a member of the Gulf Cooperation Council (GCC) states which are located in an arid region, where freshwater resources are extremely limited. In the last three decades, Kuwait and the other GCC states have experienced rapid growth in population coupled with a rise in living standards and acceleration in social, agricultural, and industrial growths, which greatly increased the demand for water supplies. Due to the scarcity of water resources in the region, non-conventional water supplies such as seawater desalination are and have been the main water resource. Kuwait has so far been able to meet demand by using its access to both the sea and abundant fuel needed in the desalination process.

However, the continuing increase in water demand will continue pressuring the limited water resources of Kuwait. The country has been following a supply side approach, responding to growing water demand by building more desalination plants; however, little has been done to control demand. Desalination may remain the resort for increasing the supplies to meet the demands, but only at the expense of increasing economic pressures.

The quantity of water consumed per capita in Kuwait is higher than it is in countries with abundant water resources. There are several reasons for such demand, but one of the main reasons is the fact that the water price is heavily subsidized in Kuwait, consumers currently pay \$0.60 USD/m^3, while the cost of desalinated water production is currently is above \$5.0 USD/m^3 (based on 2007 oil prices).

Different aspects of water demand management have been studied, and certainly water price is a crucial element in determining water demand. The main objective of this study is to evaluate the price of water as a cost effective tool to reduce water over consumption by identifying the economic and environmental benefits of water conservation using water models in the literature.

Chapter one presents a review of the water resources in Kuwait and an introduction to the desalination process and capacities since Kuwait gets over 93% of its potable water through desalting plants. A discussion of the associated costs and environmental impacts of desalination plants in general follows.

Next, the water demand pattern in Kuwait and a literature review of water management concepts are discussed. A particular emphasis was given to the importance and benefits of water conservation to sustainable development.

Then, a literature review of water demand models was conducted. Most of the demand models suggest that water consumption is elastic to price increase, with a wide range for elasticity. A study by Milan Milutinovic (24) suggested that increasing the price of water in Kuwait to \$1.0 USD/m^3, will decrease the demand 20-40%.

In chapter two, the economic and environmental benefits of water conservation using Milutinovic's price structure as a tool to eliminate the waste of water in Kuwait are evaluated. The research proposal follows the logic that if price is used to decrease/limit water over consumption, then the current desalination plants in the country will sustain the near future water demands, thus downsizing or postponing water projects. There will also be savings in fuel cost and reductions in emissions, since desalination plants in Kuwait rely on fossil fuels. A cost-effectiveness analysis approach was used to compare two scenarios, as follows:

- Scenario A: Domestic water demand under current price structure (uniform rate of \$0.60 USD/m^3).

- Scenario B: Domestic water demand under the new price structure proposed by Milutinovic ($1.0 USD/m^3 price of water, after 150L/capita/ day of free allowance).

The results of the cost-effectiveness analysis and the public perception on water demand are discussed in chapter three.

1.2 Water Resources

Kuwait is an arid country located at the north of the Arabian Peninsula and occupies a total area of 17,820km^2. The hot dry climate in Kuwait results in an annual average rain fall of 110mm, with a variability range from 31mm to 242mm. Surface runoff and groundwater recharge are rare due to high evaporation rates and insufficient duration and distribution of precipitation (1).

The main water resources in Kuwait are fresh and brackish groundwater, desalinated seawater, and treated wastewater. Wastewater is treated to the tertiary level in four plants in Kuwait; approximately 40% of the treated water is reclaimed and used for irrigation and the rest is discharged to the sea (1).

Limited fresh underground water was discovered at both Al-Rawadatain and Um-Al-Aish with an estimated natural reserve of approximately 180Mm^3 (1). However, the water demand has exceeded 506 Mm^3 in 2005 (2). The country's only natural water resource is 60 m^3/y per capita of renewable water wells, while extraction from wells is 307 m^3/y per capita (3). Currently, water is pumped from Al-Rawadatain field only at a rate of 4500 m^3/d to a bottling plant. This rate is raised to 9100m^3/d for a period of 10-15 days at a maximum of three times year when needed (2).

Brackish underground water is produced by three major entities mainly the Ministry of Energy (MOE), Kuwait Oil Company (KOC), and Private farms. It is estimated that the total output capacity of brackish water wells is 0.7 Mm^3/d with total dissolved solids (TDS) concentration ranging between 4000-9000 mg/l. Brackish water is used for blending with distilled water from desalination plants, irrigating and landscaping, household purposes, livestock watering, and construction (2).

1.3 Sea Water Desalination in Kuwait

Seawater desalination began in Kuwait during the 1950s and now it is providing about 93% of the country's fresh water. Potable water is secured by seawater desalting monitored through the Ministry of Energy: Electricity and Water, a government entity (4). There are six co-generation desalting plants (CPDP) in Kuwait producing electric power and process heat (stream) to desalinate seawater in multi stage flash (MSF) seawater desalting plants. Figure 1 shows the development of desalination plants in Kuwait since the 1950s.

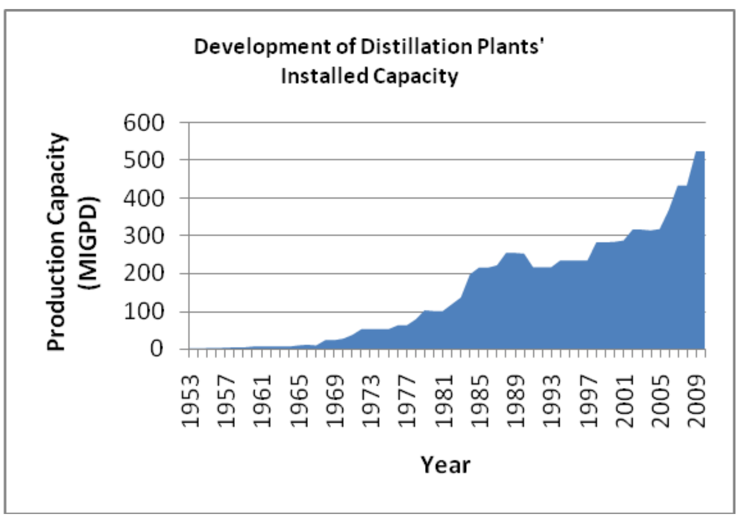

Figure 1: Development of Desalination Plants' Installed Capacity. Raw Data Source (2)

Each plant consists of multiple MSF units where seawater flows under positive pressure through a number of condensers. Seawater is heated gradually by the thermal energy (steam) of moderately low pressure (2-3 bar) extracted from steam turbines or from heat recovery steam generators combined with gas turbines (5). Up to this point, the pressure of the sea water is above atmospheric pressure and therefore below boiling pressure. In order to return to a state of equilibrium, part of the sea water flashes off such that the saturation temperature corresponds to the pressure in the stage. This process is repeated from stage to stage whereby the pressure and the temperature in each stage is less than that of the preceding stage. The brine is then discharged from the last stage by the brine pump and the distillate is drawn through from the first to the last stage condenser where it is discharged by the distillate pump (6). Figure 2 in is an illustration of MSF process.

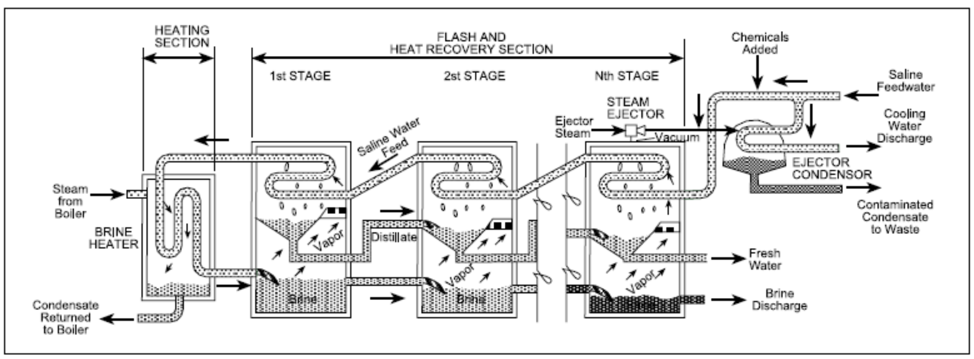

Figure 2: Diagram of Multi-Stage Flash Plant Used for Generation of Desalinated Water (6)

The success of MSF is mainly due to its simple layout and reliable performance over the years. The MSF units in Kuwait consume on average 209.9MJ/m^3, and equivalent work of 22.45 +- 2.50 kWh/m^3 (7). This is much higher than the energy consumed by reverse osmosis (RO) or multi-effect boiling (MEB) used in neighboring countries. The average energy consumed by the RO system is 5 kWh/m^3, and by the MEB is in the range of 12 kWh/m^3 when steam is extracted from steam turbines at low availability (5).

The large-scale desalination plants in Kuwait require large amounts of energy as well as specialized expensive infrastructure. The CPDPs operate by burning fossil fuels such as crude oil, heavy oil, gas oil, and natural gas to heat the sea water to generate the needed steam for power and water production. The consumption of energy for water production in Kuwait represents on the average of 18% of the total energy consumed in the cogeneration plants (8).

1.4 Desalination Cost

The cost of desalination is a major factor in implementing desalination technologies and usually is site specific. The quality of feed water is a critical design factor. Lower feed water salinity (brackish water) requires less energy and dosing of antiscale chemicals than higher feed water salinity (seawater). Large capacity plants require high initial capital investment compared to low capacity plants. However, larger plant capacity reduces the unit cost as a result of the economies of scale. As the plants increase production capacity, the marginal cost of a unit of water decreases. Site characteristics such as the location relative water source and concentrate discharge point can also affect the water production cost. Pumping, concentrate discharge, and costs of pipe installation will be reduced if the plant is located near the water source (9). Another major factor in desalination cost is variable costs which include the cost of labor, energy, chemicals, and maintenance.

The unit cost of fuels and the amount of electricity and desalted water varies depending of the plants efficiency. Fuel cost is the largest item of operating costs for any power plant, around 30–40% of the unit product cost (10). Darwish published a number of articles about desalination in Kuwait. He roughly estimated the cost of fuel energy to produce one m^3 of desalted water at \$2.762 USD/m^3 based on 209.9MJ/$m^3$and \$75 USD/barrel of crude oil (7).

Another study by Yuan Zhou, Richard S.J. Tol (11) looked at the development of desalination and its costs over time. This study considered 442 desalting plants using MSF processes worldwide over the years of 1957 to 2001, with a total capacity of 12.6 million m^3/d.

The major users of MSF technology are the Middle Eastern and North African (ME&NA) countries, such as Saudi Arabia, United Arab Emirates, Kuwait, Libya and Iran.

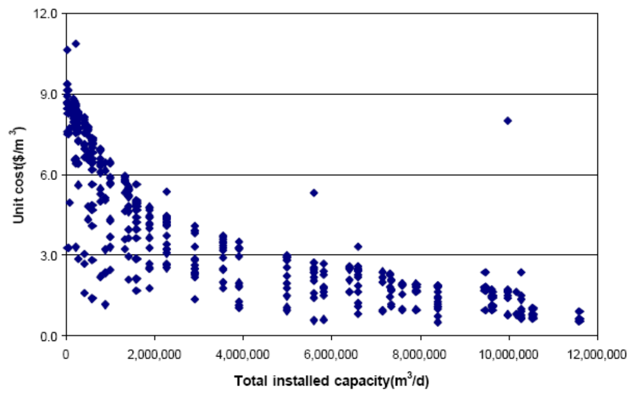

Figure 3: Unit Costs vs. Total Installed Capacity by MSF Process (11)

Figure 3 illustrates the unit costs of all the desalting plants using the MSF process over the total cumulative installed capacity. The average unit cost has fallen from about \$9.0 USD/m^3 in 1960 to about \$1.0 USD/m^3 at present, which indicates improvement of MSF technology (11). The authors used regression methods to estimate the unit costs of these desalting plants. The model for this process is specified in equation 1.

F(UNITC)=G(TIC,CAP,YEAR,ME&NA,SEA) Equation 1

Where:

UNITC = the average unit cost of desalting one cubic meter of water

TIC = the total cumulative installed capacity

CAP = the capacity of a single plant

YEAR = the contract year of the plant

ME&NA = the regional dummy

SEA = the raw water quality dummy

Figure 3 does not reflect the oil crisis in the 1970's, which had led to the dramatic increase of oil prices. The reason is that the above estimation is conducted irrespective of energy prices due to lack of information on actual energy consumption for all the plants. In order to adjust the cost of desalination to energy prices, the authors report a sensitivity analysis by calculating the unit cost over time based on the correlation between energy costs and oil prices. Figure 4 illustrates the unit costs of MSF plants with and without adjustment for oil prices. Without oil prices, there is a comparatively tighter trend than with prices adjustment. Figure 4b shows clearly higher costs during the period 1970-1985.

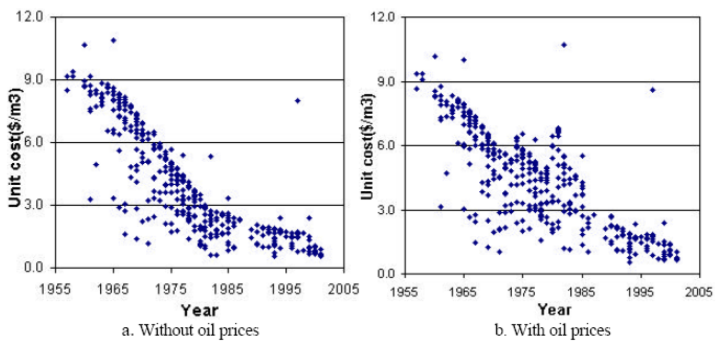

Figure 4: Sensitivity Analysis of Unit Costs Regarding Energy Costs (11)

1.5 Environmental Impacts of Desalination Plants

Desalination plants can have an indirect impact on the environment. Burning of fossil fuels to generate electricity and desalt water produces gaseous emissions such as carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) in quantities directly related to the consumed fuel energy for each desalting process.

Another major environmental problem comes from the discharge of concentrated brine, a byproduct from desalination. Concentrates are generally liquid substances that may contain up to 20% of the treated water with total dissolved solids (TDS) concentration greater than 36,000 mg/L (12).

Critical concentrate parameters are TDS, temperature (7 degree above ambient seawater temperature) (10), and specific weight (density). Concentrates are high in salinity and may contain low concentrations of chemicals such as NaOCl or free chlorine to prevent biological growth, $FeCl_3$ or $AlCl_3$ used for flocculation and removal of suspended matter, H_2SO_4 or HCl to adjust water pH, and $NaHSO_3$ to neutralizes chlorine remains in feed water (12).

These properties of concentrate can pose threats for the marine habitats and receiving water environments. Factors such as the total volume of brine being released; the constituents of the brine discharge; and the amount of dilution prior to release have potential adverse effects on marine resources. The high salt concentration of the discharge water and fluctuations in salinity levels may impact organisms near the outfall. In addition, brine has greater density than seawater and could sink towards the seabed, potentially causing adverse impacts to the local marine biota (10).

1.6 Water Demand Patterns in Kuwait

Water security depends on the availability of enough water to meet the demand of all consumption sectors at all times. These conditions are hardly met in water rich countries, as the hydrological cycle is not fully reliable. In arid countries, such as Kuwait, where there is not enough natural fresh water, water security is generally based on enough storage capacity to cover strategic and seasonal variations in consumption, non-conventional water supplies and utilization of treated wastewater. During the seventies, the oil boom, paralleled with the advances in technological innovation by the industrial world, helped to accelerate the developments in the infrastructure of Kuwait in an extraordinary manner. Recently, the rapid increase in population and vast urbanization, mainly due to the increase of income from oil, makes desalting of seawater necessary to satisfy the growing demand of freshwater.

Water use in Kuwait is divided into three sectors, mainly domestic, agricultural, and industrial (Figure 5). Domestic water use refers to the freshwater used by the residential and commercial buildings, while agricultural refers to the water used for irrigation, landscaping, and private gardens. The industrial water use covers all the industries in Kuwait except the oil sector. The domestic and the industrial sectors water usage account for 54% and 6% of the total water used in the country, while the agricultural sector water usage accounts for 40% (1). Note that the agricultural sector relies mainly on brackish water and private wells.

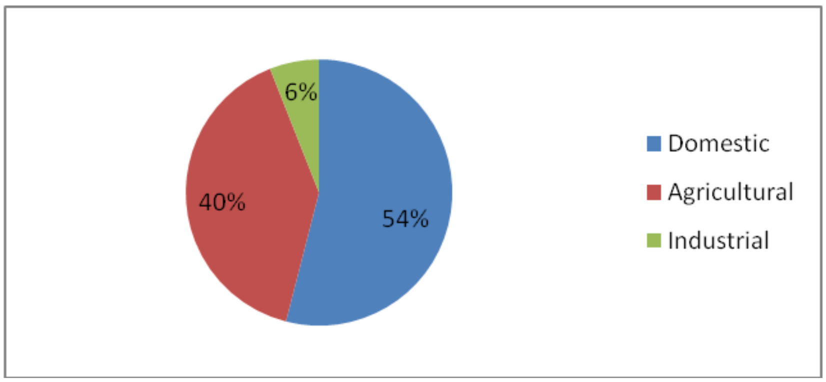

Figure 5: Water Use by Sector. Source of raw data (1)

The domestic consumption of water in Kuwait has risen dramatically during the past two decades. The total domestic water consumption has increased from 23,442 million imperial gallons (MIGs) or 107 Mm^3 in 1981 to 111,507 (MIGs) or 507 Mm^3 in 2005 (2), which represents almost 5 fold increase as shown in Figure 6. The population increase has undoubtedly impacted the water consumption in the country, from 1.4 million people in 1980 to 3 million people in 2005 (Figure 6). Nevertheless, the corresponding per capita daily water consumption has increase from 45 IG/d (205 l/d) to 100 IG/d (460 l/d) over the same period (Figure 7). The per capita consumption of freshwater in Kuwait is comparable to that in the developed industrialized countries (over 460 1/d vs USA 333 1/d and France 156 1/d).

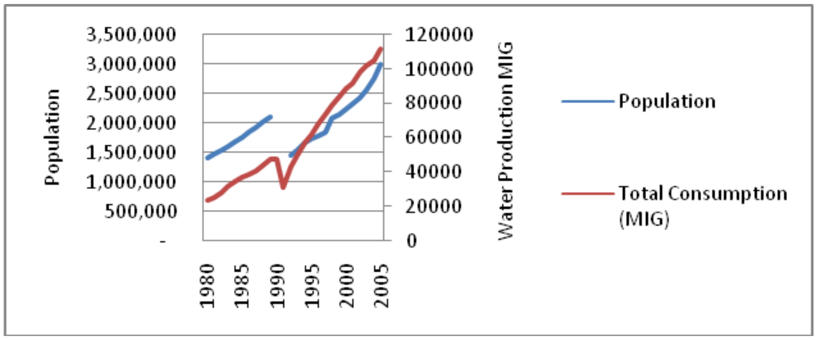

Figure 6: Annual Water Consumption from 1980-2005. Source of Raw Data (2)

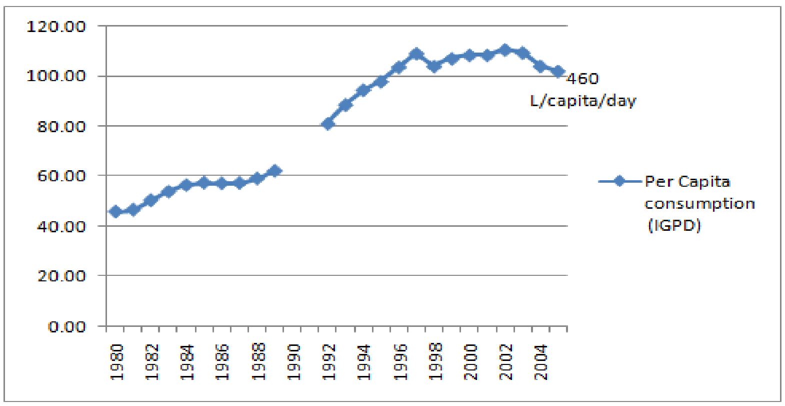

Figure 7: Annual Water Consumption per Capita from 1980-2005. Source of raw data (2)

In a report issued in 2006, the UN office in Kuwait cautioned against abuse of water, and also stated that water consumptions in Kuwait are among the highest in the world (10). There are several reasons for such high demand; lack of measures and public incentives for water conservation, lack of awareness of the water value, unaccounted-for-water (20%-25% in the Gulf region) which include water used but not paid for, as well as leakage (13), and unrealistically subsidized water prices. During the seventies, the government of Kuwait has decided to distribute the oil wealth to its citizens and residents in various ways. Among them was the decision to subsidize utilities such as electricity and water. The level of subsidies on different utilities has undergone various changes; however, no change was made to the price of water since then. Consumers pay subsidized water prices ($0.60 USD/$m^3$), while the cost of desalinated water production is currently is above $5 USD/$m^3$ (based on 2007 oil prices).

In most countries in the world a water tariff system operates to cover at least the cost of operation and maintenance, whereas in Kuwait, the Ministry of Energy (MOE) is faced by the challenge to provide an adequate supply of water with an uncontrolled demand in an industry that requires substantial investments and high operation costs. The gap between the total costs of producing desalted water and the tariffs charged is very high.

1.7 Accepted Concepts of Water Management

The three main elements of a sustainable development are economic, environmental and social. Water management concepts are the practices of planning, developing, distribution and optimum use of water resources under defined water polices and regulations. Kuwait has a serious water problem that can become a real crisis in the near future. The country's only natural water resource is 60 m^3/y per capita of renewable water wells; while extraction from wells is 307 m^3/y per capita. Desalinated seawater is the main water resource for potable water, besides low salinity brackish well water (~7% of potable water). Desalinated water represents 73.5% of total water resources, and 93% of fresh water. The water problem is a result of many factors besides limited natural resources, such as the policy used for desalination of seawater, combining desalination units with steam turbines in power plants and limited water to power production ratio imposed by the plants design, lack of timely response to match water demand increase with installed desalination capacity, lack of measures and public incentives for water conservation, unrealistically subsidized water prices ($0.60 USD/$m^3$) , lack of awareness of the water value, high cost of desalinated water production ($5 USD/$m^3$ in 2007), and other aspects. Kuwait's economy is heavily dependent on oil export revenues, and the demand for fossil fuels by CPDPs to generate power and desalt seawater is growing annually and reducing the number of barrels exported and sold in the international market, thus lowering oil export revenues.

The continued increase in water demand will continue to stress the limited water resources of Kuwait. Desalination may remain the resort for increasing the supplies to meet the demands, but only at the expense of increasing economic pressures. Because of the increasing scarcity of water resources and the significant benefits of water for society, economy and the environment, an integrated water resources management plan plays an important role in sustainable development. In energy-rich countries such as Kuwait, various strategies have been developed over the years in response to growing water demand, which call for building new seawater desalination plants using the MSF process that are energy intensive and require much time and money. The recent advances in desalination technology and the dramatic decline in cost have made desalination a viable and cost-effective solution to ensure future water supply. So, what presently remains to be done is to develop a comprehensive model for the implementation of sustainable, integrated water resources management plan in Kuwait. The plan should consider the environmental, social and economic issues of water management.

The management of water should aim to achieve the following objectives: water security, sustainable economic growth, affordable water for lower income groups which must be maintained when considering tariff structures, and cost reduction. The policy and procedure for the efficient management of water has to rely on an integrated program that places emphasis on the following major activities as shown in Figure 8.

1.7.1 Supply Management

- **Plant Efficiency**

The performance of desalination plants depends on the efficiency of the operation and maintenance. There is growing interest in employing the less costly RO process for desalination of seawater and brackish groundwater with the anticipation of declined RO capital and O&M costs.

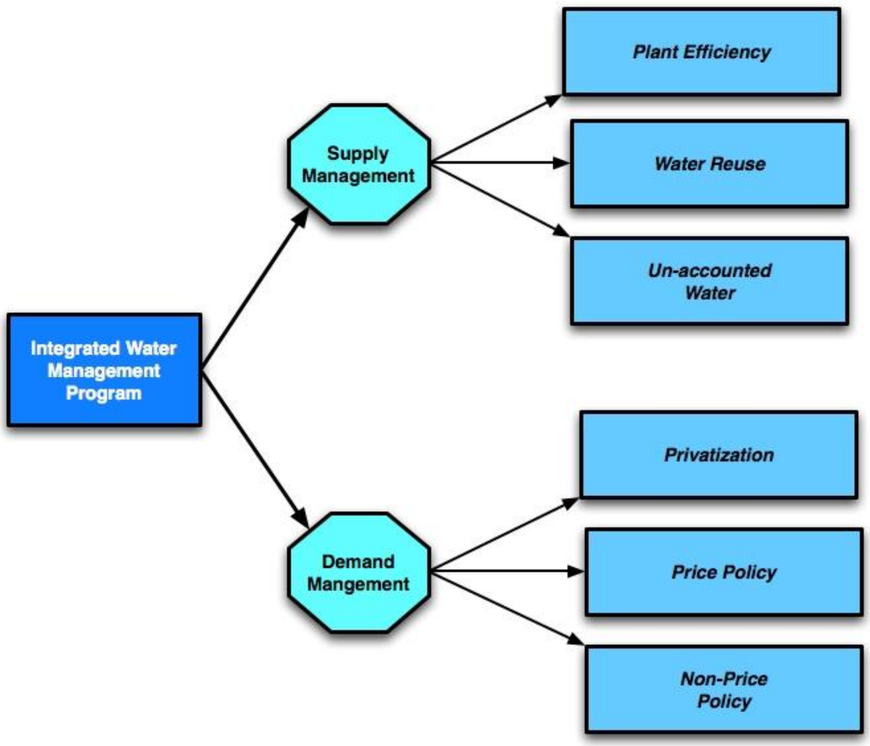

Figure 8: Holistic Approach to Water Management.

Previous studies urged the MOE to look carefully at the option of introducing a RO desalting system in future plans. Seawater desalting by the RO system has been applied successfully in Saudi Arabia and other GCC counties. The guaranteed energy consumption at the Al Fujira plant in the United Arab Emirates is 7.5 kWh/m^3 (5). This is less than 1/3 of the equivalent energy consumed by the MSF system. The 2000 MOE report stated that the 3000 m^3/d RO research project conducted by the MOE and KISR (Kuwait Institute for Scientific Research) showed the reliability of RO desalting seawater systems under prevailing local conditions. The RO desalting system is the main competitor of the MSF desalting system due to certain advantages:

- It consumes less energy.
- Continuous improvements in membrane materials.
- Production of potable water from high salinity water in the Gulf area in one stage.
- No need to be combined with a power plant or to interfere with its operation.
- It is delivered and operated in modules.

- **Network Loss**

Network loss or unaccounted-for Water (UFW) is the difference between the quantity of water supplied to a city's network and the metered quantity of water used by the customers (14). UFW has two components: physical losses due to leakage from pipes, and administrative losses due to illegal connections and under registration of water meters. The percentage of administrative losses depends on the degree of effort exerted in identifying illegal connections and in repairing meters. Reducing UFW is a crucial step to improve the financial health of water utilities and to save scarce water resources. The announced figures in the Gulf region for UFW vary from 15-20% (13). The physical losses are influenced not only by the deterioration of the piped network, but also by the total amount of water used, system pressure, and the degree of supply continuity.

- **Water Reuse**

The largest membrane-based water reclamation facility in the world was constructed in Sulaibiya, Kuwait in 2005. The facility converts 100 million gallons per day (mgd) (380,000 m^3/day) of municipal effluent (expandable to 160 mgd or 610,000 m^3/day) to 85 mgd (320,000 m^3/day) of high quality reclaimed water that will be used for agriculture, providing an alternate source to potable water in Kuwait. The project uses proven technology both for the wastewater treatment plant and for the water reclamation facility. The combination of UF and RO provides bacteria, virus and TDS removal, producing high quality water for agriculture and non-potable water applications (15). The facility, however, didn't reduce domestic water consumption since produced water is not used for potable uses.

1.7.2 Demand Management

Previously, the GGC governments have emphasized supply management, which covers the activities required to locate, develop and manage new resources. However, today they are finding it increasingly necessary to turn their attention to demand management as new water resources become more and more inaccessible and the cost of projects to augment supply escalate. Demand management includes the promotion of more desirable levels and patterns of water use. It covers both direct measures to control water use, such as regulations and technological means, and indirect methods that affect voluntary behavior, such as market mechanisms, financial incentives and public education. The mix of demand management measures may vary, but in all cases it aims to conserve water by increasing the efficiency of its use. A key issue in the management of demand is to educate the public that water can no longer be taken for granted and used extravagantly. Its production and distribution is a major burden on the budgets of GCC governments since consumers contribute only 5% to 10% of the cost.

While more attention is paid to demand management in some GCC states, in most cases it is limited to seasonal public awareness programs. Instead, it should be part of a national policy reinforced by legislation, incentives, public awareness, tariff structure and conservation, in order to direct all consumers to participate in these programs more seriously.

- **Privatization**

Currently, the water industry in Kuwait and some GCC countries is owned and operated by the government; however some countries including Kuwait are looking into privatizing the water industry. Private utility companies are run based on efficiency; therefore, the unit cost would be cheaper than that from independent authority or government managed utilities. There are two approaches which may be adapted to ensure that water and power utilities minimize their cost of operation. The industry may be restructured to increase competition where it is feasible and maximize transparency; however, the monopoly structure of the water industry in the GCC states means that government intervention may be required to bring about change. Also, the government can regulate the industry to try to ensure that the costs of the monopoly operator are minimized (16). The potential benefit from increasing efficiency in the water and power utilities sector is the likely effect on the economy. Reducing the cost of utilities will lower the government subsidies in GCC states. This in turn will lead to invest the savings in other sectors of the economy. In most countries in the world a water tariff system operates to cover at least the cost of operation and maintenance. In the GCC countries, on the other hand, the subsidies for the water and electricity sectors are so high that these utilities are either free or supplied at a nominal charge.

- **Price and Non-Price Water Policies**

In general, the level of consumption of a certain product depends not only on market interest rates, but also on the price of current consumption relative to its social cost or the price of consumption goods relative to capital goods. Under pricing goods below their social cost will lead to excessive consumption of that good. The under pricing of natural resources can stem from at least three sources. First, insecure or poorly defined property rights can lead to excessively rapid resource exploitation if the exploitation does not require much prior investment. Second, natural resource under pricing can arise from the failure of the market to incorporate the externalities associated with the use of natural resources. Examples of such externalities include the various damages from the use of fossil fuels (such as acid precipitation or climate change), or the loss of ecosystem services as flood control, water-filtration and wildlife habitat when wetlands are drained for conversion to farms for example. Third, natural resources may be underpriced because of government subsidies. The World Bank's 1992 World Development Report examined fossil fuel, electricity and water prices in 32 developing countries. In all but three of those countries, subsidies caused prices to fall below cost, even before accounting for potential externalities. Similarly, the International Energy Agency (1999) has estimated that in India, China and the Russian Federation, full-cost pricing would reduce energy consumption by 7, 9 and 16 percent, respectively (17).

One of the most effective and promising alternative to force the consumers to conserve resource is through economic incentive to those who conserve and enforcement of penalty to those wasting the resources (18). Water price policy usually refers to tariff policy which discourages high levels of consumption through price increases in higher blocks price mark-up (i.e. block pricing) and rebate schemes to encourage efficient water use in municipal water districts, at the same time without affecting the well being of the relatively poor by keeping constant lower block prices (18). There are five major types of rate schedules used in estimating water rates. These are: (a) fixed charge per period; (b) uniform rate per unit consumption; (c) peak load pricing; (d) mixed pricing; and (e) varied or block rate schedule. Non-price policy instruments are actuarial tools that do not affect the price of water, which include public education campaigns, rationing, water use restrictions and subsidies for adoption of more water efficient technologies such as low flush toilets, water saving shower heads and faucets (18).

1.8 Benefits of Water Conservation

Water conservation consists of any beneficial reduction in water losses, waste, or use. Conserving water can be beneficial in many ways, but one important reason for conservation is that it can help systems avoid, downsize, or postpone water and wastewater projects. The facilities used to treat and deliver drinking water are sized to meet demand; if the level of demand is inflated by wasteful use, people pay more in both capital and operating costs than necessary to provide safe and adequate water supply and wastewater services (19). Moreover, when the cost of supplying drinking water and processing wastewater is reduced, financial resources can be used to meet other needs. Properly planned and implemented, water conservation programs can defer, reduce, or eliminate the need for not only water supply facilities but wastewater facilities, as well. While the capital cost savings effects of water conservation are compelling enough, the potential benefits do not end there. Water conservation extends water supplies, of course, but can also reduce utility operating costs. Energy use by customers and utilities can be reduced, which saves money and reduces greenhouse gas emissions. Reducing water withdrawals also helps improve water quality, maintain ecosystems, and protect water resources.

1.9 Water Demand Models

A literature review of areas that are related to water demand was conducted. Most studies found that price has a significant impact on water demand. The use of price to manage water demand has been an issue of growing concern among decision-makers during the last decades. Economists have tried to shed some light on the effects of different types of tariffs estimating demand functions and normally focusing on the calculation of price-elasticities. Water demand models found in the literature suggest that water consumption is elastic to price increase, with a range of elasticity depending of the data and analysis methods used. The economic approach to water demand estimation uses econometric techniques to relate water consumption to some measure of the price of water and a set of explanatory variables. Most of the studies use some type of econometric model in the form $Qd = f(P,Z)$, which relates water consumption to some measure of price (P) and other factors (Z) such as income, household type, or household composition (20). However, there is no general consensus on the methodology to analyze water demand.

1.9.1 Water Demand Variables

- **Water Price**

Water demand in most cases is estimated as rather inelastic. This is because water has no substitutes for basic uses and because the customer exhibits a low level of perception of the rate structure, since water bills typically represent a small proportion of income. However, prices can play a crucial role in demand management as long as the elasticities are different from zero (20). A study by Martinez-Espineria and Nauges (21) suggests that it is probably not that useful to think about elastic or inelastic demand functions. They suggest that the water demand function will exhibit different elasticities at different levels of use and in different price ranges. In particular, water for essential uses (drinking, cooking, personal hygiene) should be expected to be highly inelastic. The amount of water used jointly with some other complementary goods (water-using appliances) is probably not very responsive in the short run to changes in prices either. The elasticity estimates are found to be almost two or three times higher than in a static framework, suggesting that previous elasticity estimates are small because residential water use does not respond immediately to price variations. This delayed reaction could be explained by the large share of water consumption dependent on durable equipment (washing-machines, dishwashers, sanitary fitting, etc.) and by the effect of habits developed over time (21).

Urban residential water pricing typically takes one of three forms: (1) a uniform marginal price; (2) increasing block prices; or (3) decreasing block prices. Under a uniform price, households pay a single volumetric marginal price at all levels of consumption. Increasing block structures charge higher marginal prices for higher quantities consumed, resulting in a water supply function that resembles an ascending staircase; decreasing block structures are stacked in the opposite direction (22). Given the type of data available, two important issues remain: (1) whether to use marginal or average price in the estimation; and (2) the simultaneity problem between price and quantity (23). The most common debate in the literature is whether to use average price or marginal price, however, a consensus has not been reached. Some researchers support the assumption that if the consumers think the water bill is significant, they will try to learn the exact pricing schedule and their consumption would be influenced by the marginal price. Otherwise, if water bills represent a small percentage of income, the consumer will react to average price.

- **Weather Variables**

Studies on water demand found that seasonal changes and climate influence water consumption. However, researchers used different variables to evaluate the effects of weather on water consumption. In the article published by Arbrues et al. (20) in 2003, he listed the different variables researchers used. Foster and Beattie (1979, 1981a) used precipitation during the growing season. Billings and Agthe (1980), Billings (1982), Agthe et al. (1986), Nieswiadomy and Molina (1988), and Hewitt and Hanemann (1995) used evapotranspiration from Bermuda grass minus rainfall. Al-Quanibet and Johnston (1985) used a variable function of temperature, minutes of sunshine, and wind speed. Billings (1987) and Griffin and Chang (1990) used average monthly temperatures, summer rain, and the ◦F by which mean temperature exceeded 58 ◦F. Stevens et al. (1992) and Agthe and Billings (1997) used temperature together with annual rainfall. In general, the studies found that summer demand is more elastic than winter demand and outdoor use is more elastic than indoor.

- **Other Variables**

House hold characteristics such as income, house size, and lot size are also expected to influence demand. Median household income is included in demand models and is expected to positively correlate with demand (18). House and lots sizes are frequently used in demand models because they are expected to have a significant influence on demand.   If the dependent variable is water use per household, household size should positively affect use. However, due to economies of scale in the use of water, the increase in water use is less than proportional to the increase in household size (20).

1.9.2 Kuwait's Water Demand Model

A study by Milutinovic (24) attempted to estimate the domestic water demand in Kuwait at various prices. The main purpose of his study was to analyze the potential impact of water pricing as a tool for managing water in Kuwait. The author attempted to develop a water model for Kuwait, however, with the lack of the data regarding household water characteristics (water consumption is generally not metered in Kuwait) and the influence that a price increase has on demand (there has not been an increase in the price of water in recent years), the perspective of his research was modified, and water demand models from the literature were adopted for Kuwait. Milutinovic used five water demand models based on studies in several arid regions:

California, Tunis, Australia, Saudi Arabia, and Spain. He performed a number of simulations analyzing the influences of different pricing schedules including constant prices, block tariffs, and free allowance followed by various pricing schemes. The author then proposed a price structure for Kuwait, a free allowance followed by a constant price \$1.0 USD/m^3. The main objective is to eliminate the waste of water by pricing it after a certain amount that would satisfy the basic needs. The quantity of the free allowance was proposed to be 150L/capita/day, which is average consumption found in European countries (Figure 10). The results of his simulations using these models (adopted for Kuwait), he concluded that a \$1.0 USD/m^3 price of water, after 150L/capita/ day of free allowance, would decrease the demand by 20-40 percent, depending on the demand model used, with an arithmetic average of %35 (24).

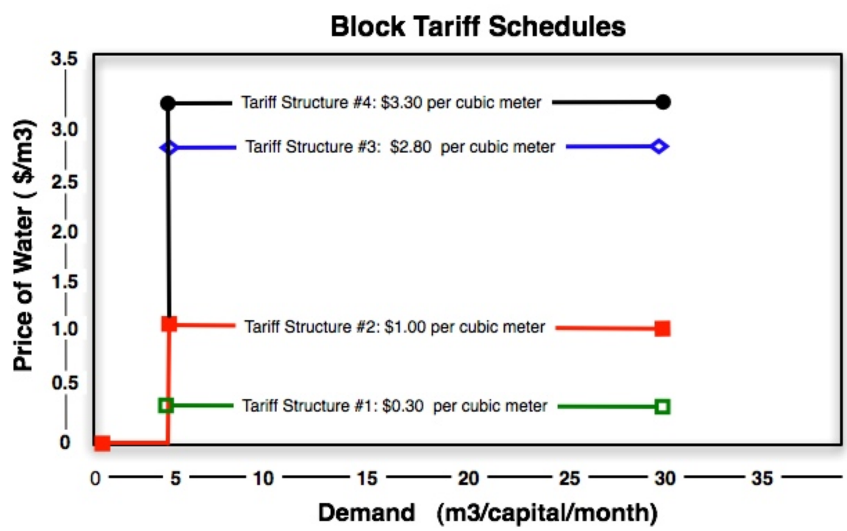

Figure 9: Price Proposal – A Free Allowance Followed by a Constant Price. Modified from (24)

- **Input Assumptions**

Since water demand models in the literature assume that demand is a function of household income and household size, Milutinovic divided consumers in groups in the following way. The data regarding household income distribution in Kuwait was not available. So, the author calculated the monthly household income based on the distribution in USA (U.S Census

Bureau), by dividing household income in the U.S by the ratio of GDP per capita in the US and in Kuwait. He assumed that Non-Kuwaitis were to have half of the GDP per capita as Kuwaitis, and income distribution was calculated in the same manner (Table 1).

Table 1 : GDP per Capita in USA and for Kuwaitis and Non-Kuwaitis (24)

	GDP per Capita	
USA	$35,721	US Census Bureau, 2004-2005 yearbook
Kuwaiti	$21,300	World Factbook, 2005 (CIA Website)
Non-Kuwaiti	$10,274	

The author divided the U.S income by the ratio of GDP for Kuwaiti and non-Kuwaiti household to the US GDP (ratio = 1.72 and ratio = 3.44, respectively), and the household income groups presented in Table 2 were assumed for Kuwaiti and non-Kuwaiti household and used as input in the simulations.

Table 2: Assumed Household Income for Kuwaitis and Non-Kuwaitis (24)

Percent of Households in each group [%]	Average Income	
	Kuwaiti (1000$/month)	Non-Kuwaiti (1000$/month)
15.8	.51	.26
25.6	1.21	.60
35	2.66	1.33
17.9	5.44	2.72
4.6	11.13	5.56

Milutinovic used household distribution data from the Economic & Financial Quarterly of the National Bank of Kuwait in the demand models and after adjusting the data. He transformed the number of houses in every category into a percentage of the total number of household (Table 3).

Table 3 : Household Size Distribution Used in the Simulations (24)

Kuwaiti	Non-Kuwaiti	HH
11%	46%	1
33%	39%	2-5
27%	10%	6-9
29%	5%	>12

1.9.3 Models Used

1.9.3.1 Saudi Arabia Model

Water consumption in four major cities in Saudi Arabia was studied by Rizaiza (25). The water demand equation in this study used a logarithmic functional form to calculate the annual water demand (Q) as a function of income (INC), average price (PRIC), family size(FSIZE), temperature(TEMP), a constant (city dependant), and garden possession GRDN (equation 2) (25).

$$Log(Q) = \alpha_0 + \alpha_1 . Log(INC) + \alpha_2 . Log(PRIC) + \alpha_3 . Log(FSIZE) + \alpha_4 . Log(TEMP) + \alpha_5 . GRDN \qquad \textbf{Equation 2}$$

Milutinovic (24) modified equation 2 to compute water demand for every consumption group in Kuwait using different prices. He assumed the average temperature to be 31C; and since data on garden ownership were not available, the garden dummy was not used. To simulate the free monthly water allowance, the author assumed that a price of \$0.1 USD/m^3 for the first $4.5m^3$/capita/month (150 L/capita/day) is close enough to free water (a zero price could not be used since the model has a logarithmic form). All consumption over $4.5m^3$/capita/month was priced at constant price rate. The coefficients were modified to Kuwait by assuming when water is free the water demand is 450 L/capita/day (average water consumption/capita in 2005).

1.9.3.2 The California Model

Renwick and Green (18) developed a model to measure the influence of price policies and non-price policies on decreasing water demand. The model is based on data in California for about 7.1 million people from eight water agencies during 1986-96. The authors used three equations in their study: household water demand, price equations and climate equations. Household water demand has a logarithmic form and was derived as a function of price variables, household income, lot size, precipitation, temperature, and non-price policies (equation 3). Milutinovic assumed that the household income is a function of household size, so a household size variable was needed in the model. However, in the original model he used, the household size is not directly incorporated in the demand equation, but it is part of the price equation. In the simulations, the household size did not have significant influence on the price elasticities; it was used to be consistent with the price proposal.

$$lnW_{it} = \beta_0 + \beta 1 \,.\, \ln(MPit) + \beta 2 \,.\, \ln(Dit) + \beta 3 \,.\, \ln(INCit) + + \sum_{i=4}^{ll} \beta i \,.\, (NPDSM) + \beta l3 \,.\, \ln(PRECit) + .LOT$$

Equation 3

Where;

i=1,….,8 agencies (cities), t = 1,….,96 months (time)

W_{it} = Household Water Demand per month

D_{it} = Difference variable (the difference between what would have been paid if all units were purchased at MP and the amount paid under the block pricing schedule)

INC_{it} = Income in $1000

HH_{it} = Number of household members

NP DSM = 8 non-price Demand Side Management (DSM) policies

PREC = precipitation

The model incorporated: price policies (MP \$0.16 - \$1.6 per m3), alternative non-price campaigns, and seasonal and climatic variability on demand in a generalized least-squares framework. The model estimated 16-20% price elasticity, also, price policy may achieve a larger reduction in aggregate demand in lower income communities that in higher income communities. To adopt this study to Kuwait, Milutinovic made modifications similar to the ones he made to the Saudi models.

1.9.3.3 The Australian Model

This study by Dandy et al. (26) analyzed the influence of an annual free allowance (136 m^3/household) in the pricing regime in the metropolitan area of Adelaide, Australia. In this model, annual water demand is specified differently for consumers that are below and above free allowance. The study showed that water demand (equation 4) above the allowed quantity (A) is more sensitive to income (or property value), climate (summer moisture deficit and winter evaporation), and pool ownership than the consumption below allowed quantity. For consumers below the free allowance, water demand is a function (equation 5) of lagged consumption Q_{-1}, property value, household, climate (Z variables) and dummy variable for year 1992 D_y.

D = 0 for Q < A

$$Q = \propto_0 + \propto_1 . Q_{-1} + \beta_1 . I + BZ + \theta . D_y + u$$ **Equation 4**

For water demand for consumers above the allowance, the author incorporated a function of price (MP and D) variables in addition to the previous variables, and different coefficients were used.

D = 1 for Q > A

$$Q = \propto_0 + \delta_0 + (\alpha_1 + \delta_1) . Q_{-1} + (\beta_1 + \gamma_1) . I + (B + \Gamma) . Z + \theta . D_y + \Phi P + u$$ **Equation 5**

Where:

Q = quantity of water consumed

A = annual allowance

I = property value

P = a vector of price variables (marginal price (MP), difference variable)

Z = a vector of other variables (household size, climate, and others)

D = variable showing id demand is above or under allowance

Q_{-1} = quantity of water consumed in previous year

D_y = 1 for year 1992 and D_y = 0, otherwise

The coefficients used in the annual static consumption mode (without lagged consumption) are presented in Table 4.

Table 4: Coefficients Used in the Static Annual Australian Model (24)

	Property value	Plot size	No. residents	No. rooms	Pool	Marginal Price	Difference variable	Constant
D = 0	0.712	.011	19.51	12.69	69.24			35.73
D = 1	0.751	0.008	2.84	2.72	-56.4	-404.4	-1.37	366.35

Milutinovic (24) used the original coefficients (Table 4) to simulate the water demand in Kuwait. D_y was not used since it is specific to Australia and lagged consumption was not included since the annual static model was used. Since property value was not available for Kuwait, Milutinovic used income instead. The income coefficient was computed so that the model would produce a demand of 450 L/capita/day for a zero price in the simulation of a free allowance followed by a constant price. The author computed the property value coefficient by assuming that the property value that of an average family own would equal to the income they earn in 133 months (11.1 years). The values of income coefficients are presented in Table 5.

Milutinovic also assumed that the annual allowance of 136 m^3 per household (2.6 members/household) or 143L/capita/day is close to the allowance that he proposed in his thesis for Kuwait.

Table 5: Income Coefficient Values for Adopting the Australia Model (24)

Possibility	Value
D<A	0.00535
D>A	0.011

1.9.3.4 Tunis Model

A model developed by Ayadi el al. (27) based on water demand data in 1980-1996 in the north African country of Tunis (Tunisia). The consumers were divided into five water consumption brackets. The lower brackets were combined into the lower block and the higher two brackets were combined into the higher consumption block based on the similarity in changes in demand. The middle bracket was not used in the model. The water demand (equation 6) is a function of income, average price, network size, rainfall and quarterly dummies.

$$Log(C) = \propto_0 + \propto_1 . Log(R) + \propto_2 . Log(P) + \propto_3 . Log(N) + \propto_4 . Log(RL) + \sum_{s=1,2,4} \propto_{5s} . QD_{st}$$

Equation 6

Portion of households in each bracket:

$$Log\left(\frac{NB}{N}\right) = \gamma_0 + \gamma_1 . Log(P) + \gamma_2 . Log(N) + \gamma_3 . Log(RL) + \sum_{s=1,2,4} \propto_{5s} . QD_{st}$$

Equation 7

Where;

C= average consumption of water per household [m^3/month]

R=average monthly income of household [$1000]

P = average price paid by household [$/month]

N = network size incorporated to capture the effect of network expansion

RL = indicator of rainfall

QD = quarterly dummy

NB = number of consumers in each bracket

Milutinovic didn't use the rainfall, quarterly dummies, and network expansion variable in his simulations. He used the first and the second Kuwaiti income groups (Table 2) to compose the lower bracket and fourth and fifth Kuwaiti income groups for upper bracket. This led to have a smaller percentage of the total population in the lower bracket, and larger percentage in higher bracket, which increases the price elasticity, because the model is specified to have a bigger elasticity for the upper group. The author calibrated α_0 coefficients to get a water demand of 450L/capita/day when the price is almost zero. Also, γ_0 coefficients were changed in order to match the group breakups. Changes made in the coefficients in adopting the Tunis model are presented in Table 6.

Table 6: Changed Coefficients for Adopting the Tunis Model (24)

		Kuwait		Tunis	
Coefficient	Description	Lower Block	Higher Block	Lower Block	Higher Block
$\alpha 0$	Interception	1.25	1.8	3.1	8.65
$\gamma 0$	Intersection	1.525	2.035	3.27	9.84

1.9.3.5 The Spanish Model

A Spanish water demand equation was developed by Martinez-Espineira and Nauges based on the Stone-Geary utility function (21). The model (equation 8) was estimated in Feasible Generalized Least Squares Framework (FGLS) using a time-series data set from Seville, Spain, which consisted of monthly values in price, consumption, income, and climate variables from 1991-1999.

$$Q_w = (1-\beta).\gamma + \beta.\frac{I_t}{P_t} + \alpha_1.BAN_t + \alpha_2.POP_t$$ **Equation 8**

Where:

Q_w = average per capita consumption

P_t = the marginal price of water

I_t = virtual income, the difference between the average salaries and the difference variable

BAN_t = binary variable, indicating the influence of the out-door-use bans

POPt = daily hours of supply restrictions

γ = the minimum consumption level (not affected by prices)

β = marginal budget share allocated to the good considered

Milutinovic used the same values of the coefficients (γ_0 and β_0) from the original model to simulate water demand in Kuwait. For income, the GDP per capita for Kuwait was used ($20,547). The BAN and restriction variables were not used in Kuwait simulations.

- **Milutinovic's Model Constrains and Assumptions**

In Kuwait, water bills are not collected efficiently which differs from the situations in the countries were original models were used. Milutinovic stated "A clear answer about what is the difference between a free situation and Kuwait's water pricing situation (water does have a pricing schedule, but bills are not collected efficiently) and how this might influence the water demand cannot be found in the water demand literature". Also, in the models used by Milutinovic, water prices increase was from a certain price significantly larger than a price zero. He also assumed that weather, density of housing, seasonal influences and other variables were constant, which might have an influence on the demand reduction.

1.9.4 Simulations Results and Discussions

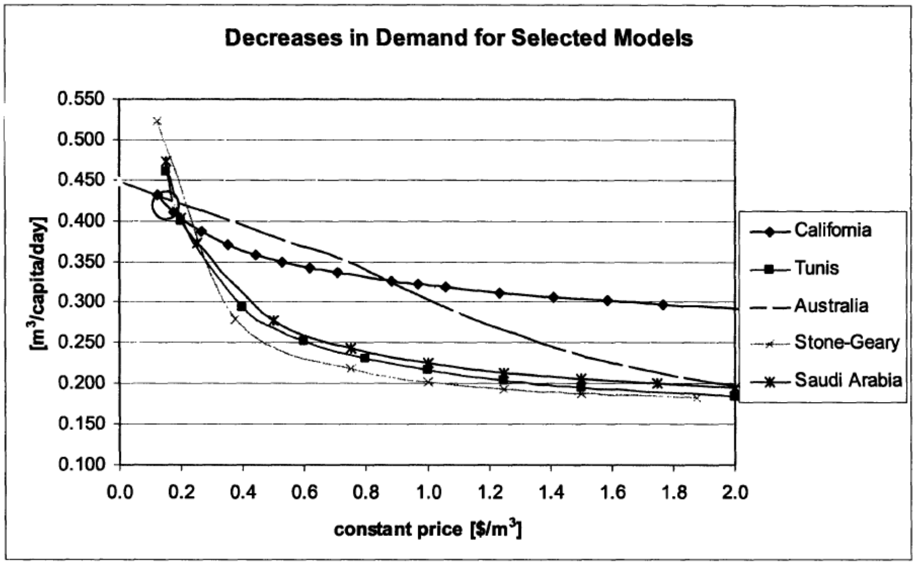

Figure 10: Decreases in Demand for Selected Models for an allowance Followed by a Constant Price (24)

Figure 11 indicate that a free water allowance 150L/capita/day (4.5 m^3/capita/day) followed by a constant water price of $1.0 USD/$m^3$ will decrease demand. The log models (Saudi, Tunis, and California) and the Stone-Geary model (Spain) showed that after a price of $1.0 USD/$m^3$ the water demand does not significantly decrease with increases in price (Figure11), indicating that there is a quantity of water that is not elastic to prices. The Linear model (Australia) suggests that a price of $1.2 USD/$m^3$ would decrease the water demand level to 200-300 L/capita/day. In general, this kind of price scheme would decrease the water demand by 25%-55% depending of the model used, with an average of 40% (24).

Since the Australian and Saudi models were based on free allowance, and in his simulations for these models he computed the initial demand for prices of $0.25 USD/$m^3$. Milutinovic presented the influence of the free allowance on demand reduction based on an initial price of $0.25 USD/$m^3$ for all demand models (Table 7).

Table 7: Reductions in Demand in Simulations at Marginal Price of $1.0 USD/$m^3$ (24)

Model	At Marginal pricing of 1 $/m3	
	Reduction from initial price of [$/m3]	With allowance of 150L/capital/day
California	0.25	17%
Tunisia	0.25	40%
Saudi Arabia	0.25	41%
Australia	0.25	28%
Spain	0.25	41%
Average		34%

1.9.5 Conclusion

In general, the California and Australia demand models projected smaller elesticities and demand reduction around 20%, the author assumed that these two models represent the lower boundary of the demand reduction. While the Tunis, Saudi, and Spain models have similar results of around 40% reduction in demand, and represent the upper boundary of the demand reduction (24).

Chapter 2: Economic and Environmental Analysis of Kuwait's Water Demand Model

2.1 Goals and Objectives

The main objective of this study is to identify the economic and the environmental benefits of water conservation using Milutinovic's price structure (24) as a tool to eliminate the waste of water in Kuwait. The research proposal follows the logic that if price is used to decrease/limit water over consumption, then the current desalination plants in the country will sustain the near future water demands, thus downsizing, or postponing water projects. There will also be savings in fuel cost and reductions in emissions, since desalination plants in Kuwait rely on fossil fuels. To do so, a cost-effectiveness analysis approach was used to compare two scenarios. The scenarios considered are as follows:

- Scenario A: Domestic water demand under current price structure (uniform rate of $0.60 USD/$m^3$).
- Scenario B: Domestic water demand with under price structure proposed by Milutinovic ($1.0 USD/$m^3$ price of water, after 150L/capita/ day allowance).

2.2 General Approach

The EPA document, USEPA Water Conservation Plan Guidelines, suggests basic planning steps that apply generically to water conservation programs (19). These steps were modified to fit Kuwait;

2.2.1 Conservation Planning Goals Identification

Kuwait is an arid country with limited natural resources. Currently, water is over consumed in the country, 460 L/capita/day, when compared to countries with abundant water supplies (USA 333L/capita/day ; France 164 L/capita/day; Germany 127 L/capita/day). Kuwait continues to meet the growing demand of water by following a supply-side approach, by increasing the number of desalination units or increasing their output, rather than controlling demand. In this study, the goals of the conservation plan are to eliminate the waste of water; postpone water projects; reduce emissions associated with water production; and lower the government's subsidy (cost).

2.2.2 Water System Profile and Planned Facilities

Currently, there are six co-generation desalting plants (CPDP) in Kuwait producing electric power and process heat (stream) from multi stage flash (MSF) seawater desalting plants (Table 8). The locations of these plants are shown in Figure 12. The present design of the MSF processes requires close to 209.9 kWh/ m^3 of total power, which includes electricity and heating steam (7). This value is close to four times that required by the RO process. However, the membrane replacement cost, extensive feed treatment, and lower plant factor for the RO process offset this large difference in energy (28).

The success of MSF is mainly due to its simple layout and reliable performance over the years. Based on the MSF operational experience in Kuwait, these MSF plants will form the backbone of the Kuwait desalination industry up to 2030 (28). Information from the MOE statistical year book 2005 (2) shows that there will be two major plant expansions in the future. By the end of 2008, another 5 x 15 MIG/day MSF units will be in service. Also, in 2011, a further 5 x 12.5 MIG/day MSF units will be in service (Table 8).

2.2.3 Water Demand Forecast

This section presents the water demand forecast in Kuwait for years 2008-2012 assuming no changes in current price structure (scenario A). The time frames for water conservation plans vary from country to country. The proceedings of the U.N seminar on long-term planning of water management indicated that countries in the Economic Commission for Europe generally

Figure 11: CPDPs Locations (Blank map from Wikipedia)

Table 8: Production Capacities of Seawater Distillation Plants in Kuwait. Source of Data (2)

Station	Shuwaikh	Shuaiba South	Doha East	Doha West	Az-Zour South	Sulaibiya	Future Water Projects	
Year of commission	1960	1971	1978	1983	1988	2006	2008	2011
No. of Units (distillers)	3	6	7	16	16	8	5 MSF	5 MSF
Installed Capacity [MIG/d]	19.5	30	42	110.4	115.2	100	90	75

use periods ranging from 10 to 50 years, and the U.S. and Canada generally use 50-year periods for long term studies (29). In countries with planned economies, the long term planning period in usually 15 years (29). The EPA Water conservation plan guidelines suggest that planners prepare water demand forecast for 5, 10, and 20 year intervals. However, the longer the planning horizon, the greater will be the uncertainty of the forecast. Due to uncertainties in the future population in Kuwait and future consumption patterns, the time frame for this study is set to a 5-year period.

To forecast the water demand for a 5-year period (2008-2012), the first step was to estimate the future population. Data from the (2) showed that the population in 2006 was 3.1 million people. Assuming the current ratio of Kuwaiti to non-Kuwaiti residents will remain the same, the total population of Kuwait by year 2012 will be around 3.8 million, assuming a growth rate of 3.5% in 2007 (30). Using the average per capita consumption of domestic water (107.14 IG/d -+ 2.98 from 1997-2005) reported by the MOE, the annual water demand for Kuwait's future population was estimated by multiplying the number of people (2008-2012) by the average water consumption per capita. Daily and seasonal variations in water consumption were not considered. Water consumption from 2004 to 2007 and projected water consumption for (2008-2012) are presented in Figure 14.

2.2.4 Water Conservation Measures

The water demand in Kuwait forecast from year 2008-2012 under new water price policy proposed by Milutinovic ($1.0 USD/m^3 price of water, after 150L/capita/ day of free allowance) is presented in Figure 14. As mentioned above, the results of the simulations using various water demand models adopted for Kuwait showed that a $1.0 USD/m^3 price of water after 150L/capita/ day allowance would decrease the water demand by 20-40 percent, depending on the demand model used, with an arithmetic average of %35. To forecast the water demand for the 5-year water plan under the new price scheme, the lower boundary (20 percent) of demand reduction was used. The lower boundary was used to simulate the demand from 2008-2012 for the following reasons: Milutinovic didn't include the GRDN dummy and rainfall when using the Saudi and Tunis models to estimate water demand in Kuwait. Even though the Spain model is based on Stone-Geary utility function, Milutinovic assumed that 150 L/capita/day is the inelastic amount of water use for Kuwaiti use. This quantity was based on the average water consumed in European countries. These assumptions over estimated the elasticities of water prices which resulted in the upper boundaries of the demand reduction. Moreover, %40 reduction in water demand seems unrealistic.

The new price structure policy is implemented in 2008. To simulate the effect of the new water price on demand, it was assumed that consumers would respond to the increase in price by adjusting their water consumption habits after approximately 1 year from implementing the new policy. The assumption was based on a study by Renwick and Archibald (31), where they evaluated the effects of demand side policies on water demand in Santa Barbara, CA between 1985 and 1990. In August 1988 Santa Barbara offered free low flow shower heads and rebates for the adoption of low flow toilets (REBATE) shown in Figure 13. In June 1989, as water became progressively scarce due to drought, the city implemented its first price policy and moved from per unit uniform rates to an increasing block price structure (PRICE1) in Figure 13. From Figure 13, the water demand had dropped approximately %32 due to (REBATE) and %29 due (PRICE1) after 1 year from implementing each policy.

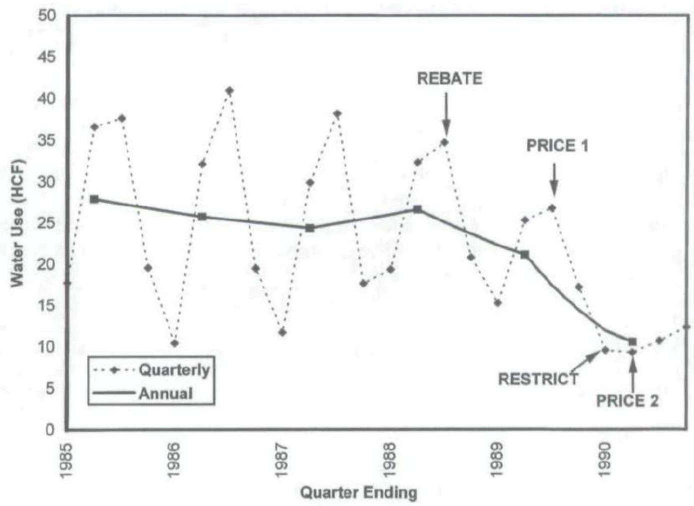

Figure 12: Trends in Santa Barbra's Mean Water Use Under Alternative DSM Policy (1980-90) (31)

Figure 14 presents the development of desalination water production capacity in Kuwait from 2004 to 2012. Currently, the six CPDPs have a total maximum production capacity of 152,241 MIG/y or 692 Mm^3/y. Also, the Figure shows future water demand under scenarios A and B from 2008 to 2012.

2.2.5 Analyze Benefits and Costs

- **Water Production and Consumption**

Under scenario A, the total amount of water consumed in the 5 years is around 696.4 billion IGs, and by 2012 the water demand will exceed the current desalination capacity. Under scenario B, however, the total amount of water consumed in the same period is approximately 583.1 billion IGs, also, current water production capacity will meet future water demand until 2020. Implementing the price structure proposed by Milutinovic (24) will save approximately 113.3 billion IGs over 5 years. This is 16.2% of water savings when compared to water that will be produced under scenario A over the same period. The 113.3 billion IGs roughly equal the volume of water consumed in 2005.

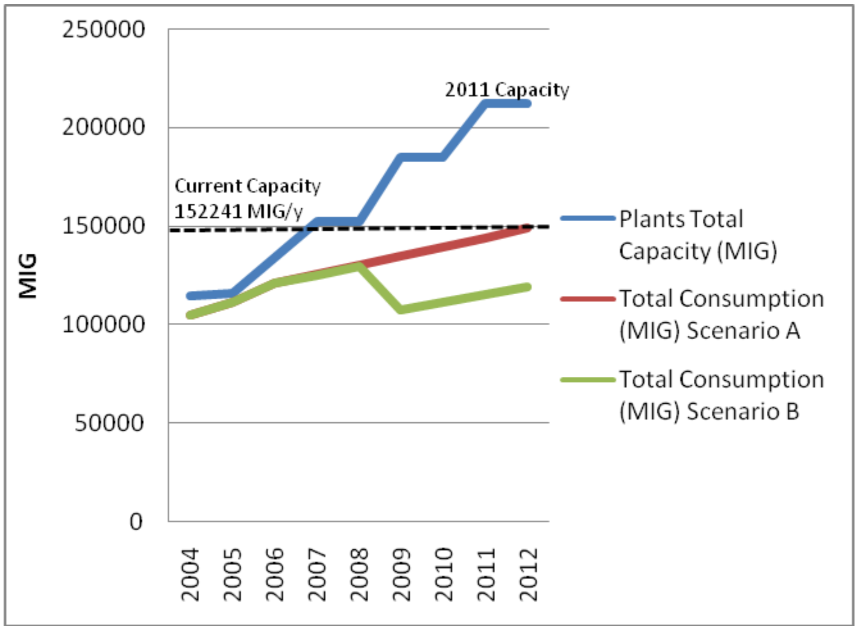

Figure 13: CPDPs Production Capacity and Water Consumption Under Scenarios A and B.

- **Fuels**

As mentioned before, the CPDPs rely on burning fossil fuels to generate the energy needed to desalinate seawater. Besides the thermal energy required to operate MSF desalting units, mechanical energy is also required to operate pumps, such as the re-circulation pump, cooling water pump, brine blow-down pump, distillate product pump, condensed steam pump, and auxiliary pump, used in the system (32). Thus, the average energy (thermal and mechanical) consumed by MSF units in Kuwait is 209.9MJ/m3 or 904.431 BTU/IG (7).

The MOE uses four types of fossil fuels, crude oil, heavy fluid oil (HFO), gas oil, and natural gas to operate the six CPDPs. These fuels are used in different volumes depending on the plant's location to fuel source. For example, in 2005 the Shuwaikh and Shuaiba stations used gas oil and natural gas only, Doha West station used HFO and natural gas, while the other three stations used all four fuels. Moreover, crude oil is not used year round in some stations; while, Az-Zour South station only used crude oil in the months from June to October when the demand for electricity and water is higher than it is for the rest of the year. The MOE statistical year book 2005 (2) and data from (33) reported fuel consumption for all CPDPs from 2001 to 2005 in terms of total annual BTUs generated from each fuel. An annual BTU average ratio for the fuels used in all six plants was determined by averaging BTU fuel ratios from 2001 to 2005 (Figure 15). To determine the energy (fuel) needed to desalinate sea water to meet the future domestic water demand over the 5-year water plan, the volume of water for each year (2008-2012) was multiplied by the average energy consumed by a MSF to desalinate 1 imperial gallon of sea water, 904.431 BTU/IG.

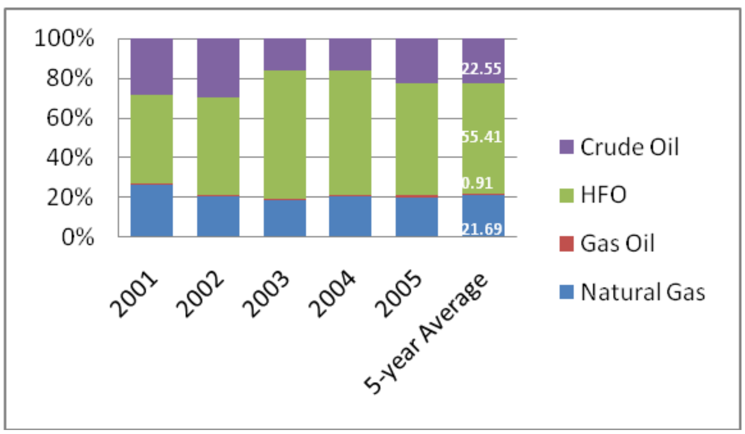

Figure 14: Percentage of Fuel Consumption from 2001-2005. Source of raw data (33)

Tables 9 and 10 present the total BTUs required to produce desalinated water over the 5-year period for scenarios A and B. Assuming that the average BTU fuel ratios (Figure15) remain constant over the 5 years, the total BTUs are divided for each fuel based on Figure 15 as follows: 22.55% of the total BTUs needed to desalinate water in each year will be generated from crude oil, 55.41% from HFO, 0.91% from gas oil, and 21.69% from natural gas. The fuel volumes were computed using the net calorific values (BTU/bbl) for HFO, Gas Oil, and Crude Oil in Table 14, and net calorific values (BTU/SCF) for natural gas in Table 15. Total energy required to meet the future water demand in Kuwait for 5 years under scenarios A and B is shown in Tables 9 and 10. Implementing the new price scheme starting in year 2008 will reduce the energy consumed by CDCPs by around 16.2%. This is an equivalent of 4.32 million barrels of Crude Oil, 172 thousand barrels of Gas Oil, 10.12 million barrels of HFO, and 21,421 million SCF of Natural gas. Currently, Kuwait exports Crude Oil only, however, the market price for fossil fuel reflects the opportunity cost incurred for burning the fuels rather than selling them at market price.

- **Costs**
  - **Fuels Cost**

In this study, only fuel cost is considered due to lack of information on other costs associated with water production such as labor, O&M, and chemicals cost. The MOE purchases fuels from Kuwait Oil Company (KOC) and Kuwait National Petroleum Company (KNPC) at market prices. To determine the cost of fuels needed for future water production from, the future prices of oil must be obtained. Due to the uncertainties in crude oil prices in the long run, crude oil prices were forecasted for years 2008 to 2012. The year 2012 is when domestic water demand exceeds the current production capacity of the existing CPDPs in the country, and an expansion is required.

Historic prices for Kuwait crude oil (Kuwait Export) were obtained from the U.S Energy Information Administration (34). The prices were originally given in nominal dollar values from 1997 to February 2008. Kuwait Export prices were adjusted to 2008 dollar values using the consumer price index (CPI) for Kuwait reported by U.N. (35). Since this analysis was conducted in March 2008, the CPI for year 2008 was assumed to be similar to year 2007 CPI. The

Table 9: Annual Fuel Consumed by CPDPs to Produce Water Under Scenario A

Scenario A	Water consumption (MIG)	Million BTU	Crude oil [bbl]	Gas Oil [bbl]	HFO [bbl]	Natural gas [Million SCF]
2008	129863	117,452,520	4,834,282	196,445	11,603,086.1	24,551
2009	134409	121,563,358	5,003,482	203,320	12,009,194	25,410
2010	139113	125,818,076	5,178,604	210,437	12,429,516	26,299
2011	143982	130,221,709	5,359,855	217,802	12,864,549	27,220
2012	149021	134,779,468	5,547,450	225,425	13,314,808	28,172
Total	696388	629,835,131	25,923,672	1,053,429	62,221,153	131,652

Table 10: Annual Fuel Consumed by CPDPs to Produce Water Under Scenario B

Scenario B	**Water consumption** (MIG)	**Million** BTU	**Crude oil** [bbl]	**Gas Oil** [bbl]	**HFO** [bbl]	**Natural gas** [Million SCF]
2008	129,863	117,452,123	4,834,266	196,444	11,603,046.9	24,550
2009	107,527	97,250,752	4,002,788	162,656	9,607,362	20,328
2010	111,290	100,654,126	4,142,869	168,349	9,943,580	21,039
2011	115,186	104,177,789	4,287,901	174,242	10,291,681	21,776
2012	119,217	107,823,551	4,437,959	180,340	10,651,844	22,538
Total	583,083	527,358,341	21,705,783	882,032	52,097,514	110,231

forecasted prices were based on an 18 month standard deviation, August 2006 to February 2008, added to the price of oil in the previous year. For example, the price of Kuwait Export in 2008 was computed by adding the 18-month standard deviation, 12.489 USD/bbl, to the average price of Kuwait Export in 2007, 66.406 USD/bbl. Figure 16 illustrates the historic and projected Kuwait Export prices (USD/bbl) expressed in 2008 dollar values.

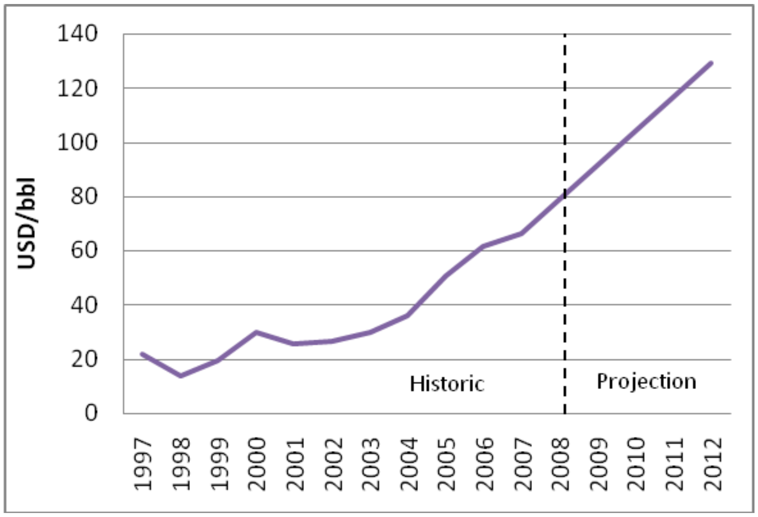

Figure 15: Kuwait Export Price Forecast. Source of Historic Prices (34)

In addition to crude oil, CPDPs use Gas Oil, HFO, and Natural Gas. The prices of these fuels are related to crude oil prices. Figure 17 illiterates the actual prices of the different fuels between 2003 and 2005 reported by (33) in Kuwaiti Dinar (KD). The Figure shows positive correlation between crude oil price and other fuels prices. On average, the crude oil price to gas oil price ratio is .741, crude : HFO is 1.095 , and crude : natural gas is 1.974. Note that crude to natural gas ratio is in MSCF/bbl. Based on this correlation, future prices for these fuels were obtained relative to forecast crude oil prices (Figure 18).

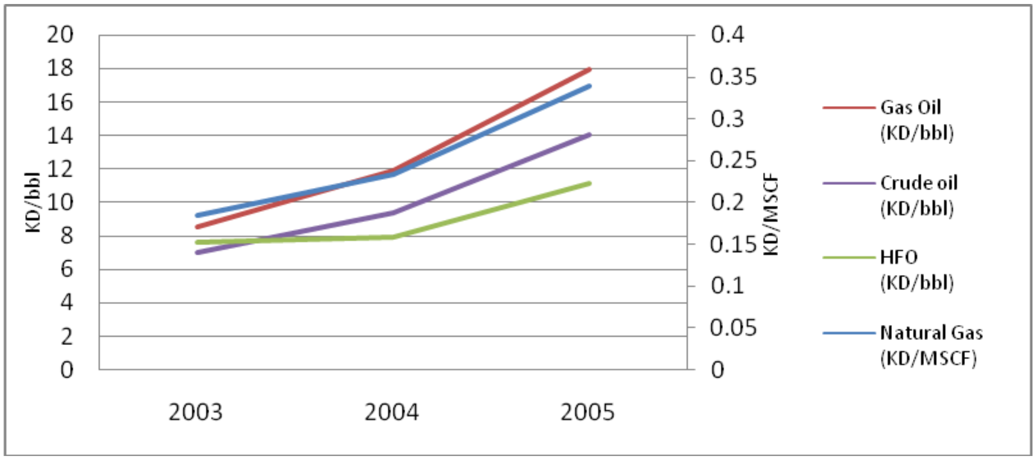

Figure 16: Actual Prices of Different Fuels from 2003-2005. Source of Faw Data (33)

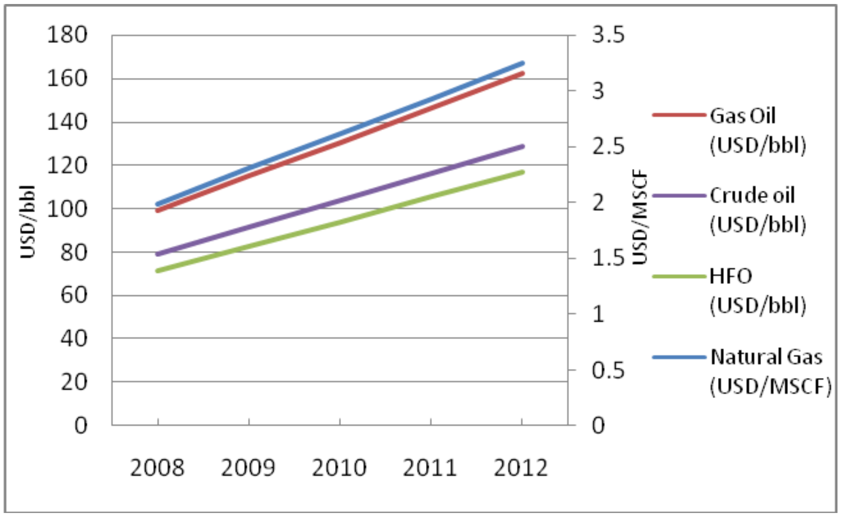

Figure 17: Projected Prices for Different Fuels

The cost of fuels needed to desalinate seawater to meet the water demands under scenarios A and B was computed based on the following equation:

$$C_i = P_{crude,i}V_{crude,i} + P_{gas\ oil,i}V_{gas\ oil,i} + P_{HFO,i}V_{HFO,i} + P_{NG,i}V_{NG,i}$$

Where;

C_i = Total fuel cost in terms of 2008 dollar value for year i (USD).

P = price of fuel at year i (USD/volume).

V= Volume of fuel at year i, (Tables 9 and 10)

The cost of fuels from year 2008 to 2012 is presented in Table 11 for both scenarios A and B. The MOE will save around 1.5 billion USDs from fuel savings in 5 years by implementing the water price scheme proposed by Milutinovic.

Table 11: Cost of Fuels [$ USD]

Scenario A	Crude oil [USD]	Gas Oil [USD]	HFO [USD]	Natural Gas [USD]	Sub Total
2008	381,794,449	19,529,675	829,315,391	48,861	1,230,688,376
2009	457,695,674	23,412,199	994,184,353	58,574	1,475,350,801
2010	538,442,287	27,542,577	1,169,578,231	68,908	1,735,632,003
2011	624,280,486	31,933,400	1,356,031,805	79,893	2,012,325,584
2012	715,467,767	36,597,842	1,554,104,395	91,563	2,306,261,567
				Total	8,760,258,330.26
Scenario B					
2008	381,793,158	19,529,609	829,312,587	48,861	1,230,684,214
2009	366,156,786	18,729,772	795,348,018	46,859	1,180,281,436
2010	430,752,397	22,033,988	935,659,474	55,126	1,388,500,985
2011	499,426,413	25,546,824	1,084,829,842	63,915	1,609,866,994
2012	572,374,085	29,278,267	1,243,283,238	73,250	1,845,008,841
				Total	7,254,342,470.16

- **Water Projects Cost**

As previously mentioned, by the end of year 2012, the water demand under scenario A will exceed the current desalination capacity. To meet this demand, the MEW will need to construct new desalinations plant or increase the current production capacity by adding more MSF units. Under scenario B, however, current water production capacity will meet future water demand until 2020. Wade (36) estimated the capital costs of MSF plants based on 31,822m^3/day desalting capacity, values are in 10^6 USD (Table 12). The author estimated that the capital cost of constructing new desalination plant producing 31,822 m^3/day is 51.4 million USD in 2001. Based on the information provided in the MOE statistical year book 2006, the ministry is planning to expand the existing capacity by 75 MIG/day by the end 2011 (Table 8). Adjusting the total capital cost in Table 12 to take into account only the expansions; capital costs for seawater intake and outfall, foundations, buildings, finance charges, and engineering and contingency were not considered part of the total capital cost. Thus, the total capital cost for 31,822 m^3/day expansion is 34.5 million USD in 2001, this is the equivalent of 39.491 million USD in 2008. That is 1,241 USD /m^3. So, an expansion of 75 MIG/day (340,956 m^3/day) will need a capital of 423.125 million USD in 2008 dollar values.

- **Cost of Policy Implementation**

The costs associated with implementing a water pricing scheme are the cost of research and information collecting, and the cost of changes in billing and metering practices. Milutinovic stated that water usage is usually not metered and water bills collection is inefficient. The law in Kuwait prevents utilities, MOE, from disconnecting services such as water and electricity from consumers even if bills are not paid. However, consumers are required to pay the water bill in full before selling their homes. So, implementing the new price scheme will require changes in the country's water policy. The decision making process is costly and time intensive. The MOE will need the approval of the National Assembly, the legislative entity in Kuwait, to implement the price scheme in the county. The effectiveness of a price rate relies on efficient billing and metering which require financial investments in metering devices, for example, and enforcement in terms of monitoring and collection.

Table 12: Capital and Operation Costs (36)

Total plant capacity:	
migd	7.0
m^3/d	31,822
Load factor (water), %	90
Annual production, Mm^3/y	10.5
CCGT rating, MW	105
Reference cycle efficiency (average), %	52
Actual cycle efficiency, %	38
Energy to power = (Actual cycle efficiency/ref. cycle efficiency)	0.7308
Energy cost, US $/GJ	1.5
Power cost, US $/kWh	0.03
Plant life, y	25
Discount rate, %	8
Amortization, %	9.37
RO membrane replacement, % pa	20

	Process costs			
	MSF	MED	RO	RO+brine booster
Capital costs, in US $ (millions):				
Distillers installed	34.5	32.4	—	—
RO plants installed	—	—	28.7	25.5
Seawater intake and outfall	2.8	2.6	2.0	1.8
Foundations and buildings, 15.0%	5.6	5.2	4.6	4.1
Financing during construction, 10%	4.3	4.0	3.5	3.1
Engineering and contingency, 10%	4.3	4.0	3.5	3.1
Total	51.4	48.3	42.4	37.7
Unit costs, in US $/$m^3$:				
Energy —				
Heat	0.242	0.219	0.000	0.000
Power	0.109	0.070	0.128	0.106
Operation and maintenance	0.126	0.126	0.126	0.126
Spares	0.082	0.082	0.033	0.033
Chemicals	0.024	0.024	0.047	0.047
Membranes	0	0	0.110	0.098
Capital charges	0.461	0.433	0.380	0.338
Total	1.043	0.953	0.823	0.747

The cost of implementing a rate design change can be summarized as follows:

Cost of Policy = *f* (research and information, hardware and software, metering and billing, other administrative costs)

To evaluate the economic efficiency of the pricing program, these costs should be compared to the benefits achieved from water saving. Due to the lack of information on such costs for Kuwait, the price tag of implementing the water price scheme in unknown. Thus, scenario B is considered economically efficient only if the economic benefits from water saving under scenario B over the 5-year water plan exceed the costs of implementing the new price scheme. The overall cost of scenarios A and B over 5 years (2008-2012) is summarized in Table 13. Since one of the goals of this water conservation plan is to reduce cost, the cost of policy implementation is the determining factor in whether scenario B is economically feasible. However, this cost-benefit analysis was conducted for 5 years only, which does not reflect the long terms benefits of water saving. Also, the environmental benefits, such as lower emissions from desalination plants, of this water conservation plan were not included in the analysis.

Table 13: Cost Analysis of Scenarios A and B, [USD].

	Scenario A	Scenario B
Water Production	8,760,258,330	7,254,342,470
Water Projects	423,126,396	None
Policy Implementation	None	Unknown
Total Cost	9,183,384,726	7,254,342,470+ cost of policy*

*The cost of policy is unknown for Kuwait.

- **Emissions**

There are number of methods to estimate emission, and the mass balance method is used in this study. Mass balance is a method that estimates emissions by analyzing inputs of raw materials to an emission unit and accounting for all of the various possible outputs of the raw materials in the form of air emissions, wastewater, hazardous waste, and/or the final product (37). Fuel analysis can be used to predict emissions based on the application of mass balance. The presence of certain elements in fuels may be used to predict their presence in emission streams. Equation 9 was used in fuel analysis emission calculations:

ER = R * PC * (MWp/MWf) **Equation 9**

Where:

ER = pollutant emission rate

R = fuel flow rate

PC = pollutant concentration in fuel

MWp = molecular weight of pollutant emitted

MWf = molecular weight of pollutant in fuel

For example, SO_2 emissions from oil combustion can be calculated based on the concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every pound of sulfur (MW = 32 g) burned, 2 lb of SO_2 (MW = 64 g) are emitted. The emissions released from burning fossil fuels depend on the properties of the fuels used (Tables 14 and 15). Combustion efficiency, also, plays an integral part in the quantity of gases emitted into the atmosphere. The average combustion efficiency of CPDPs in Kuwait is 78.38% (7). Data on fuel properties used by the CPDPs in Kuwait were gathered from (33). In this section, the annual emissions of CO_2, NO_2, and SO_2 from each of the fuels are calculated based on the volume of fuels used to produce water over the 5-year period.

- **Emissions from Liquid Fuels**

Emissions from liquid fuels (HFO, Gas Oil, and Crude Oil) were estimated using fuels chemical properties data provided by (33).

Table 14: Liquid Fuels Properties. Source of raw data (33)

Content	Units	HFO	Gas Oil	Crude Oil
Carbon Residue , Conradson	% wt	11.36	0.038	10.0*
Sulfur	% wt	3.391	0.332	2.645
Nitrogen	% wt	0.4*	N/A**	0.14*
Net Calorific Value	BTU/bbl	5609002.36	5440804.20	5480149.93
Specific Density	bbl/M.T	6.487	7.438	7.192

*Cited from (10) (38) ** Very low value, assumed to be zero in calculations

Conradon carbon residue (ash) is the amount of carbon residue left after the combustion of petroleum products. The annual emissions rate in kilograms per year of carbon dioxide, sulfur dioxide, and nitrogen dioxide were estimated using the following equations:

$C + O_2 \longrightarrow CO_2$

CO_2 [Metric Ton] = (.7838) (100 - %wt carbon residue) ($\frac{44\ CO2}{12\ C}$) (density [M.T/bbl]) (Volume [bbl])

$S + O_2 \longrightarrow S\ O_2$

SO2 [Metric Ton] = (.7838) (Sulfur content) ($\frac{2\ SO2}{1\ S}$) (density [M.T/bbl]) (Volume [bbl])

$N_2 + 2O_2 \longrightarrow 2\ NO_2$

NO_2 [Metric Ton] = (.7838) (Nitrogen content) ($\frac{42\ NO2}{28\ N2}$) (density [M.T/bbl]) (Volume [bbl])

- **Emissions from Natural Gas**

Natural gas consists of various type of gases mainly methane, ethane, and propane, and it has different chemical and physical properties at different pressures (Table 15). The CPDPs use Natural gas at both low and high pressure depending the plant's design. However, since the plants didn't report on usage ratios of natural gas at different pressures. The emissions from natural gas will be expressed in a range from low to high.

Table 15: Properties of Natural Gas used in Kuwait (33)

Content	Units	Average @LP	Average @HP
C1 Methane	%	79.72	87.91
C2 Ethane	%	15.00	8.74
C3 Propane	%	1.96	0.80
iC4 iso-Butane	%	0.35	0.15
nC4 n- Butane	%	0.59	0.22
iC5 iso-Pentane	%	0.19	0.14
nC5 n- Pentane	%	0.14	0.11
C6 Hexane	%	0.00	0.00
C7+ Heptane	%	0.00	0.00
H2S Hydrogen Sulphide	%	0.03	0.01
O2 Oxygen	%	0.00	0.00
H2 Hydrogen	%	0.00	0.00
Co2 Carbon Dioxide	%	1.67	1.57
N2 Nitrogen	%	0.36	0.36
H2S Hydrogen Sulphide	ppm	473.53	291.14
RSH Mercaptan Sulphur	ppm	N/A	N/A
Net Calorific Value	BTU/SCF	1092.67	982.77
Net Gas Density	lb/SCF	0.05	0.05
Net Specific Density	SCF/TON	41900.45	44156.07

In this analysis, carbon dioxide emitted from butane and pentane was assumed to be zero because the percent by weight of these gases is close to zero. The carbon dioxide emitted from burning natural gas is the sum of CO_2 produced when methane, ethane, and propane are combusted in the present of oxygen, and the release of CO_2 already present in natural gas. The combustion of natural gas has is assumed as follows

Methane: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Ethane: $2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Propane: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Nitrogen: $N_2 + O_2 \rightarrow 2NO_2 + H_2O$

Hydrogen Sulfides: $2H_2S + 3\ O_2 \rightarrow 2\ SO_2 + 2H_2O$

The basic equation used to estimate the CO_2, NO_2, and SO_2 emitted by burning natural gas is:

Mass [Metric Tons] = (.7838)(% wt)(MWp/MWf)(density [M.T/SCF])(Volume of natural gas)

Tables 16, 17, and 18 present the annual emissions of CO_2, NO_2, and SO_2 respectively. Table 19 presents the total emissions under both scenarios. Since the natural gas is used at low or higher pressure at different plants, the total emissions are shown a range from high (upper boundary) to low (lower boundary). On average, plants producing water under scenario B emit 16.2 % less emissions than plants producing water under scenario A.

- **Application of Emission Factors in Ranking Gaseous Emissions**

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. It is expressed as a ratio of the amount of a pollutant emitted per throughput of material, for example, pounds of NO_x per gallon of residual oil burned (37). Emission factors are founded on the

Table 16: CO_2 Emissions [M.T], Values Are Corrected for Ash.

Scenario A		From Crude Oil	From Gas Oil	From HFO	From NG @ LP	From NG @ HP	Total (upper boundary)	Total (lower boundary)
	2008	1,738,608	28,348	4,557,087	1,242,581	1,164,615	7,566,624	7,488,658
	2009	1,799,458	29,340	4,716,584	1,286,071	1,205,377	7,831,453	7,750,758
	2010	1,862,440	30,368	4,881,666	1,331,083	1,247,564	8,105,557	8,022,037
	2011	1,927,626	31,430	5,052,525	1,377,671	1,291,228	8,389,251	8,302,808
	2012	1,995,092	32,531	5,229,363	1,425,890	1,336,422	8,682,875	8,593,407
	Total	9,323,222	152,016	24,437,225	6,663,296	6,245,205	40,575,760	40,157,668
Scenario B								
	2008	1,738,608	28,348	4,557,087	1,242,581	1,164,615	7,566,624	7,488,658
	2009	1,439,568	23,472	3,773,269	1,028,855	964,300	6,265,163	6,200,608
	2010	1,489,952	24,292	3,905,332	1,064,865	998,051	6,484,441	6,417,626
	2011	1,542,101	25,144	4,042,019	1,102,137	1,032,983	6,711,401	6,642,247
	2012	1,596,073	26,024	4,183,491	1,140,712	1,069,136	6,946,301	6,874,725
	Total	7,806,301	127,280	20,461,198	5,579,150	5,229,085	33,973,929	33,623,864

Table 17: NO_2 Emission [M.T]

Scenario A		From Crude Oil	From Gas Oil	From HFO	From NG @ LP	From NG @ HP	Total (upper boundary)	Total (lower boundary)
	2008	2,425		18,440	5,369	5,097	26,234	25,962
	2009	2,511		19,086	5,559	5,273	27,156	26,871
	2010	2,599		19,754	5,754	5,458	28,106	27,810
	2011	2,690		20,444	5,954	5,650	29,088	28,784
	2012	2,783	N/A	21,161	6,161	5,847	30,106	29,792
	Total	13,008		98,885	28,797	27,325	140,691	139,219
Scenario B		-		-	-	-	-	-
	2008	2,425		18,440	5,369	5,097	26,234	25,962
	2009	2,007		15,270	4,445	4,219	21,722	21,496
	2010	2,077		15,802	4,601	4,367	22,480	22,246
	2011	2,152		16,355	4,762	4,520	23,269	23,028
	2012	2,225	N/A	16,929	4,931	4,679	24,085	23,833
	Total	10,887		82,795	24,108	22,882	117,790	116,565

Table 18: SO_2 Emissions[M.T]

Scenario A		From Crude Oil	From Gas Oil	From HFO	From NG @ LP	From NG @ HP	Total (upper boundary)	Total (lower boundary)
	2008	27,870	49	121,316	260	83	149,495	149,319
	2009	28,846	52	125,561	267	86	154,727	154,545
	2010	29,856	52	129,954	278	88	160,141	159,951
	2011	30,900	55	134,503	288	91	165,746	165,549
	2012	31,983	57	139,211	299	93	171,549	171,344
	Total	149,456	265	650,546	1,392	441	801,659	800,708
Scenario B								
	2008	27,870	49	121,316	260	83	149,495	149,319
	2009	23,077	42	100,448	216	68	123,783	123,635
	2010	23,885	42	103,964	223	70	128,114	127,960
	2011	24,721	44	107,602	231	73	132,598	132,439
	2012	25,585	44	111,369	239	75	137,237	137,074
	Total	159,653	761	544,699	1,168	369	706,281	705,481

Table 19: Total Emissions [M.T] Under Scenarios A and B.

	Scenario A		**Scenario B**	
	Upper boundary	Lower Boundary	Upper boundary	Lower Boundary
CO2	40,575,760	40,157,668	33,973,929	33,623,864
NO2	140,691	139,219	117,790	116,565
SO2	801,659	800,708	706,281	705,481
Total	41,518,110	41,097,595	34,798,000	34,445,910

premise that there exists a linear relationship between the emissions of air contaminant and the activity level. They are used by regulatory agencies as a tool in developing emissions inventories for air quality management decisions and in developing emissions control strategies.

Based on fuels properties data provided by the MOE, the emission factors were calculated for each fuel assuming that the average combustion efficiency in the plants is 78.38%. Table 20 lists the emission factor in [kg/volume] for the fuels used in CPDPs. Emission factors were also calculated per unit of water produced, 12.81 kg/m^3 of CO_2, .044 kg/m^3 of NO_2, and 0.253 kg/m^3 of SO_2.

Table 20: Emission Factors [kg/volume], Corrected for %78.38 Combustion Efficiency.

	CO2	NO2	SO2
Crude Oil [bbl]	360	0.5	5.8
Gas Oil [bbl]	144	N/A	.25
HFO [bbl]	397	1.6	10.4
Natural Gas LP [thu.SCF]	51	0.22	0.01
Natural Gas HP [thu.SCF]	47	0.21	0.003

Chapter 3: Economic Models and the Real World

3.1 Price Ceilings and Government Subsidies

Price ceilings are government-mandated prices that attempt to control the price of a good or service. They are usually imposed to keep down the price of something perceived as too expensive, and protect consumers from certain conditions that could make necessities such as water unattainable. In a competitive market, meaning that there are enough buyers and sellers in the market for bidding to take place, the price of a good or a service is at equilibrium. Equilibrium price (Pe) is the price at which the quantity demanded is equal to the quantity supplied (Qe) (Figure 19).

However, water is not a good that producers compete to supply. So to protect consumers' welfare from high water prices, and also to conform to the distribution of wealth policy in the county, the government of Kuwait sat a price ceiling to domestic water at $0.60 USD/m^3. P_c in Figure 19 represents the government's imposed ceiling price. Suppliers can no longer charge the equilibrium market price P_e, and are mandated to sell water at the price set by the government P_c. At P_c, MOE will reduce water production from Q_e to a quantity equals to Q_S to operate efficiently, however, the lower price increases consumer demand for water from Q_e to Q_D. When the demand increases beyond the ability to supply, shortages occur. To prevent shortages, the government of Kuwait subsidizes the MOE to increase water production to Q_D at price Pc. The subsidy lowers the cost of production causing the supply curve to shift from S_1 to S_2. Milutinovic's proposal was to increase the price of water to $1.0 USD/m3. At this price, the market operates closer to equilibrium conditions, leading to a decrease in the demand for water.

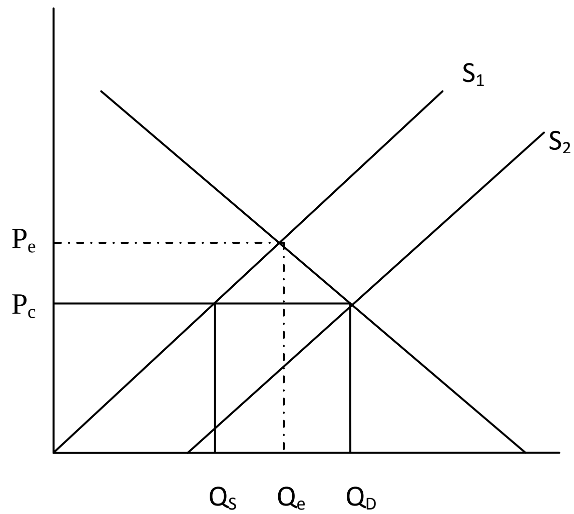

Figure 18: Hypothetical Illustration of the Effect of Price Ceiling and Government Subsidy on Water Markets. Pe: equilibrium price, Pc: price ceiling, Qs: quantity supplied, Qe: quantity at equilibrium, Q_D: quantity demanded, S_1: supply at equilibrium, S_2: supply after subsidy.

To evaluate the efficiency of a proposed policy, economists use the total surplus to make welfare judgments about different ways of producing and distributing goods. Total surplus equals consumer surplus plus producer surplus. Consumer surplus is defined as the extra value individuals receive from consuming a good over what they pay for it, also it is the area under the demand curve and above price paid. On the other hand, producer surplus is the extra value producers get for a good in excess of the opportunity costs they incur by producing it, also it is the area above the supply curve and below price paid. The total cost to supply water was not measured since labor and chemical costs are unknown. Thus, total surplus and subsidy were not computed.

Nevertheless, the reduction in the government's subsidy by adopting scenario B was measured as follows. The government's subsidy is the amount paid to the producers to operate under an inefficient market. In Kuwait's case it is the difference between the total cost to produce water and the total revenues from selling water to consumers. The subsidy is described by the following equation:

Subsidy [USD] = C_{water} – R **equation 10**

Where;

C_{water} = the total cost of water production in USD (fuels, labor, chemicals, etc)

R = Revenues generated from selling water at price P_i

Under Scenario A, approximately 3,165.9 million m^3 of water will be purchased by consumers in 5 years at a price \$0.60 USD/m^3. Thus, the total amount paid by consumers is around 1.9 billion USD (2008 dollars). Under scenario B however, consumers will consume 2,651 million m^3, 1,044 million m^3 of water will be provided for free and the rest at a price of 1 USD/m^3, that is 1.61 billion USDs (2008 dollars). The difference between the price paid by consumers in scenarios A and B is 290 million USDs. In scenario B, this amount is paid by the consumers to the producers rather than the government to producers under scenario A. Thus, the amount of subsidy over a 5 year period based on equation 10 is as follows;

Subsidy = (fuel cost + other cost) – revenues

Under Scenario A;

Subsidy = (8.76 billion USD + other cost) – 1.9 billion USD,

= 6.86 billion USD + other costs

Under Scenario B;

Subsidy = (7.26 billion USD + other cost) – 1.61 billion USD,

= 5.65 million USD + other costs+ implementation cost

It is clear that adopting scenario B will not only reduce fuel costs, but also, increase the revenues generated by the MOE causing a substantial reduction in the government subsidy over 5 years.

3.2 Cost Effectiveness Analysis

The original idea was to perform a benefit-cost analysis test. This analysis proceeds on the explicit basis that a project or policy be deemed socially worth-while if its benefits exceed the costs it generates. However, since the costs of implementing a new price scheme and the benefits (avoided damage) of reducing emissions are unknown, a benefit-cost analysis is not viable in this case. Thus, cost effectiveness analysis is used in this study to analyze the effectiveness of scenarios B in reducing water consumption, fuel cost, and emissions.

Cost effectiveness analysis (CEA) is a specific type of economic analysis in which all costs are related to a single, common effect. It is used to compare different resource allocation options in like terms. The cost-effectiveness of a policy option is calculated by dividing the annualized cost of the option by non-monetary benefit (39). The usual procedure is to produce a cost-effectiveness ratio (CER):

$$CER = \frac{C}{E}$$

Where;

C= money units.

E = some environmental unit

Effectiveness (E) measures range from the amount of the reduction in pollution measured in physical terms, to the ultimate improvements in human health or the environment measured in terms of specific effects and damages avoided (39). The cost effectiveness of scenario B based on water production, fuel usage, and total emissions over the 5-year plan is presented in Table 21. For water and fuel, the CERs were computed by dividing the cost of a scenario (Table 13) by the total volume consumed in 5 years. The CEA ratio for emissions was the cost divided by the total emission for all gases (CO_2, NO_2, and SO_2) in metric tons. To measure the effect of implementation costs on scenario B, a contingency fee of 15% was added to the cost.

Table 21: Cost-Effectiveness Analysis

	A	B (w/o imp. cost)	B (w/imp. cost)	Savings(w/o imp. cost)
Cost	9,183,384,726	7,254,342,470	8,342,493,841	1,929,042,256
Water [MIG]	696,388	583,083	583,083	113,305
Crude Oil [bbl]	25,923,672	21,705,783	21,705,783	4,217,889
Gas Oil [bbl]	1,053,429	882,032	882,032	171,397
HFO [bbl]	62,221,153	52,097,514	52,097,514	10,123,639
Natural Gas (MSCF]	131,652	110,231	110,231	21,421
Upper boundary [M.T]	41,518,110	34,798,000	34,798,000	6,720,110
Lower Boundary [M.T]	41,097,595	34,445,910	34,445,910	6,651,685
BTU	629,835,131	527,358,341	527,358,341	102,476,790
		CER B (w/o imp. cost)	**CER B (w/ imp. cost)**	
Water [$/IG]				
[$/IG]		0.0640	0.0736	
[$/m3]		14.102	16.218	
Fuel [$/BTU]				
BTU		70.79	81.41	
Emissions [$/M.T]				
Upper boundary		1079.50	1241.42	
Lower boundary		1090.60	1254.19	

CER_B measure the cost of reducing a single effect. For example, reducing the need for water saves $14 USD per m^3 of water. CER values can be used to compare the effectiveness of the water price as a management tool with other conservation/management tools such as RO or the use water efficient appliances. However, determining which option is best in terms of economic efficiency is difficult due to the uncertainties in the data and the problem posed by benefits and costs, such as pollution reduction and management implementation costs that can be quantified but not monetized.

3.3 Public Perceptions

In summer of 2006, a questionnaire containing 10 questions was distributed to 126 people in Kuwait, 66 males and 60 females. The objective of the survey was to measure the public perception of issues such as domestic water usage, water price, alternative water sources, and the environment in general. The questions were closed-ended questions, where the public opinions were evaluated by yes/no, multiple-choice, and ordinal questions. The responses were analyzed using SPSS, and the results are shown below. The demographic data for the studied sample is shown in Table 22.

Table 22: Demographic Data on the Sample Studied

Age	Number	Percentage
18-25	47	37.9
25-35	46	39.5
35-45	19	15.3
45+	9	7.3

When asked about the source of drinking water, more than 50% of the respondents choose filtered water, followed by bottled water and tap water (Figure 20). The responses regarding water, price, water price, alternative water sources, and the environment in general are summarized in Table 23.

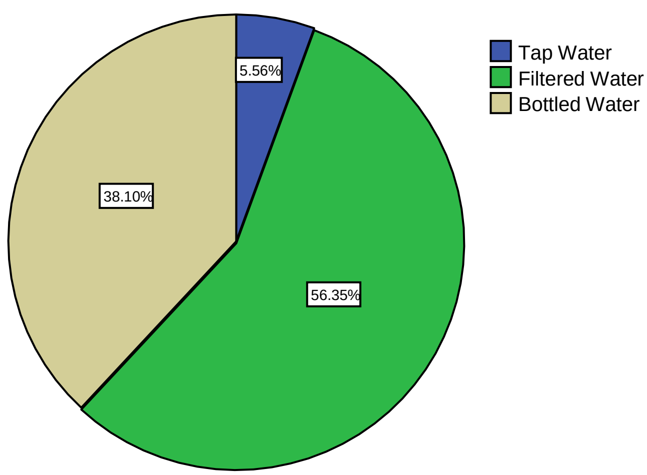

Figure 19: Sources of Drinking Water Reported by Consumers

Table 23: Survey Results

Survey Questions	% Respondents
Do you agree on increasing water price to prevent shortages?	n = 125
Yes	20
No	80
Who should pay for water?	n = 126
You 100%	16.7
Government 100%	16.7
50/50	59.5
Other	7.1
What is causing water shortages?	n = 119
Not enough water plants	41.2
Increase in Population	20.2
Over consumption	37.8
Other	0.8
Will you drink/use high quality recycled water if it is cheaper?	n = 125
Yes	33.6
No	66.4
If yes, how much cheaper?	n = 45
10%	8.9
20%	8.9
30%	13.3
40%	31.1
above 50%	37.8
What may be an obstacle to your use of recycled water?	n = 126
Cost	7.9
Religion	23.0
Quality	64.3
Other	4.8
In your opinion what is the major environmental issue in Kuwait?	n = 126
Water Pollution	36.5
Air Pollution	48.4
Land Pollution	14.3
Other	0.8
Should the environment and water sustainability be discussed in the Parliament?	n = 126
Yes	91.3
No	8.7

3.4 Conclusions

This research has made a preliminary attempt to assess the economic and the environmental impacts of two water price schedules (scenarios) in semi-arid/arid countries. Kuwait was used as the model country. Two scenarios were evaluated based on a 5-year (2008-2012) water plan using economic indicators (cost of fuels, cost of water projects), and environmental indicators (water production, CO_2, NO_2, and SO_2 emissions). Scenario A was the current price schedule used in Kuwait (uniform rate of \$0.60 USD/m^3). Scenario B was the price proposal by Milutinovic (\$1.0 USD/m^3 price of water, after 150L/capita/ day allowance). A cost-effectiveness analysis was then used to determine the overall effectiveness of each scenario using the above indicators.

The results of this study suggest that adopting scenario B will cut the water demand by 113.3 billion imperial gallons over 5 years. Thus, adopting scenario B would postpone the need for new water projects to the year 2020. Under scenario A, water demand would outstrip water production capacity by the year 2012.

Implementing the new price schedule (Scenario B) starting in year 2008 will reduce energy consumption for water desalination by around 16.2%. This is equivalent to 4.32 million barrels of Crude Oil, 172 thousand barrels of Gas Oil, 10.12 million barrels of HFO, and 21,421 million SCF of Natural gas. This translates into net fuel savings of 1.5 billion USDs at 2007/08 prices, and 16.2 % emissions reduction in 5 years. Liquid fuel analysis suggests that HFO and crude oil emit 397 and 360 kg CO_2/bbl, respectively. Also, HFO emits two times more NO_2 and SO_2 than crude oil. Emission factors were also calculated per unit of water produced, 12.81 kg/m^3 of CO_2, .044 kg/m^3 of NO_2, and .253 kg/m^3 of SO_2. Such emission factors could be used to evaluate alternative fuels and the environmental performance of different desalination technologies.

The tentative findings of the cost-benefit analysis were inconclusive due to unknown costs such as chemicals, labor, and policy implementation costs. Such costs are available in the literature for other countries; however, no studies were conducted to evaluate these costs for Kuwait. Benefits of non-market goods such as reduced gaseous emissions, and brine discharge are quantified but not monetized for Kuwait. Note that this cost-benefit analysis did not reflect the long term benefits of water saving, i.e., 10 years and beyond, since the analysis was conducted for 5 years only due to uncertainties in future oil prices and people's water consumption habits.

The economic efficiency of each scenario was not measured due to the lack of data mentioned above. However, it was clear that adopting Scenario B would not only reduce fuel costs, but also, increase revenues generated by the MOE causing a substantial reduction in government subsidies over the 5 years.

The results of the cost-effectiveness analysis suggest that CER_B measures the cost of reducing a single effect. However, determining which option is best in terms of economic efficiency is difficult due to the uncertainties in data and by the presence of benefits and costs, such as pollution reduction and management implementation costs that can be quantified but not monetized. Thus, even if economic efficiency was the single guide to policy decisions, benefit and cost estimates alone would not be adequate to define a "best" policy.

Cost of water is not only a theme in this thesis but it is a forcing function as one attempts to evaluate cost-benefit and cost-effective of price schedules. It is interesting to note that the public survey points to additional challenges in a country such as Kuwait, where the value of water has social gravitas. After analyzing the public perception questionnaire, the results showed that 80% of the respondents did not agree on increasing the current price of water in the country. However, when asked about who should bear the cost of water, 60% suggested that the cost of water should be split equally between the government and the consumer. Note that the government of Kuwait subsidizes more than 80% of the total water cost. These results suggest that the consumers are unaware of the current water price structure or water price, which is not uncommon in the literature. Another key observation was the public opinion on the main causes of water shortages. In providing reaction to questions about past shortages, only 38 % of the respondents thought that over consumption of water was the main cause, while the majority (> 40%) thought that Kuwait didn't have enough desalination plants to cover demand. This suggests that the public has a myopic awareness of water supply resource economics.

Overall, the high rate of water consumption shows that the assumed values associated with water availability, namely the quantity of untreated water, fuel, and the aforementioned environmental costs are considered trivial. The public views water as a free community resource with almost zero economic value. However, it is clear from the above analysis that water indeed has economic and environmental values, thus arguing that it should be recognized as an economic commodity. So, implementing an integrated water management plan so as to curb wasteful water use is essential to mitigate economic impacts of over-consumption of water on the country's main source of income, namely fossil fuels.

The plan should also consider the social and environmental dimensions of water conservation (Figure 21). In semi-arid/arid countries as commonly found in the Middle East, this effort to plan is difficult for many reasons. These include a lack of available usable information, long term planning that considers the social, economic, and environmental factors of water, and the increasing pressure on society as water consumption continues to rise with expanding urban development. This task will continue to be challenging in situations where decisions on water subsidies will continue to be based on incomplete information.

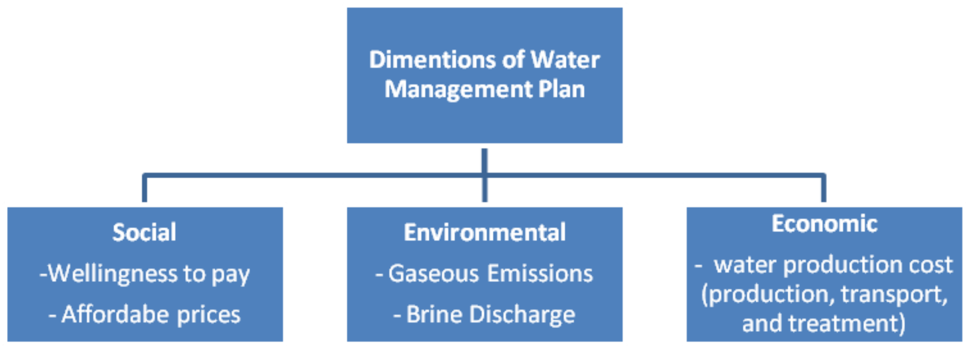

Figure 20: Multi-Dimensional Water Plan

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