Water Demand Management in the Caribbean: A Case Study of Barbados

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Abstract

Water demand management attempts to balance the supply of and demand for water by controlling the competing water demands. It realizes the change by influencing peoples' behavior with respect to water use. Water demand management (WDM) is necessary in water scarce regions like Barbados. The Government of Barbados has recognized the need for WDM as demonstrated by the implementation of measures such as universal metering and water pricing.

This research looks at the impact of water pricing and metering on residential water use in Barbados. Econometric demand models of residential water use are developed to assess the potential of pricing policies to conserve water. Price elasticities between –0.18 and –0.93 were obtained suggesting that pricing policies can be used to reduce and control residential water consumption in Barbados. The results of the models are then used to investigate the impact of different rate structures on water use and revenue generation. It is predicted that a 26% decrease in water demand and a 52% increase in revenue collected from water bills would be achieved if the 1997 proposed water rate increase is implemented. In addition, results indicate that water production decreased by 12% from 1997 to 2000, coinciding with the implementation of the Universal Metering Program. However, per-capita consumption has been on the rise in recent years suggesting that metering must be accompanied by a substantial increase in price to encourage water conservation.

Résumé

La gestion de la demande d'eau est une mesure visant à équilibrer les ressources et les demandes en eau. Cette approche influence les comportements individuels face à l'utilisation de l'eau. Elle est nécessaire dans les régions confrontées à une pénurie de l'eau, telles que la Barbade. Des mesures, comme la tarification et le comptage d'eau, démontrent que le gouvernement de la Barbade reconnaît le besoin urgent de mieux gérer la demande d'eau.

Les rôles de la tarification et des compteurs d'eau en Barbade comme moyens d'influencer les demandes résidentielles en eau sont examinés. Des modèles de régression sont développés pour étudier la relation entre la demande en eau et le prix de l'eau. Des valeurs de l'élasticité par rapport au prix entre –0.18 et –0.93 ont été affichées. Les résultats sont utilisés pour analyser l'influence des structures tarifaires sur la demande d'approvisionnement en eau et sur les revenues. La hausse du prix de l'eau, suggérée en 1997, produirait une baisse de la demande en eau résidentielle de 26% et une hausse des revenues de 52%.

L'étude a aussi démontrée que la production d'eau a baissé de 12% pendant le programme d'installation de compteurs d'eau. Cependant, la demande en eau résidentielle est à la hausse suggérant que le comptage de l'eau, sans variation dans les prix, n'influence pas nécessairement la demande en eau.

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Table of Contents

List of Tables

List of Figures

List of Symbols

a: undefined model constant

AP: real average price ($BBD\$/m^3$)

b: undefined model coefficient

b: per capita water use

b_{price}: coefficient of price

BBD$: Barbados Dollars (1 BBD$ approximately equals 0.7 CAN$)

Billing: frequency of billing dummy variable

$C_{i,m,n}$: percent change in consumption in each district for every model and year from 2003 to 2025

$\hat{C}_{i,m,n}$: average change in consumption in each district for every model from 2003 to 2025

$C_{i,n}$: average change in consumption per district over the four models

C_i: overall change in consumption per district over the eight scenarios and four models

C: average change in consumption over all districts

D_n: district dummy variable

Drought1: drought dummy (drought if rainfall < historical mean)

Drought2: drought dummy (drought if rainfall < (historical mean – 1 stdev))

Drought3: drought (previous year was a drought year (rain < historical))

Drought4: drought dummy (previous year was a drought year (rain < (historical – stdev))

Droguht5: drought dummy (previous 2 years were drought years (rain < historical)

Drought6: drought dummy (previous 2 years were drought years (drought if rain< (historical – stdev))

d-statistic: Durbin-Watson Statistic

GDP: real Gross Domestic Product change (%)

(H): high income district

Inc: average annual real household income per district (000's BBD$)

Inc/AP: income divided by average price

Inc/MP1: income divided by price of lower block

Inc/MP2: income divided by marginal price

IncDev: deviation of annual income of district from average annual income of all districts

IncHigh: high income dummy variable

IncLow: low income dummy variable

IncMed: medium income dummy variable

(L): low income district

(M): medium income district

mgd: mega-gallons per day

MP1: real marginal price (price of lower block in BBD$/$m^3$)

MP2: real marginal price (BBD$/$m^3$)

P: population

P.E.: price elasticity

Pdum: price dummy variable

PU: predicted water bills under the current rate structure

PV: predicted Water Bills under new rate structure

PX: predicted water demand under the current rate structure

PY: predicted water demand under new rate

Q: water consumption

Q: average annual household water consumption per district (m^3)

R^2: multiple coefficient of determination

Rain: annual rainfall (mm)

Rain1: assumption number 1 for rainfall change

Rain2: assumption number 2 for rainfall change

RainDev: deviation of rainfall from historical mean

t: time

Temp: average annual temperature (^{o}C)

u: unit use coefficient

Wet1: wet season in previous year was dryer than normal (rain < historical mean)

Wet2: wet season in previous year was dryer than normal (rain < historical mean – stdev)

X: undefined explanatory variable

List of Acronyms

BWA: Barbados Water Authority

CIMH: Caribbean Institute of Meteorology and Hydrology

GDP: Gross Domestic Product

NAV: Net Annual Value

OLS: Ordinary Least Squares

UFW: Unaccounted-for-water

WDM: Water Demand Management

WLS: Weighted-Least Squares

WRM/WL: Water Resources Management and Water Loss Studies

Chapter 1. Introduction

Water is essential to meet our basic needs. The benefits of this important resource are clearly evident. Water gives us life, accelerates economic and social development, underpins food security, nourishes our fragile ecosystems and provides a place for leisure activities. Yet, our water resources are continuing to be threatened by a rapidly increasing demand and diminishing quality.

Overexploitation of surface and groundwater sources has led to an unfavorable ecological and economic situation. The continuing population and economic growth will cause the demand for water to grow even further, thus placing a greater burden on the available water resources. The area of irrigated land is now five times greater than at the beginning of the century and the demand for irrigation water is projected to increase (Rosegrant et al., 2002). This rising demand may well put global food security at risk. What is even more alarming is that a large number of people still lack clean and safe drinking water. In the developing world, about 40% of the rural population still lives without an adequate water supply, and about 60% are without adequate sanitation (UNDP-World Bank Water and Sanitation Program, 1998). It is estimated that some 50 000 people die each day from water-borne and water related diseases (Grabow, 1996). These examples are just of few of many important water related problems. Therefore, it is clear that managing our water resources will present one of the greatest challenges of this century.

Traditionally, water resources were managed from a supply-side approach. This entailed increasing the supply of water to meet the various demands. This concept of supply augmentation is unsustainable in the long run due to physical, financial and economic constraints. Supply-driven projects are becoming more and more expensive because the most suitable and accessible water resources have already been used. Investment requirements per capita are also increasing due to an increase in per capita water consumption (Grima, 1973). In addition, large water supply projects often involve numerous social and environmental conflicts.

The problems and failures of the supply-driven approach over the past decades have prompted the international community to explore new approaches for managing water. The experiences from the International Drinking Water Supply and Sanitation Decade (1980-1990) inspired a new approach that focused more on the management of water as part of a broader environmental protection and sustainable development goal. The principles emerging from the Dublin Conference (1992) and the Earth Summit (1992) intended to meet the goal of efficient, equitable and sustainable use of water. The need for a new management approach was also the focus at the Second World Water Forum in The Hague, March 2000. In essence, these meetings changed the way we view our water resources. Water now needs to be recognized as an economic good that must be managed in a holistic manner relying on integrated water resources management. The meetings stressed the need for water demand management policies, such as pricing mechanisms, to ensure the efficient and sustainable use of water resources.

It is now recognized that more emphasis should be placed on managing water demands, particularly as current water use is approaching the limits of sustainability in many regions. Water demand management requires water managers to enforce some means of decreasing the quantity of water demanded while conserving supply sources to ensure sustainability of use (Moncur, 1987). Water policy makers are equipped with many instruments with which water demand may be influenced such as metering, pricing, water-saving devices, leakage control and awareness programs.

The fundamental key to water demand management is the need to understand the factors determining water demand. A thorough understanding of all socioeconomic, climatic and demographic variables affecting water use will allow policy makers to make better decisions regarding what variables to control or modify. A model capable of evaluating the impacts of different policies on future water demand can assist water experts whenever new policies are being considered.

Water demand, more precisely domestic water demand, is conventionally estimated using econometric demand models where demand is a function of a set of explanatory variables that includes the price of water. This type of model can then explain the effect of the explanatory variables on water demand. This is accomplished by calculating the elasticity of the different variables. The value of price elasticity is a key component in assessing the benefit of water demand management policies.

Water demand management (WDM) is necessary in water scarce regions like Barbados, which is ranked among the world's ten most water scarce countries (UNEP, 2000). This Caribbean island is almost entirely dependent on groundwater to meet its various demands (Mwansa, 1999). The Government of Barbados has recognized the need for WDM as demonstrated by the implementation of measures such as universal metering, water pricing, reduction of unaccounted for water, and public education campaigns.

This research provides an insight into the impact of water pricing and metering on residential water use in Barbados. There is a need to determine how effective these measures are in controlling demands. An understanding of the effects of water price on consumption will help establish and formulate effective, efficient and equitable pricing structures. Econometric demand models of residential water use have been developed to assess the potential of pricing policies to conserve water. The results of the models were then used to investigate the impact of different rate structures on demand reduction, revenue generation and equity.

The analysis used in this research relies on cross-sectional annual time-series data for seven districts in the parish of St-James, Barbados. Residential demand is estimated as a function of income, water price, rainfall and billing frequency. Price and income elasticities are calculated. The results compare well with past residential water demand studies and confirm the hypothesis that water price does have a positive effect in reducing domestic water demands. Furthermore, results indicate that water production decreased considerably from 1997 to 2000, coinciding with the implementation of the Universal Metering Program.

Chapter 2 will take a closer look at managing water from a demand-driven approach. Water demand management measures will be described. Chapter 3 briefly reviews some water demand models commonly used. More emphasis will be placed on econometric demand models. Chapter 4 will look at water resources management in Barbados. First, the geography, geology and hydrology of the island will be described. Then, a brief history of water policies and legislations will be explained. Important studies regarding water resources in Barbados will also be discussed. The water supplied and demanded on the island will then be compared. The chapter finally concludes by exploring new water management policies and initiatives undertaken in Barbados. Chapter 5 will present the econometric demand models developed for this research. Data requirements, variable specification, modelling methods, and model results will be discussed. Chapter 6 will explore the implications of the demand models for water resources management and policy making in Barbados. The impact of water price changes will be presented focusing on demand reduction, revenue generation and equity considerations. Chapter 7 will explore the benefits of the Universal Metering Program in Barbados. Conclusions and recommendations will be given in chapter 8 and 9.

Chapter 2. Water Demand Management

This chapter will explore the concept of water demand management in more detail. Numerous demand-side measures will be described. The shift from the supply-side to the demand-side approach will first be discussed.

2.1 From Supply to Demand Management of Water

Water has long been treated as though there is an unlimited supply. It has usually been provided free or at little cost to consumers. The priority of water utilities was to provide the required water supply to meet the demands primarily by structural measures. However, relying fully on supply-side solutions to meet the given demands is constrained by hydrologic, economic and financial limits.

In many places, the current water supplies are approaching their physical limits. It is inevitable that new supplies will be needed in the future as demand increases. However, capacity cannot be expanded indefinitely. The lowest cost and most accessible sources of water have usually already been developed. New sources of supply will have much higher financial and environmental costs. The World Bank states that the cost of a cubic meter of water from the "next project" is often 2 to 3 times the cost of current supplies (Bhatia and Falkenmark, 1991).

The environmental costs of water supply projects are also increasing. The depletion of aquifers, the damming of rivers and the destruction of wetlands are all environmental costs associated with the traditional supply-side management approach. Moreover, the cost of the disposal of wastewater is also rising. An example of a devastating environmental catastrophe is the desiccation of the Aral Sea. The sea has shrunk considerably causing the collapse of fisheries and the deposition of large amounts of salt and toxic chemicals from agricultural use in the catchment basin.

Relying on large new water supply schemes will require considerable capital, operating and maintenance costs that many governments and water utilities are in no position to bear. Many water utilities are already in a poor financial position. This can be attributed to numerous reasons, but none are more important than the failure in pricing for cost-recovery (Winpenny, 1994). The poor financial performance of water utilities is also attributed to the high proportion of leaks and to the weak billing and collection systems. The World Bank (1993) states that the level of unaccounted for water in most developing countries is 3 to 5 times that of industrial countries. In the Caribbean, water loss varies from 30% to 70%.

In summary, the supply-driven approach alone is unsustainable due to hydrologic, economic and financial reasons. This approach relies predominately on structural measures to augment the water supply. The increasing water demands due to population and economic growth will put further stress on the available water resources. Hence, additional supplies will eventually be needed but at much higher costs. Moreover, the traditional approach does not encourage the conservation of water in the long run. This has pushed water policy makers and experts to consider a new approach to water planning and management that focuses on increasing the efficient, equitable and sustainable use of water.

The shift from the traditional way of managing water emerged from numerous international conferences that advocated a more sustainable approach to managing this precious resource. The 1977 World Water Conference in Argentina designated the 1980's as the International Drinking Water Supply and Sanitation Decade. The focus of that decade was to improve public health by expanding service coverage to everybody. The Decade increased awareness of the importance of adequate and reliable water supply services. During the Decade, governments and donor agencies relied fully on augmenting the available supply and improving sanitation services. However, the achievements of the Decade fell short of its original goals.

During the 1990's, the scope of debates expanded on the targets of the earlier decade but focused more on the management of water as a part of sustainable development. International meetings like the International Conference on Water and the Environment held in Dublin in 1992 and the 1992 Earth Summit in Rio de Janeiro paved the way for a new way of thinking about our water resources. The Dublin principles formed the basis of Chapter 18 of Agenda 21 that emerged from the Rio Summit (Table 2.1). Chapter 18 proposed seven focus areas (Table 2.1) for the freshwater sector that serves as a blueprint for action to be taken. The need for a new management approach was also the focus at the Second World Water Forum in The Hague, March 2000. In essence, these meetings changed the way we view our water resources. Some important issues arising from these meetings include: a) the recognition of water as an economic and social good that needs to be managed in an efficient, equitable and sustainable manner, b) the need for a holistic approach relying on integrated water resources management, c) the involvement of all sectors of society in decision-making, and d) greater focus on pollution control policies. The need for water demand management policies, such as pricing mechanisms, to ensure the efficient and sustainable use of water resources was a focal point at these meetings. The following section explores the concept of water demand management.

Table 2.1 Dublin and Agenda 21 Principles

Dublin Principles:

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognized as an economic good.

Agenda 21:

- Ensure the integrated management and development of water resources.
- Assess water quality, supply and demand.
- Protect water resources quality and aquatic eco-systems.
- Improve drinking water supply and sanitation.
- Ensure sustainable water supply and use for cities.
- Manage water resources for sustainable food production and development.
- Assess the impact of climate change on water resources.

2.2 Water Demand Management: What is it?

Water demand management attempts to balance the supply of and demand for water by controlling the various water demands. It realizes the change by influencing peoples' behaviour with respect to water use. Its main objectives are to raise water use efficiency, improve social equity and development, protect the environment, and sustain water supply and water services so that future generations can benefit from them (Mosai et al, 2000). Demand management is the adaptation and implementation of strategies that will achieve these goals.

Water demand management was initially pursued in water scarce regions because the development of new supplies would be too costly and/or was physically limited. Policy makers were forced to consider non-structural methods that would ensure that all users could benefit from the scarce resource. The rising water demands stimulated by population and economic growth have led to a situation in which many regions are now facing water shortages. With the increase in demands also comes the increase in wastewater released to the environment. This has caused the deterioration of the quality of water, therefore reducing the amount of clean water available. Over-abstraction of water resources has contributed to the increase in harmful levels of substances such as salt in the groundwater. Water demand management can play an important role in solving these problems.

Water demand management policies can be difficult to implement due to a general resistance from many people, including politicians, because water is generally seen as a purely social good. Most people believe that, since water is essential to life, it should be provided to the population at little or no cost (Dumars et al., 1995). As a result, governments are reluctant to raise tariffs to match the "real" value of water or even the costs of distribution (Winpenny, 1994). In Trinidad and Tobago, water rates remained unchanged from 1937 to 1985 (Mycoo, 1996). In Barbados, water rates have not changed since 1991. The result is that water is underpriced and consumers do not have incentives to conserve it. Pricing mechanisms and metering, however, raise equity concerns. Many people believe that conservation measures may lead to a loss of social welfare and income.

Water demand management measures should be used in conjunction with traditional supply-side approaches. Effective water demand management policies can greatly reduce future water use. It has been demonstrated that even with the simplest water conservation programs, water usage may be reduced by 20% to 30% without substantially affecting social welfare (Martin et al, 1980). As a result, the search for new supplies and construction of treatment plants can be postponed. A decrease in water demand will also result in a decrease in operating costs.

Water demand management requires water managers to enforce some means of decreasing quantity demanded while conserving supply sources to ensure sustainability of use. The next section will look at some commonly used demand-side measures.

2.3 Demand Management Measures

As rising water demands have pushed existing supplies to their limits, attention has moved to demand management policies as a way of avoiding higher supply costs and frequent shortages. Water policy makers are now equipped with many instruments with which water demand may be influenced. The most commonly used measures include market mechanisms such as pricing, metering and water markets, and non-market measures such as water saving devices, leakage control, education programs, water use restrictions and regulations.

2.3.1 Market Mechanisms

Market mechanisms influence the behavior of users by using the price of water to encourage its efficient use either by raising the price of water or developing water markets.

A) Water Pricing

The traditional supply-oriented approach has failed to treat water as an economic good (Garn, 1998). This has led to the overuse of this scarce resource. However, numerous studies have shown that water does have an economic value and that users do respond to water prices. The relationship between water demand and the price of water is indicated by the value of the price elasticity. Price elasticity is defined as the percent change in water use divided by the percent change in water price (Weber, 1989). Prices that accurately reflect the cost of water send signals to consumers about the value and cost of water. Higher prices encourage consumers to modify their consumption habits and reduce wasteful water use. An effective pricing mechanism therefore assists in the efficient use of water resources by influencing the quantity of water used (Baumann et al., 1998). Moreover, higher prices are essential for recovering costs and allocating water with greater value use (Ayub and Kuffner, 1994).

Consumers are presented with various water rate structures. The most common are the flat rate, uniform rate, seasonal rate, declining block rate and increasing block rate.

a) **Flat rate.** The customer is charged a fixed amount regardless of the quantity of water used. This gives no incentive to conserve water. This type of tariff structure has been used in areas where there is an abundant supply of water (Baumann et al., 1998). Flat rates are easy to administer and design.

b) **Uniform rate**. In this type of structure, the user is charged a constant price per unit of water used. It is very popular because of its simplicity to design and implement. However, customers who use an excessive amount of water are not penalized because the unit price does not vary with consumption.

c) **Seasonal rate**. Customers are charged higher rates during the summer (or peak demand) seasons. This encourages consumers to reduce water consumption during peak periods. This type of rate can be used as a means of recovering the incremental cost of providing water during a utility's peak-use season (Weber, 1993). Seasonal rates have been shown to be effective in dealing with short-term summer peaks (Jones, 1984).

d) **Decreasing block rate.** This type of rate uses a minimum charge for a small initial quantity and then the price decreases in succeeding blocks. Decreasing block rates have been common in areas with substantial excess supplies of water. However, they may not be appropriate when water utilities are operating close to near capacity, because they do not encourage water conservation.

e) **Increasing block rate**. In an increasing block rate structure, rates increase with increasing water consumption. Each succeeding consumption block is more expensive. Large water users bear the costs associated with providing large quantities of water. This type of rate is often proposed to promote water conservation through higher rates. One of the advantages of an increasing block rate is a lower average unit price for the low water use customers (Gysi and Loucks, 1971).

Economic principles require that the price charged for water should be equal to the marginal cost of supply. In order to achieve this principle, universal metering is needed to measure household water consumption and charges should change with the volume of water used. Furthermore, costs should attempt to reflect all measurable environmental costs in addition to distribution, treatment and disposal costs.

The volumetric or block rate structure is also recommended for reasons of equity. An increasing block rate structure provides a minimal amount of water (lifeline) at low unit prices. This allows poorer customers the ability to obtain water for their basic needs. The minimum amount of water required to meet basic needs varies according to what is defined as "basic needs". The values may range from 20 liters to 50 liters per person per day (Abrams, 2001). Under increasing block rates, higher water consumption users will pay higher unit charges that reflect the increasing costs of providing water to meet peak loads (Winpenny, 1994). However, studies have shown that block rate structures may not be appropriate when many households share a single water connection since the number of people per connection will be large (Whittington, 1992).

To be effective in controlling demand, the price of water must be significant (Perry, 2001). However, the tendency over the past decades has been to provide water at little cost to users. As a result, users tend to oppose any raise in prices since they have been accustomed to very low prices. Moreover, most people are not informed about the real costs of supplying water. Increasing water tariffs is usually perceived as a means of cost recovery and not as a way of curtailing demand (Winpenny, 1994).

B) Metering

Water metering can be used to reduce wasteful water use as it increases people's awareness of their consumption. It allows for an accurate account of water consumption that leads to a better management of the resource. Studies for cities in British Columbia have shown that metering caused a 15% to 20% reduction in residential water use (Leidal, 1983). Metering also facilitates the detection of water leaks. The lack of meters in many places makes the process of cost recovery and conservation even more difficult. In addition, typical house meters are often inaccurate at very low flows and may not monitor all flows (e.g. leaking toilet).

The widespread use of meters presents some implementation difficulties. Meters incur high capital costs and costs associated with the regular reading, maintenance, billing, and accounting (Bahl and Linn, 1992). On the other hand, the actual long-term costs may be lower because of lower water use and hence a lower unit cost of water production.
The decision to meter customers by itself does not provide any incentive to conserve water. To be fully effective in controlling water demand, a metering program should be accompanied by an appropriate tariff scale (Grima, 1973).

Bishop and Weber (1996) summarized the most important reasons for metering water consumption:

- Metering permits more accurate analysis of the demands for water by customer groups
- Metering permits monitoring water consumption by individual accounts which is essential for implementing demand management programs
- Metering permits the pricing of water use with a rate structure that encourages conservation and allows recovery of costs

C) Water Markets

Water markets primarily operate for the agricultural sector. They include groundwater and surface water markets, water auctions, and the transfer of water rights. Water markets attempt to optimize water use by encouraging users to sell some of their water to others for higher-value purposes (Winpenny, 1994). For example, farmers can be given incentives to drop low-value applications if they can increase their benefits by selling the water.

Groundwater markets have been shown to increase the efficient use of water by ensuring that water is sold to those who can use it to its highest value. However, caution must be taken since groundwater markets can sometimes encourage excessive pumping of aquifers (Winpenny, 1994).

Auctions are a way of selling water to the highest bidder. They allow users to reveal how much they value the water. If auctions are conducted efficiently, then economic theory suggests that the social benefit from using the water is maximized (Winpenny, 1994).

In practice, the economic efficiency of water markets is likely to be imperfect when compared to the performance of an ideal market. There are many reasons why there is such a gap between the theory and practice of water markets. A precondition for effective markets is the clear definition of property rights. However, property rights are seldom defined and transferred properly. The most significant reason why the water market does not behave like an ideal free and open market is because there is no other substitute for water. Water must be distributed on a large scale, usually by one main water agency.

Hence, consumers do not generally have the choice from whom they wish to purchase water.

2.3.2 Non-Market Mechanisms

Non-market mechanisms take a variety of forms, such as leak control, public education, water saving devices, laws and water re-use. Some of these measures, such as regulations and restriction, force users to conserve water. Others, such as leak control, are direct interventions used to improve the efficient delivery of water.

A) Leak Control

Water leaks, which are usually the result of old systems or a lack of maintenance, cause substantial financial losses as well as critical water losses. It is therefore important to minimize water losses due to leakage and thus, urgent investment in additional water sources can be deferred. Unfortunately, the lack of meters in many places makes the task of quantifying and identifying leaks quite difficult.

B) Water Saving Devices and Public Education

There exist many technologies that individuals can adopt to conserve water. Some of these technologies include low volume flush toilets, dual flush toilets, high performance showerheads and front loading washing machines to name a few. There are also many ways in which industries can reduce their water wastage. In order for these technologies to be implemented and accepted, water utilities and local politicians should encourage and invest in extended application of these technologies.

These technologies and other conservation methods will never succeed unless the behaviour of water users changes through public education and awareness campaigns. A well designed public education program can achieve substantial reduction in water demand. Campaigns should target all consumers and should be conducted at the household and neighbourhood level. Children should particularly be targeted in the awareness programs to encourage water conservation at an early age.

C) Water Regulations and Restrictions

Non-market mechanisms, such as regulations and restrictions, may be used to compel users to reduce their water consumption. Water restrictions are a means of forcing consumers to conserve and reallocate their water. Authorities have the power to cut off supplies at times of droughts or to reallocate water to other users. Restrictions are usually placed on non-essential activities such as lawn watering. Such involuntary measures can be effective but may not be efficient or equitable.

Regulations attempt to allocate scarce water supplies in an equitable manner (Winpenny, 1994). They include the issuing of fixed quotas and charging of tariffs for those who consume water above a certain norm as a way of discouraging excessive wastage. These types of measures are commonly used in the industrial sector.

If well administered, regulations and restrictions can have a positive effect in increasing the sustainable and equitable use of water. However, they require a great deal of monitoring and enforcement and will only be successful if the public understands the reasons for such measures.

D) Wastewater Reuse

Water reuse is sometimes considered as a supply-side action since it represents a new source of water. However, it also represents a demand-side approach because it conserves water. Wastewater reuse for irrigation has numerous advantages over the conventional use of freshwater. In many regions, the cost of providing wastewater for irrigation is lower than the marginal cost of providing freshwater for irrigation (Jin and Young, 2001). It is stable, reliable and not affected by severe weather. It also contains nutrients for crops and hence may reduce the use of chemical fertilizers (Jin and Young, 2001). The main concern in adopting this method is the risk of pollution and human health damage. Fortunately, controlling and monitoring the waste treatment level can minimize the risk.

2.4 Concluding Remarks

The growing water demands, together with the increasing cost of supplies, have pushed the need for water demand management. Water demand management focuses on influencing or controlling all competing water demands, and hence can postpone the construction of new water supplies and treatment plants. A decrease in demand will also lower system operating and maintenance costs.

This chapter looked at several market and non-market demand management measures. Water pricing and metering was shown to influence the amount of water used by individuals. Water markets try to optimize water use. Leakage control assures that only the required amount of water needed to meet all the demands is delivered into the distribution network. Water saving devices and education campaigns encourage water conservation. Water restrictions and regulations force consumers to reduce water usage. Finally, wastewater reuse lowers the amount of water demanded.

There is a need to determine how effective these demand-side measures are in influencing or reducing demand. First, knowledge of how water demand is affected by different variables, such as water price, is required. The next chapter will describe how water demands are generally modeled.

Chapter 3. Water Demand Modeling

The previous chapter presented the concept of water demand management. Methods used to control water demands were also explained. An essential part of any planning process is understanding the factors determining residential water demand. A water demand model can be developed to assess the impact of various variables on water use.

Water use is dependent upon various demographic, climatic and socio-economic variables such as population, income, temperature, precipitation, water prices, water using appliances and demand management activities. A water demand model attempts to evaluate the effect of some of these variables on water demands. Once a water demand model has been developed, it can then be used to explore the impacts of demand management measures. Demand models are generally classified according to the type and number of explanatory variables utilized in the water demand model. The methods also vary in the degree of complexity. The following section will present the most typical water demand modeling techniques.

3.1 Bivariate Models

Bivariate models are models that use a single variable to explain water use. The model takes the following form:

$$Q = a + b*X \tag{3.1}$$

Where a and b are coefficients and X is the explanatory variable.

In most applications, the explanatory variable is population. This method is most often employed for aggregate data. The two most common forms of the bivariate model are the per capita and unit use coefficient models.

A) Per Capita Coefficient

This has been perhaps the most widely used method to date. Population is multiplied by an extrapolated water use coefficient (Baumann, Bolland, Hanemann, 1998). The model is as follows:

$$Q = b*P \tag{3.2}$$

Where b = the per capita water use

P = population

Q = average water use

A crucial problem with this method is that many factors affecting water use are assumed to be either unimportant or perfectly correlated with population. The model cannot be used for disaggregate water use. Moreover, per capita water use tends to vary from place to place as well as over time. Hence, the per capita coefficient approach is usually not very accurate. However, it is simple and requires very little data.

B) Unit Use Coefficient

This method explains water use in a specific sector in terms of a single variable other than population. For instance, total employment alone may be used to explain water use in office buildings (Baumann, Bolland, Hanemann, 1998). Others have derived unit use coefficients for every sector (municipal, industrial, etc.). The unit use coefficient model is as follows:

$$Q = a + u^{*}X \tag{3.3}$$

Where u = unit use coefficient

X = explanatory variable

a = may or not be zero

This method is convenient if the sector in question is small or if the costs of collecting data are high. However, as with all bivariate models, many factors affecting water use are neglected.

3.2 Multivariate Models

Multivariate models represent water use in terms of a number of explanatory variables. In general,

$$Q = f(X_1, X_2, \ldots X_n) \tag{3.4}$$

Where Q = water use per unit of time

X_i = explanatory variables

This function can take different forms such as the linear form:

$$Q = a + b_1 X_1 + b_2X_2 + \ldots + b_nX_n \tag{3.5}$$

Other forms include the log-log and log-linear forms:

$$\log(Q) = a + b_1\log(X_1) + b_2\log(X_2) + \ldots + b_n\log(X_n) \tag{3.6}$$

$$\log(Q) = a + b_1 X_1 + b_2X_2 + \ldots + b_nX_n \tag{3.7}$$

A) Multivariate Requirement Models

In multivariate requirement models, requirement means that demand is assumed to be independent of price. These are empirical models incorporating variables that are observed to be significantly correlated with water use but do not necessarily imply any theory of water use, and may omit some important explanatory variables such as water price and income (Jones, 1984).

Multivariate requirement models have been successfully used in the manufacturing sector (Baumann et al., 1998). The number of employees and value of output are some examples of variables included in these types of models. Unfortunately, data requirement are considerable and often difficult to collect.

B) Econometric Demand Models

Econometric demand models are based on standard economic theory that states that a household's demand for any good decreases as price increases and increases as income increases. These models, unlike requirement models, always include the price of water and income (or a proxy for income). Since econometric demand models are based on the theory of demand, the explanatory variables are likely to be correlated to the dependent variable in the future as well as at the present.

The number of variables used depends on the available data, required level of accuracy and local conditions. Model parameters are generally estimated using ordinary least-squares techniques. Econometric demand models are predominately developed for residential water demands for single-family detached households. Case studies using econometric demand models have shown to accurately predict water use.

The next section will look at econometric demand models in more detail as they are used in this research to evaluate the effect of price changes on water demands.

3.3 Econometric Demand Models

Before the 1960's, the estimation of water demand was generally obtained by multiplying population with an average per-capita water use. Since then, water demand has been extensively studied by developing and applying econometric demand models with the emphasis on determining how water use is affected by different variables such as price, income, rainfall and temperature. Econometric demand models allow for the determination of the sensitivity of water demand to changes in the explanatory variables (e.g. price, income, rainfall). This is known as elasticity and is more precisely defined as the percent change in water use divided by the percent change in one of the explanatory variables. For instance, a price elasticity of -0.4 signifies that a 10% increase in the price of water will result in a 4% decrease in water demand. Elasticity between –1 and 1 is termed inelastic and implies that an increase in an explanatory variable is less than proportional to an increase/decrease in water demand.

3.3.1 Variables

Variables used in econometric demand models are generally classified into economic and non-economic variables. Economic variables include the price of water, income and frequency of billing. Examples of non-economic variables are weather, demographics, and seasonality. Dummy variables are also frequently employed in econometric models to describe qualitative conditions.

A) Water Price

Price can have a positive effect in reducing the quantity of water demanded by influencing people's behavior. Putting a price on water informs customers that water has a value and it should be used in an efficient and sustainable manner. Numerous studies have shown that price does reduce the quantity of water demanded but this effect is less than proportional to an increase in price (Nieswiadomy, 1992; Lyman, 1992; Moncur 1987). Residential water demand is most often inelastic because water has no other substitute, although there are alternative ways of delivering water (e.g. water vendors, rainwater harvesting), and because water bills are typically a small portion of household income.

The correct specification of the price variable in an econometric demand model depends on the type of rate structure. Under a uniform rate, the price variable to use is straightforward since the price of water does not vary with consumption (see section 2.3.1). However, there has been a great debate on what is the most suitable price specification to be used under block rate structures. The three most important price specifications used are the marginal price, average price and the "difference variable". Marginal price is the price that a customer would pay for an additional unit of water. Average price is obtained by dividing the total water bill by the amount of water used. The difference variable, suggested by Taylor (1975) and Nordin (1976), is defined as the difference between the total water bill and what the consumer would have paid if all units of water were purchased at the marginal price. Table 3.1 summarizes the price elasticity obtained according to different price specifications. Most of these studies were conducted in the United-States and a few in Europe.

In residential demand studies, a household is faced with the decision on how much water to use in a given month. This is determined by how much more (or less) the household is willing to pay for water (Gibbs, 1978). The additional cost of a unit of water is the marginal price and not the average price. Therefore, the marginal price is generally believed to be the correct price specification governing a household's decision on how much water to use.

B) Income

Most residential demand models include an income variable. Income is used to indicate the ownership of water-using appliances, ability to pay for water, size of household and lawn, personal lifestyle and household habits. In general, customers with a high income own more water-using devices, are able to pay more for water and have a larger home and lawn than those with a lower income. Water demand is therefore expected to be positively related to income.

Table 3.1. Price Elasticities

Price specification	Study	Price elasticity
Marginal price	Howe and Lineweaver (1967)	-0.21 to –1.57
	Gibbs (1978)	-0.51
	Carver and Boland (1980)	-0.02 to –0.7
	Moncur (1987)	-0.3 to –0.68
	Metzner (1989)	-0.25
	Martin and Kulakowski (1991)	-0.26 to –0.7
	Lyman (1992)	-0.39 to –3.33
	Nieswiadomy (1992)	-0.02 to –0.17
	Hoglund (1999)	-0.1
Average price	Gibbs (1978)	-0.62
	Foster and Beattie (1979)	-0.27 to –0.76
	Danielson (1979)	-0.27
	Hanke and de Maré (1982)	-0.15
	Weber (1989)	-0.202
	Nieswiadomy (1992)	-0.22 to -0.6
	Hoglund (1999)	-0.22
Difference variable	Agthe and Billings (1980)	-0.18 to –0.705
	Billings and Agthe (1980)	-0.267 to –0.49
	Agthe et al. (1986)	-0.26 to –0.62
	Nieswiadomy and Molina (1989)	-0.09 to –0.86
	Renwick and Green (2000)	-0.16
	Martinez-Espineira (2002)	-0.12 to –0.28

For studies employing aggregate data, the income variable used in demand models is usually the total income for an area divided by the number of households or the population (Arbués et al., 2003). In many aggregate demand studies, the Gross Domestic Product (GDP) is used as a proxy for income. The Gross Domestic Product is an indication of the change in an economy. As GDP grows, incomes grow, causing domestic demand for water to also grow. GDP is therefore expected to be positively related to water use.

In household studies, income is commonly represented by various proxies such as assessed property value or lot size. Ideally, household level income data is preferred but this is seldom obtained. Household income is often extrapolated from Census data and adjusted for inflation and GDP change. Most studies have concluded that as the income increases, people tend to consume more water (see Table 3.2). Table 3.2 lists elasticities for different income specifications.

Table 3.2 Income Elasticities

Income specification	Study	Income elasticity
House value	Howe and Lineweaver (1967)	0.324 to 0.38
	Grima (1973)	0.561
	Danielson (1979)	0.334
Income per household	Wong (1973)	0.2 to 0.26
	Gibbs (1978)	0.51 to 0.8
	Agthe and Billings (1980)	1.33 to 7.89
	Hanke and de Mare (1982)	0.11
	Al-Qunaibet and Johnston (1985)	0.01 to 0.211
	Moncur (1987)	0.04 to 0.08
	Lyman (1992)	0.122 to 0.147
	Renwick and Green (2000)	0.25

C) Frequency of Billing

Another important determinant of water demand is the frequency of billing (Arbués et al., 2003). People who are frequently billed should have a better understanding of the rate structure. Hence, they are expected to react faster to changes in water tariffs. This would imply that water use should decrease with the number of billing periods. However, some studies have shown that fewer but bigger bills have a greater effect in reducing water use (Stevens, 1992). Customers faced with large bills may try harder to change their habits to reduce their water bills.

D) Weather

It is hypothesized that weather plays a large role in determining water use, especially outdoor use which is directly related to rainfall and temperature. Water use also depends on the availability of water supplies which is a function of weather and climate. Numerous variables representing the effect of weather on water demand have been employed. They include precipitation (Foster and Beattie, 1979; Renwick and Green, 2000), daily rainfall (Danielson, 1979), evapotranspiration from Bermuda grass minus rainfall (Billings and Agthe, 1980) and average temperature. Many authors found that it is the deviation of rainfall and temperature from historical mean that impacts water use and not the total rain or temperature (Bishop and Weber, 1996). Al-Quanibet and Johnston (1985) used a variable that is a function of temperature, minutes of sunshine and wind speed. All these studies have found a negative relationship between rainfall and water demand and a positive one between temperature and water demand.

E) Demographics

The change in population and household size affects the amount of water consumed. If the population is increasing, there will be more people consuming water, and therefore overall water demands should increase. If the number of persons in a household is increasing as well, there will be more people using water in that household and therefore household demands will subsequently increase. However, some studies have shown that the increase in water use is less than proportional to the increase in household size (Danielson, 1979; Hoglund, 1999). Other variables describing demographics include the number of children in the household and the number of persons per meter.

F) Indoor vs. Outdoor Use

Some authors have disaggregated water use into outdoor and indoor uses. Variables for outdoor use include the irrigable area per dwelling, size of garden, sprinkler system and pool ownership. Studies have demonstrated that outdoor water uses are generally more responsive to price changes (see Howe and Lineweaver, 1968; Grima 1973). This is because outdoor water uses are non-essential uses and therefore, there is a greater opportunity to reduce these uses. Water use has also been disaggregated according to winter and summer seasons. Winter demand is most often less sensitive to price changes than summer water demand (Lyman, 1992) because most of the water consumed during the winter is for indoor purposes. Danielson (1979) found a summer price-elasticity of –1.38 and a winter price-elasticity of –0.27. This suggests that increasing prices in the summer season will have a greater effect in reducing consumption.

G) Dummy Variables

Dummy variables are frequently included in econometric models to measure the effect of qualitative or on-off conditions. A dummy variables takes on the value of 1 when the condition is true and 0 otherwise. Dummy variables can be used to identify when water restrictions have been enforced (Moncur, 1987) or water prices have changed. They are useful for representing conservation measures enforcement. They can also be employed to indicate the different seasons within a year.

H) Seasonality

Seasonality should not be confused with weather variables. Water consumption is clearly affected by the time of the year. Weather variables such as rainfall and temperature do not necessarily measure the seasonality effect because they do not efficiently define the spring and fall transition periods (Weber, 1989). Bishop and Weber (1996) identified seasonality by a seasonal index for each month relative to 1 that defines the normal level of water use for each month relative to the average month. Dummy variables can also be used to indicate seasonal effects.

3.3.2 Data Types

Econometric demand models are typically conducted using two different types of data, time-series or cross-sectional data. In time-series data, observations of all variables are taken at regular time intervals such as daily, monthly or annual readings. Time-series analysis can be very useful if data is available for a long period of time because water use trends can be identified and used for forecasting future water use. Unfortunately, this type of data is seldom obtained and as a result, time series analysis using short periods of time are used which can be problematic in identifying medium to long term trends. Price structures do not usually change for long periods. Hence, the effect of price on water demand cannot be determined accurately by using short time-series. In addition, much of the economic-demographic information of a particular sample is unavailable (Morgan, 1974).

In cross-sectional data, observations are taken at a given time across different entities such as households or communities. Surveys are commonly employed to collect information on different variables (household income, water-using appliances, pool ownership, etc.) for a sample of households. Cross-sectional analysis allows for a better understanding of why water demand varies across households and is used to develop policy decisions. The underlying assumption when using cross-sectional data is that relationships that exist among variables at a certain time will continue into the future (Jones et al, 1984).

One other option consists of combining cross-sectional with time-series data in a panel-data approach, known as pooling. As a result, the number of observation will be increased, thus improving the reliability of the parameters. Pooling is most useful when the length of the time-series is short and/or when there is a small sample in the cross-sections. This type of data also allows for the inclusion of variables that vary over time such as price and rainfall or over cross-sections, but that may not necessarily be varying over both dimensions (Hanke and de Mare, 1982).

3.3.3 Regression Problems

Econometric demand models are generally developed using ordinary least squares regressions (OLS). There are five major assumptions that must be met for the OLS method to be the optimal estimator (Kennedy, 1998):

1. The dependent variable can be calculated as a linear function of a set of explanatory variables
2. The expected value of the error (disturbance) term is zero
3. The error (disturbance) terms all have the same variance
4. It is possible to repeat the sample with the same independent variable values
5. The number of observations is greater than the number of independent variables and no exact linear relationship between independent variables exists

This section will look at the problems encountered when some of these assumptions are violated.

A) Multicollinearity

Multicollinearity occurs when one of the independent variables is linearly related to one or more of the other explanatory variables. This violates assumption 5 stated above. Multicollinearity in the data could arise for several reasons such as the data collection method, constraints on the model, model specification and an overdefined model (Montgomery & Peck, 1992). The major consequence of this undesirable feature is that the variances in the estimates of the parameters of some of the collinear variables will be quite large (Montgomery & Peck, 1992). High variances means that the model parameter estimates will not be precise.

Multicollinearity is generally detected through the use of the correlation matrix. Statistical software usually includes a matrix of correlation coefficients between all pairs of the independent variables. A correlation value above 0.8 indicates high correlation between variables.

B) Heteroscedasticity

One of the main assumptions regarding regression analysis is that the error variance is constant. Heteroscedasticity occurs when this assumption is violated (assumption 3). As a result, the least squares regression method is no longer the best fit. Hence, the regression model statistics are no longer as reliable.

One way of detecting heteroscedasticity is to plot the residuals against any of the model variables. For example, if income is used as an independent variable in a micro-economic survey, there tends to be more variation in errors as income increases. This shows that the model errors are not constant throughout the regression. Weighted-least-squares (WLS) can be used to correct for heteroscedasticity. Good descriptions of the WLS process are given in Draper & Smith (1998), and Montgomery & Peck (1992). The deviation between the observed and expected value of the dependent variable is multiplied by a weight chosen inversely proportional to the variance. More weight would thus be given to observations that exhibit less variance such as low income households.

C) Autocorrelation

Autocorrelation is generally a problem with time series data. Here, the error from one observation is related to the error of another thus violating one of the least square regression assumptions (assumption 3). Autocorrelation could arise for several reasons such as random shocks (disturbances), data manipulation and failure to include an important variable in the model (Kenndey, 1998). For instance, a severe drought may affect water demands for many time periods after the drought occurred.

Autocorrelation is commonly detected by visual inspection (residual plots) or by the Durbin-Watson test. Most computer regression programs provide the Durbin-Watson statistic (or *d* statistic) in their output. A *d* statistic of 2 indicates that no autocorrelation is present. The further away the *d* statistic is from 2, the more likely that there is a problem of autocorrelation.

3.4 Concluding Remarks

Water demand models are developed to understand the variables affecting water use. Demand models differ in their complexity and structure. Bivariate models, such as the per-capita and unit-use coefficient models, explain water use with one explanatory variable. Other important variables known to affect water demand may be omitted. Multivariate models, such as requirement and econometric demand models, represent water use in terms of a number of variables. The choice in model depends on the type and quantity of data and on the required use of the model. To study the impact of policy changes on residential water demand, such as increasing water tariffs, an econometric demand model is most appropriate. These types of models can assist policy makers by providing information on the sensitivity of water use to changes in the explanatory variables (price, income, etc.).

Chapter 4. Water Resources Development and Management in Barbados

Chapter 2 looked at managing water from a demand-driven approach. Chapter 3 discussed how water demands are generally modeled. In particular, emphasis was placed on the evaluation of the effects of different variables, such as price and income, upon water demands. The following chapters will look at the effect of some of the important variables that explain residential water demand in Barbados. First, an overview of water resources development and management on the island will be discussed.

4.1 Introduction

4.1.1 Location and Area

Barbados is the most easterly island in the Caribbean. It is located 165 km west of St.Vincent and the Grenadines. The island is roughly pear shaped and is 34 km long by 23 km wide for an area of about 430 km^2. The island population in 2000 was approximately 269 000, which gives a population density of 625 persons/km^2, thus making it one of the most densely populated islands in the Caribbean.

4.1.2 Climate

Barbados enjoys a tropical maritime climate with average annual temperatures ranging from 25°C to 28°C. The island is characterized as having a sub-humid to humid rainfall regime. Precipitation shows a greater variation than temperature in both time and space (UNEP, 2000). The annual rainfall ranges between 1140 mm/yr and 2150 mm/yr, with a mean of 1412 mm/yr. Most of the rainfall occurs during the wet season which lasts from July to November. The wet season is the primary source of potable water on the island (UNEP, 2000). The west-central parts of the country receive the greatest amount of rainfall while the north and south coastal regions receive the least. Relative humidity and evapotranspiration are generally high throughout the year.

4.1.3 Geology

Unlike most of its neighbours in the Caribbean, Barbados is not of volcanic origin. It emerged as a coral-capped sea mount, which formed the tip of an uplifted ridge of sedimentary material (Leitch, 1997). When the sedimentary material was uplifted towards sea level, coral started to grow in layers that can be seen today. The coral cap is made up of a very highly fissured coral limestone formation. The coral limestone covers about 85 % of the island (Forde, 1995). It varies in thickness from 26m to 100m, and is underlain by an impervious layer made up of clay, sand, shale and marl (Forde, 1995). The rest of the island is known as the Scotland District and is located in the north-eastern section. Here, the coral formation has been removed by erosion (Forde, 1995). The area consists mostly of clay, shale and sandstone.

4.1.4 Hydrology

The island's hydrological characteristics are governed by its geology. Most of the Scotland District is impermeable because of the fine grained and low hydraulic conductivity clays and shale. Hence, surface runoff is more pronounced in this region due to the low infiltration of rainfall.

In contrast, the coral cap area is highly porous and permeable, which allows for high rainfall infiltration. Rainwater percolates into the soil moving through cracks and joints until it reaches the bottom of the coral cap. The rocks that underlie the coral cap are of low permeability. Over time, the coral cap formed well-developed underground channel systems. These channels then follow the slope of the interface of the limestone and underlying oceanics. The result is a system of underground rivers and streams that have been described as the "stream water" area of Barbados (see Figure 4.1).

As the stream water moves towards the coastline, it gradually rises to be above seal level at the coast. This creates a coastal reservoir of fresh water known as the "sheet water" which floats above the salt water. It varies in width from a few hundred meters to up to 3 km. Most of the public wells in use today are located in the "sheet water" zone and most of the privately owned wells are in the "stream water" zone (Mwansa, 1997). Figure 4.1 shows the hydrologic structure of the island.

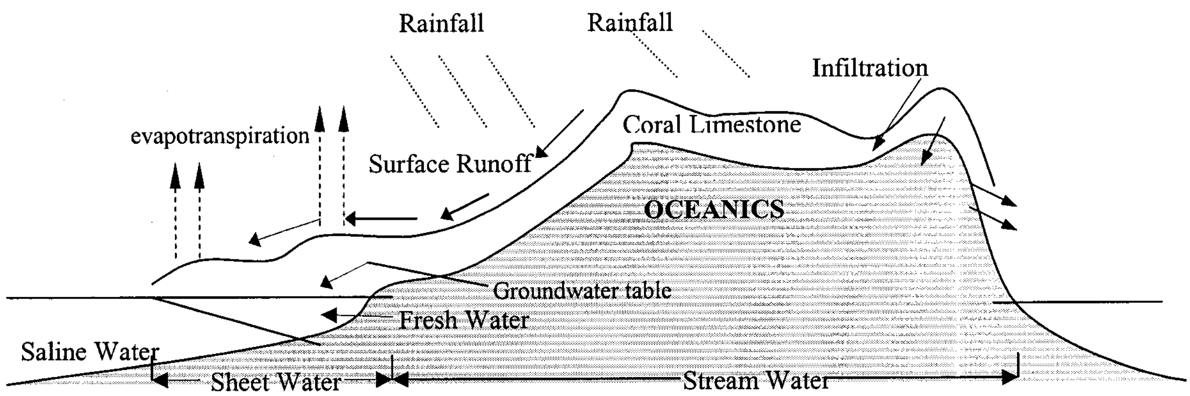


Figure 4.1 Hydrologic Structure (source: Barbados Water Authority 1998 Annual Report)

4.2 Legislation and Institutional Framework

4.2.1 History

Water resources management has undergone many changes throughout the history of Barbados. In 1857, the government approved the formation of a private water supply company under the Water Works Act. This company was responsible for the supply of water to the capital, Bridgetown. In 1886, the Water Supply Act was established, from which emerged a second private company whose duty was to supply water to the rural areas. In 1895, the government brought the two companies together to form the Water Works Department, which is the predecessor to the present Barbados Water Authority (Mwansa, 1997).

Barbados is almost entirely dependent on groundwater supplies to meets its demands for water. However, prior to 1953, no license was needed to abstract water from a well (Mwansa, 1997). In 1953, the Underground Water Control Act was passed and allowed for the creation of a Water Board that controlled and managed the development and protection of groundwater resources (Mwansa, 1997). The Water Board also had the responsibility of issuing licenses for the construction of new wells and the deepening of existing wells.

In 1963, because of concerns about the quality of the groundwater resources, the Groundwater Protection Zoning Policy Act was established. This act was based on a zoning system intended to protect the groundwater against bacteriological contamination. It was not designed to protect against chemical pollution. The criteria used for separating the zones were the attenuation rates of bacteria based on travel times. This system divided the island into five water protection zones, with zone 1 being the most restrictive with respect to allowed physical development, and zone 5 having no restrictions (see Appendix A).

4.2.2 Barbados Water Authority

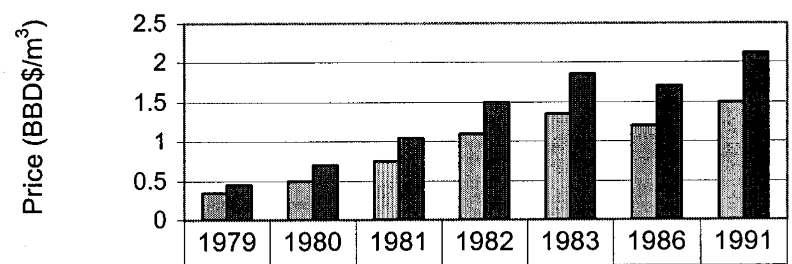
The Barbados Water Authority (BWA) was established in October 1980 through the Barbados Water Authority Act CAP 274A. The BWA took over the management of the Water Works Department and the responsibility for the Water Board. The Barbados Water Authority Act gives power to the BWA to provide water and sewerage services to the entire island, create regulations and manage, allocate and monitor the water resources (Klohn-Crippen, 1996-1998).

Table 4.1 Water Consumption and Revenue Generated by Sector in 2000

Sector	**Total Water Consumed (%)**	**Revenue Generated (%)**
Domestic	68	59
Commercial	14	17
Hotel	7	9
Government + Statutory Institutions	9	12
Port Authority	2	3

The BWA was initially required to recover operating costs, whereas capital costs were subsidized by the Government. Since then, the BWA has tried to move towards financial self-sufficiency by selling water to all customers via metered and un-metered connections (R.M. Loudon, 1994). About 95% to 98% of operating revenues are obtained from the sale of water. Customers were billed quarterly until 1994 and are now billed on a monthly basis. Table 4.1 shows the approximate relative share of revenue generated by the different sectors in 2000. As presented, the domestic sector is by far the largest consumer of water on the island and responsible for the greatest share of the water authority's operating revenues.

Water rates changed many times prior to 1991 (Figure 4.2). In 1979, the domestic metered rate was $0.35/m^3$ and $0.45/m^3$ for non-domestic customers. In the following four years, rates increased every year. In 1986, there was actually a reduction in domestic, commercial and fixed rates. Rates were then increased in 1991 and have not changed since.



	1979	1980	1981	1982	1983	1986	1991
domestic rate	0.35	0.5	0.75	1.1	1.35	1.2	1.5
commercial rate	0.45	0.7	1.05	1.5	1.85	1.7	2.12

Figure 4.2. Domestic and Commercial Water Rates (source: Barbados Water Authority Water Rates Table)

The current water and sewerage rates for metered and non-metered customers are shown in Table 4.2 and Table 4.3. All metered customers pay a uniform rate except for metered domestic users who are faced with a two-block rate structure (Table 4.2). It had been argued that this current block tariff does not constrain demands to any significant degree (Klohn-Crippen, 1996-1998). The first block allows a generous quantity of water at a relatively low price. The second block is unlimited and the price increase is quite modest. Also, if domestic customers use less than 13 cubic meters of water in a month, they essentially pay a flat rate of BBD$20 for their water. This actually encourages usage of water up to this level.

Rates for non-metered customers are based on the Net Annual Value of the property and the number of fittings. These indicators are used as a proxy for income/lifestyle and hence water use. Non-metered customers typically pay between BBD$13.33/month to BBD$53.33/month. Current rates charged for non-metered customers are listed in Table 4.3.

Table 4.2 Rates for Metered Customers[1]

Domestic	Minimum of BBD$20/month if customer uses less than 13m^3 per month BBD$1.5/m^3 if customer uses between 13m^3 and 34m^3 per month BBD$2.12/m^3 for use over 34m^3 per month For sewerage, add 1/3 of water bill
Commercial (including hotels)	BBD$2.12/m^3 For sewerage, add 2/3 of water bill
Port Authority	BBD$3.50/m^3
Agricultural (government sponsored programs)	BBD$1.31/m^3

1. source: Barbados Water Authority, personal correspondence

Table 4.3 Rates for Non-Metered Customers (in BBD$)[1]

$0 to $114 Net Annual Value	$160 per annum
$114 to $150 Net Annual Value	$160 per annum + $1.40 per $1 NAV over $114
$150 to $336 Net Annual Value	$225 per annum + $1.06 per $1 NAV over $150
$336 and over	$447 per annum + $1.13 per $1 NAV over $336, $640 max.
Water Closet	$70.31 per annum
Shower Bath	$35.15 per annum
Other Bath	$50.62 per annum

1 source: Klohn-Crippen, 1996-1998

The BWA's net income in a given year is the sum of all operating income and interest and other income. Operating income comprises of operating revenues minus expenses. Over the past two decades, the BWA struggled to achieve positive net incomes. Figure 4.3 shows the change in net income/loss from 1987 to 2000. As shown, the BWA experienced its largest net income during 1992-1995. This can be attributed to the increase in operating revenues due to the increase in water tariffs in 1991. However, the BWA's financial performance began to decline thereafter. Operating revenues from 1997 to 2000 could not keep up with the ever increasing operating expenses. Operating expenses increased for numerous reasons. First, in 1997 the BWA commenced its Universal Metering Program which sought to add 60 000 new meters. Second, the cost of producing and treating a cubic meter of water increased during this period. In 1995, it cost on average 0.67$ to produce a cubic meter of water and 0.92$ in 2000. Third, construction on a new desalination plant started in 1999. Fourth, the BWA embarked on a more vigorous leak detection campaign starting in 1995. Finally, the BWA was committed to paying back its loan from the Interamerican Development Bank (IDB) for the financing of the South Coast Sewerage Project.

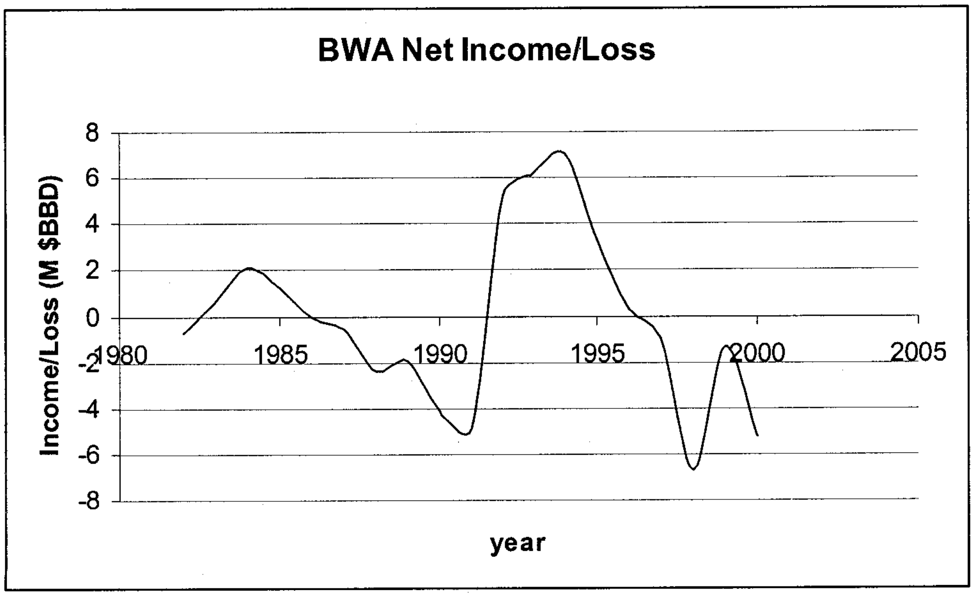


Figure 4.3. Barbados Water Authority Net Income (source: BWA Annual Reports)

4.3 Previous Studies

Three major water resources assessments have been conducted in Barbados. The first in 1945 by Alfred Senn, the second in 1978 referred to as the "Barbados Water Resources Study", and the third major study from 1996 to 1998 called the "Water Resources Management and Water Loss Studies". In addition, in 1994, a water metering study was conducted by R.M Loudon Limited for the Barbados Water Authority.

4.3.1 1946 Study

Alfred Senn was the first to attempt to quantify the water resources of Barbados. Senn's main efforts were used to map the geological structure of the coral rock and to measure its influence on the flow and nature of groundwater. He also performed a water balance and his results indicated that evaporation accounted for 75% of rainfall, runoff 5% and groundwater replenishment, 20%. He estimated that 310 x 10^3 m^3/day (67.6 mgd (mega gallons per day)) of groundwater was available under average rainfall of 1500 mm (60 inches) per year and 210 x 10^3 m^3/day (46 mgd) under 1000 mm (40 inches) of rainfall.

4.3.2 1978 Barbados Water Resources Study

In 1978, Stanley Associates of Canada and Consulting Engineers Partnership Ltd., produced a six volume study of the water resources of Barbados (Stanley Associates Engineering, 1978). The study was initiated by the Government of Barbados because of concerns for the increasing demands for water and deteriorating water quality and also to investigate the potential for increasing recharge of groundwater aquifers.

The study estimated the developable water resources of Barbados at 263 x 10^3 m^3/day (54.79 mgd) under average rainfall conditions and 156 x 10^3 m^3/day (34.37 mgd) under drought conditions. The study also predicted domestic water demands in 1993 based on three different growth rates of per capita demand and a population growth rate. Total annual domestic consumption in 1993 was predicted to be in the range of 17 x 10^6 m^3 to 27 x 10^6 m^3 (actual consumption was 16 x 10^6 m^3). In addition, technical and economic feasibility of reuse of treated wastewater for irrigation and groundwater recharge were reviewed.

4.3.3 1994 Water Metering Study

This study was conducted by R.M. Loudon Limited to give recommendations to the BWA for a water metering program (R.M. Loudon Ltd, 1994). The BWA was committed by agreement with the Interamerican Development Bank to install 40 000 new meters from 1994 to 1996. The consultant company was required to give advice on the type, sizes, number and the area distribution of meters based on water consumption patterns and use.

The study began by assessing water consumption patterns and consumption data. The accuracy of currently installed meters was then measured by testing a sample from all the meters currently installed. Finally, recommendations on the planned installation of the 40 000 new meters were made.

4.3.4 Water Resources Management and Water Loss Studies (WRM/WL)

The WRM/WL studies were conducted by Klohn-Crippen Consultants Ltd., in association with Stanley Associates Engineering Ltd and Consulting Engineers Partnership from June 1995 to February 1997 (Klohn-Crippen Consultants, 1996-1998). The studies were commissioned to address the growing concerns of quality and supply of water in Barbados, especially after periods of serious water droughts in 1993 and 1994. The main objective of the studies was to "develop a comprehensive water resources management program in which all elements of an integrated approach are considered" (WRM/WL). The primary elements of the studies were: analysis of existing situation, water rights issues and legislation, water demand analysis, water conservation, water loss estimation and reduction program, groundwater recharge and water source augmentation alternatives and the development of a 20 year Water Resources Development and Management Plan.

Some of the main findings of the WRM/WL studies were (Klohn-Crippen, 1996-1998):

- Present groundwater abstractions either equal or exceed the safe yields for an average rainfall year.
- Developable groundwater resources are smaller than previously estimated
- Losses from the BWA distribution system are about 60%

- Reducing the losses to 30% by 2016 is recommended
- Reduction of water lost from the distribution system is the most desirable and cost effective method to conserve water
- Desalination of brackish water and sewage reuse are the most suitable alternatives to provide additional water.

4.4 Water Supply and Demand

This next section will take a closer look at water availability, abstractions, and consumption on the island. Some of the key problems regarding water resources management will also be discussed.

4.4.1 Overview of Groundwater Abstractions

A) Public Abstractions

Groundwater accounts for 80% of the island's water resources and for 97% of its public water supply (Klohn-Crippen, 1996-1998). Almost all of the island's potable water is pumped from 21 groundwater wells in the coral area and additional water is obtained from 2 springs in the Scotland District (Klohn-Crippen, 1996-1998). Water pumped by the BWA from 1983 to 2002 is shown in Figure 4.4. The BWA's abstractions in 1996 from these sources amounted to 58.8 x 10^6 m^3 or 161 x 10^3 m^3/day, of which 54.7 x 10^3 m^3/day is abstracted from the Belle Pumping Station and 26.1 x 10^3 m^3/day from Hampton Pumping Station (BWA production data). This means that 50 % of the island's public supply is obtained from these two stations.

It is important to note that production data prior to 1996 may be flawed because of the inaccuracy and lack of meters at the pumping stations. For example, the Belle Pumping station, which supplies about a third of the water into the system, was not properly metered prior to August of 1995. After the proper metering in 1995, the output from the Belle station was found to be 54.7 x 10^3 m^3/day, but for years it was estimated to be 40 x 10^3 m^3/day (source: 1996 BWA annual report). This results in an error of approximately 27%. In addition, the proper metering of the Hampton pumping station (which supplies approximately 15% of the water into the system) was not completed until October 1995.

In 2000, the first desalination plant on the island to supply potable water was in operation. The amount of water produced at the plant is also shown in Figure 4.4. Water from the desalination plant accounted for about 10 % of the water in the distribution system in 2002. The total amount of water supplied into the distribution system is therefore the sum of water pumped from groundwater and that produced by the desalination plant.

Water production has grown steadily to meet the demands of a growing population and due to an increase in the standard of living. However, between 1996 and 2002, a continuous decline in water pumped from groundwater is observed. The amount of water pumped from groundwater sources fell from 58.8 x 10^6 m^3 to 48.8 x 10^6 m^3 during this period, a decrease of 17%. This decline can be attributed to a number of factors but it coincides directly with the implementation of the universal metering program (see section 4.5.1). After the year 2000, the desalination plant began to supply about 10% of the total water in the distribution system. Therefore, the total water supplied into the system actually increases in 2000 but declines in the following years.

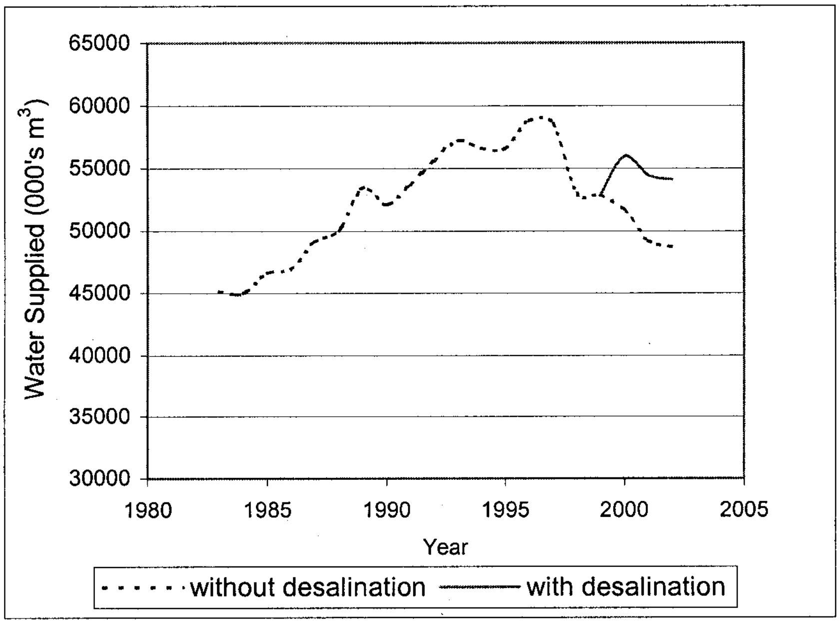


Figure 4.4 Water Production (BWA water production data and WRM/WL studies)

B) Private Abstractions

There are approximately 120 private wells operating in Barbados mainly used for irrigation. Since a majority of the wells are not metered, it is difficult to say just how much water is being pumped from these sources. The 1996/1998 Water Resources Management and Water Loss studies indicated that about 55 x 10^3 m^3/day (12 mgd) are being pumped from private wells (Klohn-Crippen, 1996-1998). Total abstractions from public and private wells in 1996 were therefore approximately 220 x 10^3 m^3/day (47 mgd).

4.4.2 Water Availability

Barbados is ranked among the top ten water scarce countries in the world because the available supply is well under the 1000 m^3 per capita set internationally as the limit below which a country is classified as water scarce (UNEP, 2000). Moreover, total water abstractions from groundwater resources are quite high when compared to the available water resources. The available water resources were estimated in two major studies, the 1978 Water Resources Study and the 1996/1998 Water Resources Management and Water Loss studies. Table 4.4 shows a breakdown of the water resources according to these two studies. Based on these estimates, groundwater abstractions in 1996 of 216 x 10^3 m^3/day (47 mgd) either exceed or approach the available water resources under normal and drought conditions.

Table 4.4 Available Water Resources

	1978 Study (Stanley Associates, 1978)				WRM/WL Studies (Klohn-Crippen, 1996-1998)	
	Average rainfall condition 1500 mm (60 inches)		1 in 15 yr design drought		Average rainfall condition 1400 mm (56 inches)	
Source	m^3/day	(mgd)	m^3/day	(mgd)	m^3/day	(mgd)
groundwater	210 x 10^3	45.27	140 x 10^3	30.18	20 x 10^3	44.57
surface water	33 x 10^3	7.19	13 x 10^3	2.89	16 x 10^3	3.5
spring water	8.2 x 10^3	1.8	5.9 x 10^3	1.3	5.5 x 10^3	1.2
wastewater					30 x 10^3	6.6
runoff	2.4 x 10^3	0.53	0	0	1.5 x 10^3	0.32
Total	250 x 10^3	54.79	160 x 10^3	34.37	220 x 10^3	49.59

4.4.3 Overview of Water Consumption and Customers

The water pumped into the public distribution system is delivered to metered and un-metered customers. Currently, all non-metered customers are residential users. Metered customers are separated into different customer groups for billing purposes: 1) domestic metered; 2) commercial; 3) hotels; 4) government buildings (including schools); 5) statutory institutions; 6) port authority. Figure 4.5 shows the change in the number of customers. The number of customers prior to 1996 was obtained from the BWA annual reports and those after 1996 from the BWA customer database (see Appendix B).

As shown in Figure 4.5, the total number of customers connected to the public supply network has grown steadily over the years with some minor fluctuations. These small fluctuations may be due to people moving out of Barbados, customers passing away, illegal connections, or other reasons. The increase in water connections is a reflection of the Government's efforts and determination to supply water to its growing population and economy. In 1996, only 32% of the customers were metered, the majority being non-residential customers (source: BWA consumption database). The public distribution system now covers over 96% of the island.

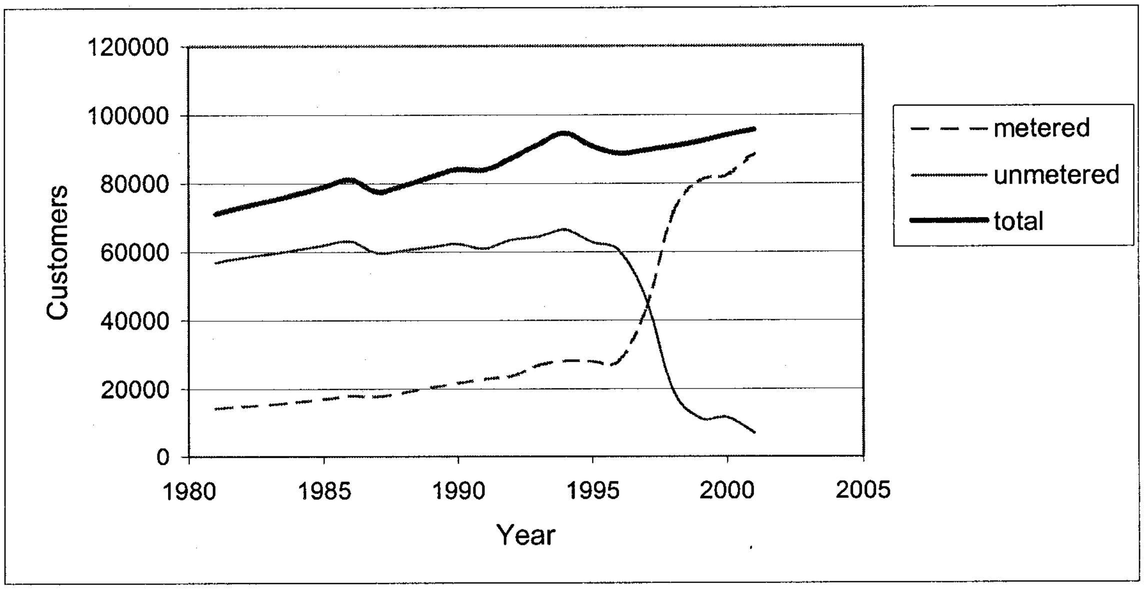


Figure 4.5. Number of Customers (source: BWA Annual Reports and BWA Consumption Database)

The water produced is used by billed metered and un-metered customers. Water not used by these customers is termed unaccounted-for-water (UFW). Unaccounted-for-water includes system leakage, illegal connections, unbilled metered and un-metered consumption and metering inaccuracies. Two major studies have estimated unaccounted-for-water in Barbados and the results indicate a value of 40% to 60% (R.M. Loudon, 1994 and Klohn-Crippen, 1996-1998). Consumption is obtained from meter readings and hence only consumption values for metered customers are available. Figure 4.6 shows the change in metered water consumption over time. Consumption values prior to 1993 were obtained from the WRM/WL studies. After 1996, metered consumption was calculated from the BWA customer database (see Appendix B)

Metered consumption has grown steadily reflecting the increase in metered connections. Metering of water first appeared in the late 1960's after Barbados became independent. Meters were first installed where customers had off standard plumbing fittings or because they felt it was more economical (R.M Loudon, 1994). By 1978, about 18% of all accounts were metered with 8% of all residential customers and most non-residential customers being metered. In 1982, it was decided that all dwellings with a floor area exceeding 239 m^2 needed to be metered. By 1993, all non-domestic customers and about 30% of residential customers were metered. A universal metering program was commenced in 1997. As shown in Figure 4.6, metered consumption increased from 13.53 x 10^6 m^3 to 28.23 x 10^6 m^3 from 1996 to 2001, while metered customers increased from 32% to 93%.

Although total metered consumption in Barbados increased considerably in the past two decades, the consumption per metered customer is actually decreasing. This is because prior to 1996, most metered customers were non-residential users (commercial, industrial, hotels, etc.) who generally consume a lot more water than residential customers. In 1984, a metered customer consumed on average 662 m^3 of water per year (10.8 x 10^6 m^3/16 295 customers), 534 m^3 in 1993, and 319 m^3 in 2001.

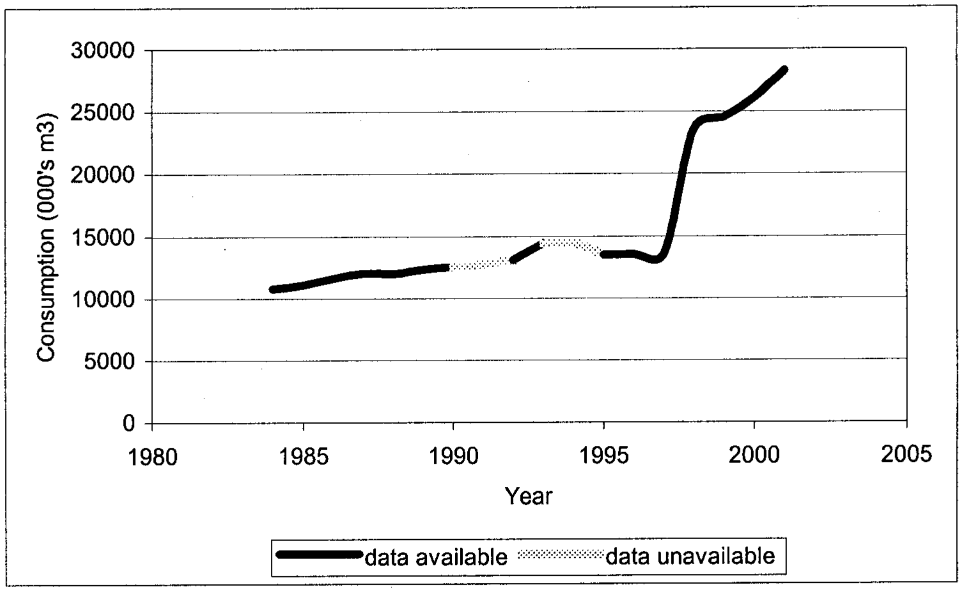


Figure 4.6. Metered Consumption (source: BWA Annual Reports and BWA Consumption Database)

A more meaningful calculation is to describe how the average consumption per residential metered customer is changing through time. Table 4.5 shows that the average consumption per metered residential customer seemed to be increasing up to 1996, and then started decreasing. The decrease can be attributed to efforts by the BWA to promote water conservation. Average consumption per residential customer has decreased from 242 m^3/yr in 1993 and 246 m^3/yr in 1996 to 227 m^3/yr in 2000 (Table 4.5)

Table 4.5 Consumption per Metered Domestic Customer

year	Metered Domestic Customers	Consumption (10^6 m^3)	Consumption per Metered Domestic Customer (m^3)
1993	20 840	5.04	242
1996	23 213	5.72	246
2000	77 708	17.6	227

The average domestic water use in Barbados is compared to water use in Canada and Europe (Table 4.6). As displayed in the table, the average domestic water consumption per capita in Barbados is higher than most countries in Europe but lower than Canada.

Table 4.6 Per Capita Domestic Water Use

Country/Continent	Per capita domestic water use (litres/day/capita)
Canada	350*
Barbados	210
Europe	150*

* Source: Presentation by Jiri Marsalek at the 57th CWRA Conference, 2004

4.4.4 Problems

The following section will describe some of the main water resources problems on the island. It was only after 1997 that great efforts were made to correct some of the problems. The main areas of concern with respect to water resources management are water scarcity and quality. The 1978 Water Resources Study (Stanley Associates, 1978) as well as the 1996/1998 WRM/WL studies (Klohn-Crippen, 1996-1998) concluded that groundwater abstractions from most wells either equalled or exceeded the safe yield estimates for an average rainfall year. Increases in abstractions are due in part to an increasing population served by the public water supply, a growing and diversifying economy (including tourism), and an increase in the standard of living. Moreover, leakage from the distribution system is a source of concern. The higher the leakage, the more water that has to be pumped out to meet the given demands. Some estimate unaccounted-for-water to be around 40% to 60% of the pumped volume. The studies also showed that demands cannot be met during drought years (1 in 15 year) without affecting the water quality through saltwater intrusion and some customers experiencing water outages. In fact, salinity level showed an upward trend during two consecutive drought years in 1993 and 1994.

There has also been growing concern over the increasing use of agricultural chemicals and the release of hazardous chemicals and substances into the environment. There has been an increase in nitrate concentrations in the groundwater believed to be attributed to the extensive use of agricultural chemicals. The risk of water contamination is accentuated by the inappropriate disposal of solid and liquid wastes.

These problems and others that include the reducing rate of aquifer recharge, together with the public outcry resulting from the 1993-1994 supply outages, have motivated the Government of Barbados to look for new approaches to manage the limited water resources in a more sustainable and efficient manner. The next section will look at some of the policies proposed and implemented in the past years to correct the emerging problems of water scarcity and diminishing quality.

4.5 New Policies and Initiatives

As discussed earlier, Barbados is faced with certain crucial water management issues such as water abstraction rates close to the reliable yield level, risk of salt-water intrusion, higher risks of contamination from liquid and solid wastes and chemicals, and excessive leakage from the distribution system. The Government recognized these problems and proposed a Policy Framework for Water Resources Development and Management in 1997 that took into account the findings and recommendations of the WRM/WL studies and of previous studies. The policy direction now includes a greater focus on water demand management measures and reduction of water losses. Alternative supply management and augmentation schemes as well as institutional restructuring and capacity building have also been given greater attention. The following sections describe both demand-side and supply-side measures that have recently been implemented or suggested to improve the management of the island's water resources.

4.5.1 Demand Management

Barbados has traditionally relied on augmenting supplies to meets its demands for water. Only recently has there been a shift towards considering demand-side alternatives such as metering, pricing and public education campaigns.

A) Universal Metering

Up until 1997, only 30 % of all domestic customers were metered which made it very difficult to control and quantify water consumption. However, all commercial and industrial customers were metered. In 1997, the Government approved a universal metering program to be supplemented with a proposed water tariff change. The first part of the program consisted of installing 40 000 meters. The second part consisted of adding another 20 000 meters on the island. Metered customers increased from 28 301 to 88 616 from 1996 to 2001.

The metering program was completed in 2000 and cost approximately US$ 3 million. There was an immediate decrease in demand soon after the program commenced resulting in a reduction of abstraction from groundwater sources. Moreover, the water utility's operating revenues rose because domestic metered customers pay on average more than fixed rate customers.

B) Change in Water Tariff

Metered customers currently pay based on the volume used. All customers except for residential customers are faced with a uniform rate. Residential customers are faced with a two-step increasing block rate structure. However, due to the presence of a minimum charge, customers who use less than the minimum value end up paying a flat rate. The current prices are believed to be too low to offer signals to conserve water. In 1997, the Barbados Water Authority proposed to change the tariff in order to encourage the efficient use of water as well as to improve its financial status. The proposed tariff is a three-step increasing block rate structure (Table 4.7). Unfortunately, the proposed change in price has been put on hold awaiting the approval of the Fair Trading Commission, which is responsible for reviewing and approving water tariff modifications.

Table 4.7 Proposed Water Tariff Change[1]

Amount (m^3)	Price ($BBD)	
	current tariff	proposed tariff
0-10	1.5	3
10-25	1.5	4
25-34	1.5	6
over 34	2.12	6

1. WRM/WL Studies (Klohn-Crippen, 1996-1998)

C) Public Education/Awareness Campaigns

There have been many activities undertaken to inform and educate the public about water conservation and efficient water use. Some of the major campaigns include: water conservation messages in all media, national consultation meetings and workshops, lectures by BWA personnel to specific target groups, discussion panels and distribution of 30 000 low water use fixtures to fully paid-up BWA customers.

An example of a successful conservation campaign is the West Terrace Primary School Water Conservation Project. The project consisted of retrofitting the school's traditional wash basin taps, installing "water hogs" in the toilet cistern and retrofitting the male washrooms with battery operated urinal flush controls. Leak detection and repair work were also undertaken. The result was that water consumption at the school dropped by 39% (Mwansa, 1999).

D) Rainwater Roof Catchments

Over the past decade, the Government of Barbados has been enforcing a rainwater roof catchment program. The program seeks to encourage the use of rainwater for secondary purposes such as watering of lawns and washing of cars. Regulations regarding rainwater roof catchments depend on the size and type of the building. The current regulations only apply to constructions after 1995.

4.5.2 Supply Management

A) Reduction of Unaccounted-for-Water (UFW)

The last study that estimated unaccounted-for-water in Barbados was the 1996/1998 Water Resources Management and Water Loss Study. Unaccounted-for-water was estimated at 60% using metered records and estimates from a sample of fixed rate customers. This value is considered too high and therefore actions must be taken to reduce the unaccounted-for-water. The WRM/WL studies concluded that reducing the unaccounted-for-water to 30% by the year 2016 is the most desirable target. This will provide reserve capacity for an average rainfall year. Reducing unaccounted-for-water can be achieved through intensified leak detection, replacement and repair of pipes and pressure control.

B) Alternative Supplies

Barbados is highly dependent on groundwater resources, but sometimes water demands cannot be met from this source alone. During the drought years of 1993 to 1994, over 3000 households were regularly without water. Therefore, additional capacity is needed to increase protection against drought conditions. Desalination, wastewater reuse and rainwater harvesting are some of the measures adopted by the government.

A brackish water desalination plant started operating on February 15, 2000. The plant was provided on a build-own-operate basis to the Barbados Water Authority. It was intended to deliver 30 000 cubic meters per day of potable water for a period of 15 years. Water from the desalination plant meets all international standards. Currently, the plant supplies 10% of the total water in the distribution system. The WRM/WL studies estimated the cost of desalination in Barbados to be 2.16 BBD$/$m^3$.

Wastewater reuse can provide additional non-potable reserve capacity and replace unnecessary use of potable water. Treated wastewater can be used, depending on the level of treatment, for groundwater recharge, industrial cooling water and irrigation. Previous studies agreed that the water demands of the major golf courses (Sandy Lane, Royal Westmoreland) on the island can be met from treated wastewater (Klohn-Crippen, 1996-1998). Upgrading the Graeme Hall Treatment Plant to the tertiary level can supply treated wastewater for irrigation in the south and east of the island.

The use of rainwater roof catchments was described earlier as a demand-side measure since it promotes conservation of potable water mostly by domestic users. However, rainwater roof catchment systems also augment the supply of water. Greater encouragement for the implementation of these systems through proper incentives should be continued.

C) Groundwater Recharge

Groundwater recharge is essential to the sustainability of the resource. It may be used to mitigate or control saltwater intrusion into coastal aquifers. In Barbados, recharge is mainly promoted by suckwells and gullies. A suckwell is essentially a deep pit that facilitates percolation. In Barbados, suckwells are used everywhere, except in some areas on the east coast because the exposed oceanic soil has a low permeability. There are probably more than 10 000 suckwells, mostly on private lands or estates. Recharge can be facilitated by cleaning the suckwells and constructing check dams in the gullies.

D) Impoundments

The potential of utilizing the surface runoff in the Scotland District has been reviewed and analyzed in the WRM/WL studies. Potential surface water resources obtained from impoundments in the Scotland District were estimated to be about 16 000 m^3/day (Klohn-Crippen, 1996-1998). Other locations for surface impoundments have also been investigated.

4.6 Concluding Remarks

This chapter reviewed the development and management of water resources in Barbados. A brief history on the evolution of water management institutions on the island was provided. The change in metered customers and consumption was presented. Currently, metered customers make up approximately 96% of the total customers in Barbados as a result of the Universal Metering Program. The metering program, together with the construction of a new desalination plant, was intended to improve the water security on the island. However, problems of water shortages and quality still loom in Barbados today.

The development, distribution and treatment of the water resources are the responsibility of the Barbados Water Authority (BWA). The BWA has been experiencing financial difficulties and proposed to raise water prices in order to improve its financial status as well as to encourage water conservation. The analysis of water price changes requires a thorough understanding of how the price of water affects water demands. The following chapter will present how the relationship between price and water demand is derived.

Chapter 5. Barbados Residential Water Demand Models

Chapter 4 presented a brief overview of water resources development and management in Barbados. Some of the key problems regarding water resources were discussed. In addition, several initiatives and policies undertaken to attempt to solve some of the water related issues were described. In particular, attention was given to water demand management measures as a means of controlling water demand. However, there is a need to determine just how effective these measures are in reducing demand. This chapter will look at the effect of water pricing on residential water demand in Barbados. Although the demand models presented in this chapter contain several variables other than price, price is the only demand management tool that is included. The impact of price is obtained by measuring the price elasticity of demand which is defined as the change in water demand divided by a change in price.

The earliest investigations into the impact of price on water demand have usually relied upon aggregate cross-sectional data. Studies were later conducted with less aggregated data. Soon after, there were increased attempts to use even less aggregated data and to use time-series instead of cross-sectional data to estimate household demand models. Hanke (1970) concluded that water use data should ideally be collected for individual households over a long period of time so that water use patterns can be analysed over time and between households.

Demand analysis using aggregate data is suitable where data is limited. The dependent variable usually being modeled is the average consumption over a sample of households for a given time period (monthly, annual). Typical explanatory variables may include rainfall, GDP, population and the average price of water. However, such an analysis neglects the difference in consumption between individual households.

This research models water use in Barbados based on a time-series of cross-sectional observations of water consumption at the community level using econometric demand modeling techniques. A sample of households from seven different districts was selected for the analysis. Data was collected for water consumption, income, rainfall, temperature and water price. Tests for multicollinearity and heteroscedasticity were made. Elasticities were estimated from the developed models. The following sections will present the developed water demand models.

5.1 Study Area and Sample Selection

Customer monthly consumption was provided by the Barbados Water Authority in digital format (see Appendix B). This database provides monthly consumption for every customer on the island from 1994 to 2002 (2002 records are only available until October). Consumption data prior to 1994 is archived in paper format, but is still accessible upon request. The non-digitized data extends back to 1985. As mentioned earlier, the last water price change occurred in 1991, therefore it is important to obtain a time-series of consumption data that includes this price modification. A time-series of 15 years was used for this study (1987 to 2001).

The decision on the sample size and study area was based primarily on data and time constraints. Because a large portion of the available consumption data is not in digital format, quite a lot of time is needed to retrieve this data from the archives. Hence, only a small sample of customers from the population was feasible. It was decided to look at water use in the Parish of St-James (Figure 5.1). St-James is characterized by districts having a wide range of income, and hence water consumption patterns. This is important in assessing the effect of water price on different income groups. In St-James, like most of Barbados, the majority of the population live in detached houses. The average number of persons per house in St-James is 2.85 (2000 Census), slightly lower than the national average of 3.

There were 6741 occupied separate dwellings in St-James in the year 2000. This number is still too great for analysis given the available resources. Therefore, a smaller sample from the 6741 households was needed. It was decided to study water use for several districts in St-James. The selected districts belonged to various income groups. Seven districts were finally chosen and classified according to income level (Table 5.1). The letters L, M, and H will be used to indicate low, medium and high income groups respectively. The income levels were based on the 1990 Census. The 2000 Census does not provide any information regarding household earnings.

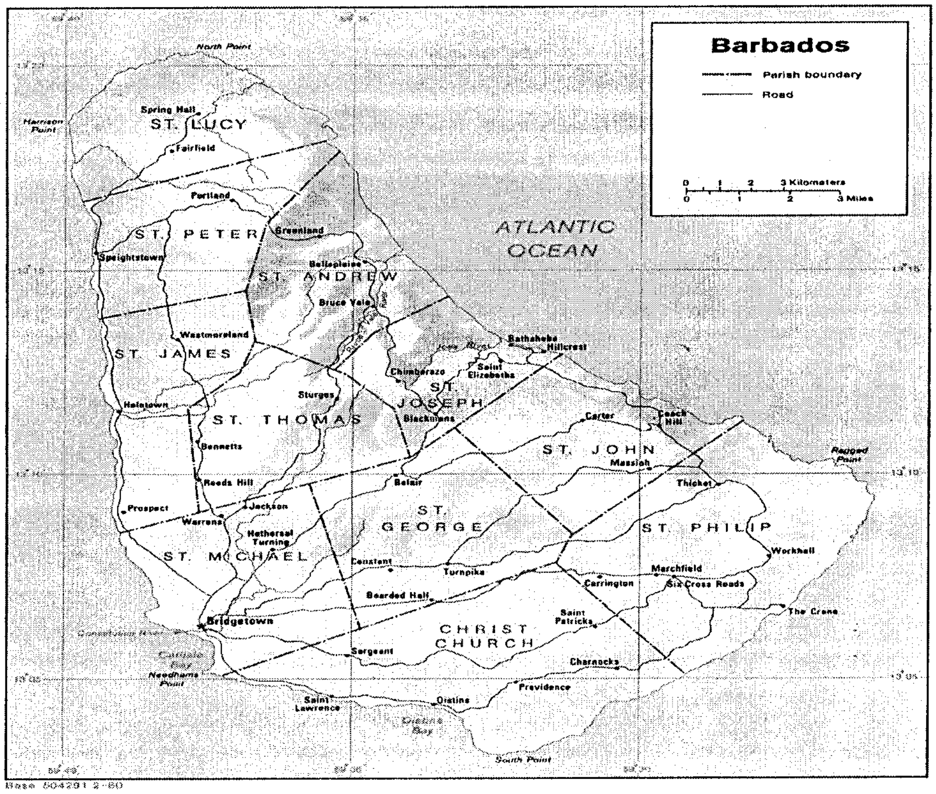


Figure 5.1 Parishes of Barbados (source: http://www.lib.utexas.edu/maps/americas/barbados)

Once the districts were selected, a sample of households from each district was needed. First, only customers who were metered in 1994 were chosen since they would most probably have been metered before 1994. Then, monthly water consumption for each of these customers was plotted from 1994 to 2001. Customers with few or no missing consumption values were selected. The second step involved retrieving water consumption from the archives for each of these customers. Only customers who have lived in the same house for the duration of the study period (1987-2001) were kept. The final number of customers chosen from each district is also displayed in Table 5.1. A total of 136 out of the 6741 (2%) occupied detached dwellings were used for analysis.

A problem might exist if the households metered prior to the 1997 Universal Metering Program belong primarily to a specific income group (high, medium, low). As mentioned in section 4.4.3, meters were first installed where customers felt it would be more economical. Hence, it is expected that meters were first installed for low water users since their water bills would decrease when metered. In the 1980's, a decision to meter dwellings with a floor area exceeding $239m^2$ was implemented. As a result, it can be argued that this decision targeted mostly middle and high income households. Therefore, there does not seem to be any bias towards a specific customer class and the collected sample is believed to be representative of the population.

Table 5.1 Districts

Income Level	District Name (see Appendix C)	Sample Size
Low (L)	Orange Hill	23
	Hoytes Village	15
	Prospect	12
	Fitts Village	25
Medium (M)	Bagatelle	21
	Sunset Crest	25
High (H)	Sandy Lane	15

5.2 Characteristics of Data Collected

This next section will examine the data collected in Barbados. Three major databases were acquired; water consumption, income and weather. Previous and current water prices were also obtained.

5.2.1 Consumption

Water consumption data for 136 households from seven districts over a period of 15 years was finally selected for analysis. Ideally, monthly water demand for each household should be modeled to capture the difference in consumption between households. However, monthly consumption for certain years prior to 1994 was missing. Moreover, monthly income data was not available for most of the 136 households (see section 5.2.2). As a result, it was concluded that an analysis of monthly water use at a household level is not appropriate. Hence, average annual household water consumption for each district was used instead. This gives a cross-section of 7 districts over a period of 15 years for a total sample size of 105. Figure 5.2 shows the average annual household water consumption over each district from 1987 to 2001. Note that some consumption values prior to 1994 are estimates since there were several missing data. Missing monthly consumption data was replaced by the mean monthly consumption during the study period. In addition, on a few occasions, values of monthly water consumption for some households were far greater than any other months. This can be attributed to errors in meter reading but may actually be the true consumption in some cases. For instance, large consumption figures may be attributed to water leakage from faulty faucets. Therefore, large consumption values were not excluded from the analysis.

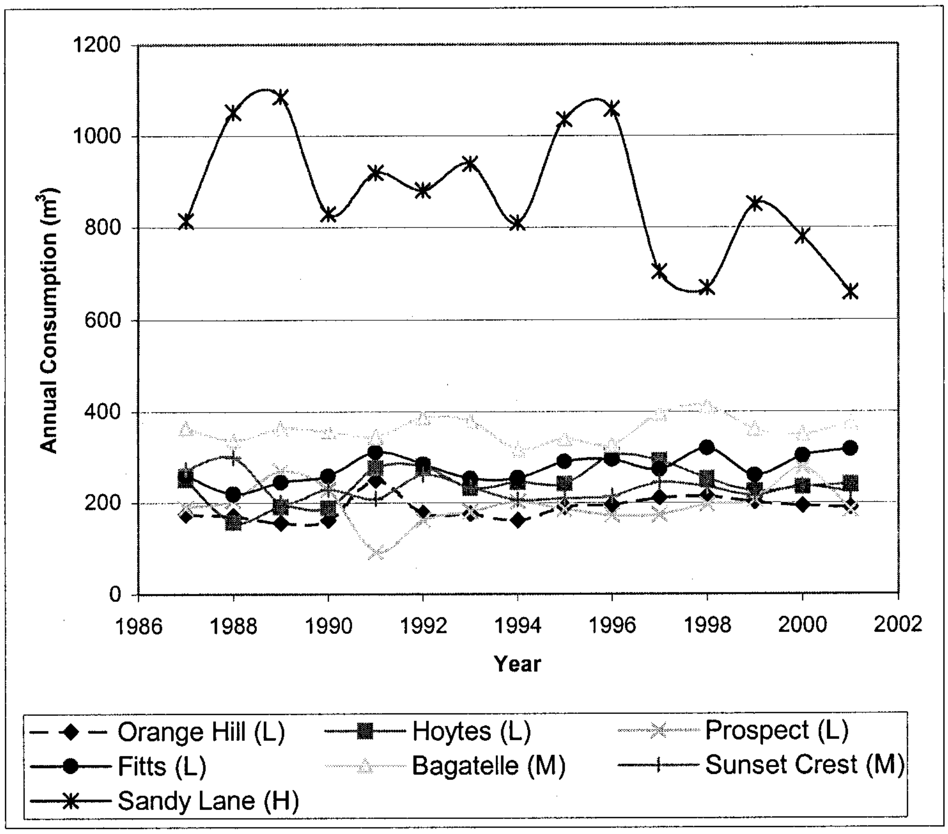


Figure 5.2 Water Consumption (source: see Appendix D)

5.2.2 Income

Income data was provided by the Treasury Department of the Government of Barbados. A database containing household annual income from salaries and wages for the Parish of St-James was obtained. However, only data after 1996 was available. The customer's income and district of residence is contained in the database. No information is available that pin points any particular individual. A household level analysis using this type of income data is unsuitable. Average annual household income for each district was calculated instead. Incomes were then adjusted using real GDP growth rates (using 2001 as a base year) to obtain a time-series of income values (Figure 5.3). Real GDP is the difference between GDP and inflation and is presented in Appendix D. Income was therefore assumed to be directly related to changes in GDP. This assumption is believed to be the most appropriate given the available information. All values are presented in 2001 dollars. Missing income data from 1987 to 1995 was computed by starting at the earliest available household income data from 1996. For instance, income in 1995 is equal to income in 1996 multiplied by (1 - real GDP change between 1995 and 1996). Income in 1994 is equal to income in 1995 multiplied by (1 - real GDP change between 1994 and 1995), and so on.

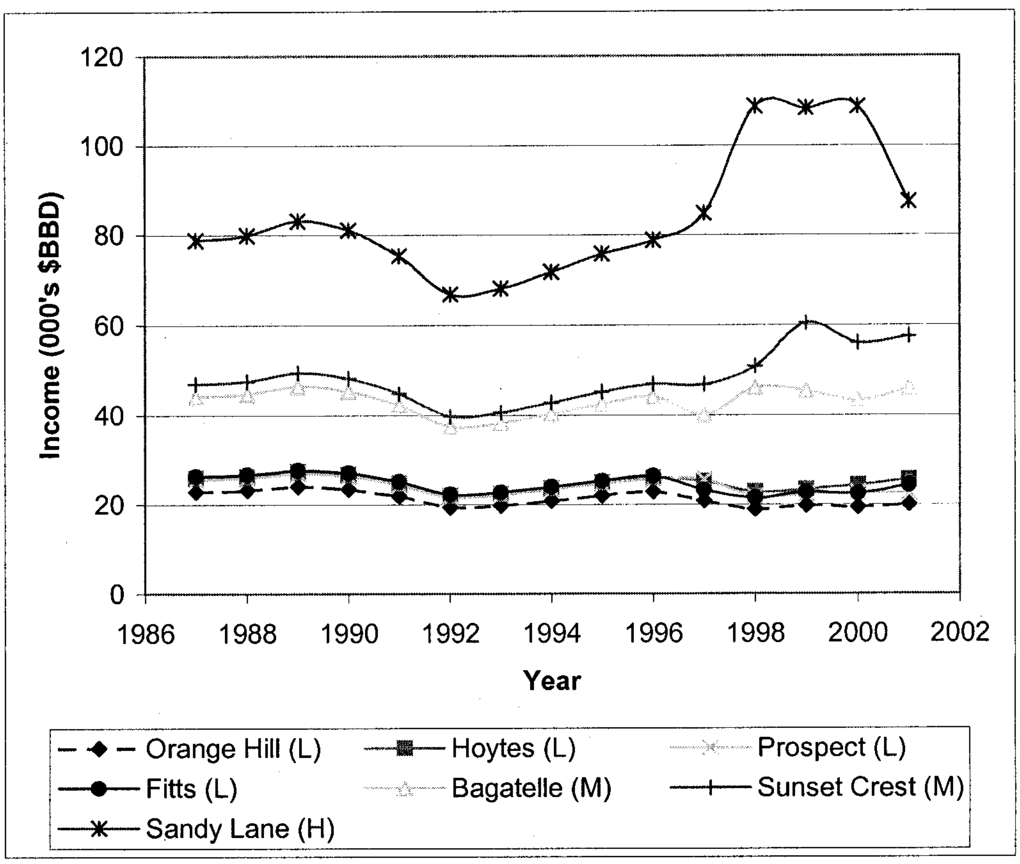


Figure 5.3. Average Annual Household Income in 2001 Dollars (source: Appendix D)

5.2.3 Water Price

Two price specifications were calculated from the data, average price and marginal price. The average price is defined as the total water bill divided by the total consumption. The average price was computed for each customer at every month. Then, for a given year, the average monthly water price faced by the average household in a district was evaluated. Average prices were then converted to 2001 prices. The final result is displayed in Figure 5.4.

In general, there was a slight increase in real average prices for most of the districts between 1991 and 1992. This coincides with the raising of water tariffs in October 1991. Moreover, the minimum charge for those who use less than 13 m^3 per month also increased in 1991 (from 10$ to 20$). Since many of the customers from the sample use less than this amount, they end up paying more per unit of water purchased after 1991. After the increase in water price in 1991, the real average price of water faced by most districts started decreasing slightly and then remained more or less constant.

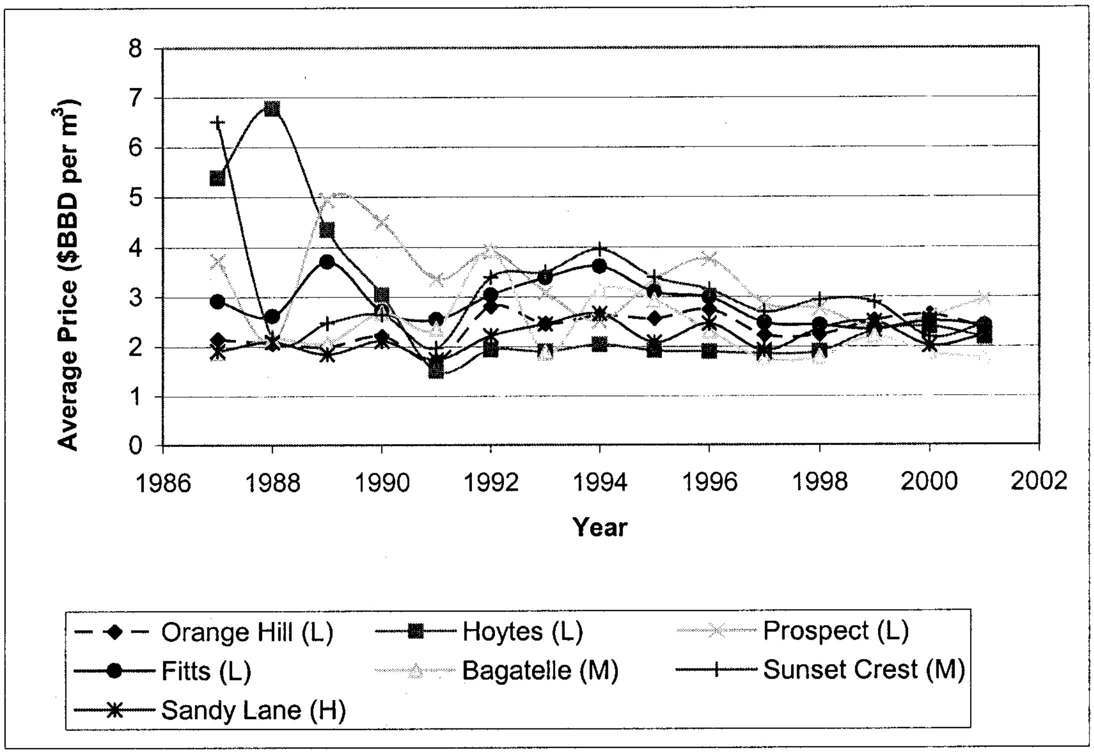


Figure 5.4. Average Price per District in 2001 Dollars (source: Appendix D)

As displayed in Figure 5.4, there are a few instances, especially prior to 1994, where the average price of water in a given year is far greater than other years. For example, the average price of water in 1988 (in 2001 prices) faced by the average household in Hoytes is 6.78 $BBD per cubic meter. This high value is due to the low consumption values recorded for the small available sample from Hoytes in 1988. The average price of water for customers using less than 13 m^3 per month is equal to 20$ divided by consumption. Therefore, for low consumption, the average price of water will be quite high.

Marginal price is the price of the last unit of water purchased. In a block rate price structure, it is the price of the block at the given consumption level. If a customer is faced with a flat rate, the marginal price is essentially 0. In our data, the marginal price is defined as follows:

From 1987 to 1991:

Monthly consumption > 50 m^3, marginal price = 1.7$/$m^3$

50 m^3 > Monthly consumption > 13 m^3, marginal price = 1.2$/ m^3

Monthly consumption < 13 m^3, marginal price = 0

From 1992 to 2004:

Monthly consumption > 34 m^3, marginal price = 2.12$/ m^3

34 m^3 > Monthly consumption > 13 m^3, marginal price = 1.5$/ m^3

Monthly consumption < 13 m^3, marginal price = 0

The average marginal price per district was obtained in the same manner as the average price. The results are shown in Figure 5.5. The nominal price of water has not changed since 1991, but the real price is constantly varying due to inflation and water use changes. As displayed in the figure, there was a small increase in marginal prices after 1991. This is mainly due to the increases in the price of the two blocks in the rate structure. The first block increased from 1.2 $/$m^3$ to 1.5 $/ m^3, and the second block from 1.7 $/ m^3 to 2.12 $/ m^3. Marginal prices slightly started decreasing slightly after 1992 due to positive inflation.

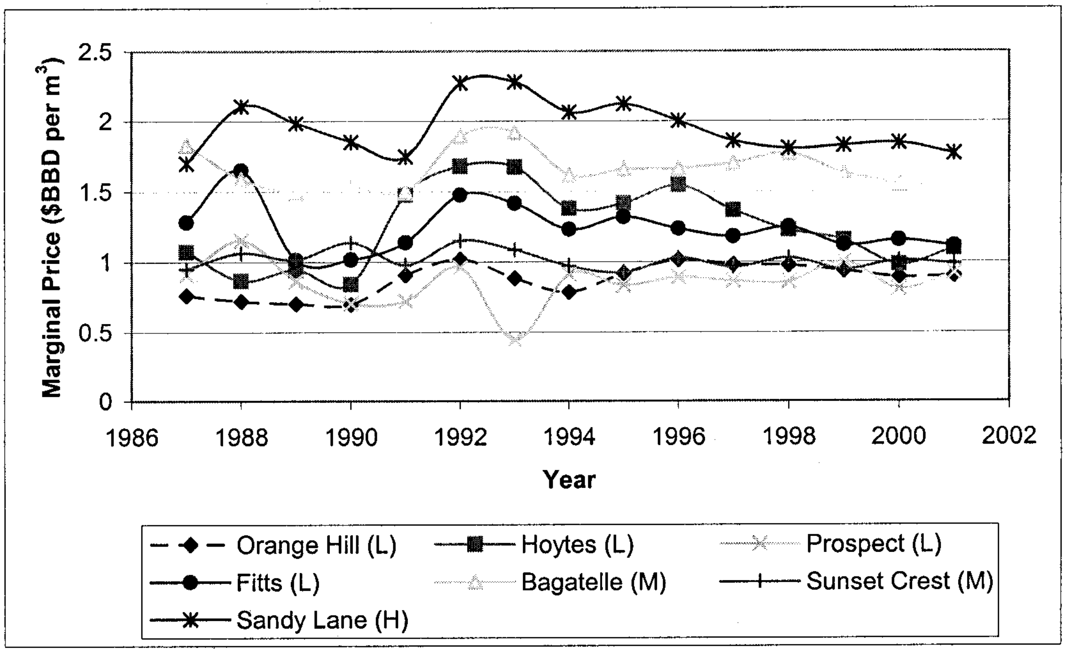


Figure 5.5. Marginal Price per District in 2001 Dollars (source: Appendix D)

5.2.4 Weather Variables

Monthly rainfall from 1971 to 2002 was obtained from the Caribbean Institute of Meteorology and Hydrology (CIMH). It was decided that rainfall from the CIMH gauging station should be used since it is the station located nearest to the seven sample districts. Annual rainfall at the CIMH station is shown in Figure 5.6. The historical average (1971 to 2002) is 1241 mm per year.

The year 2002 was the driest year ever recorded at the CIMH station. In fact, 2002 was preceded by two consecutive years with below average rainfall. Sub-normal rainfall was also observed in 1997, 1993-1994, and 1989. The years 1988, 1990 and 1998-1999 were characterized as having above normal rainfall conditions. Temperature data was also obtained from the Caribbean Institute of Meteorology and Hydrology. Average annual temperatures showed very little variation over the years (mean = 26.4 ^{0}C, standard deviation = 0.3 ^{0}C).

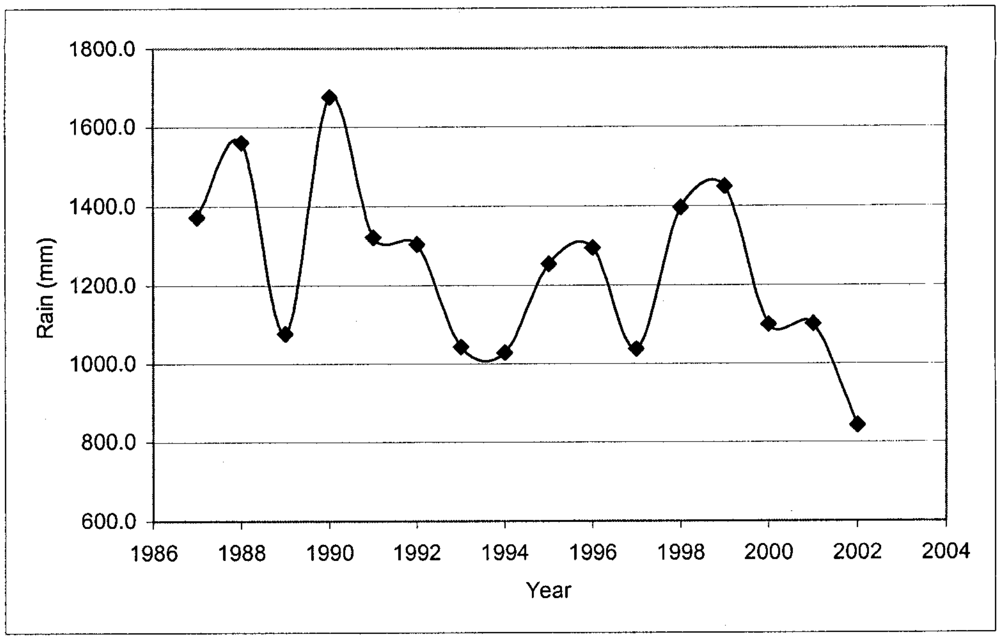


Figure 5.6. Annual Rainfall (source: Appendix D)

5.3 Demand Models

This next section will describe the demand models developed for the purpose of this research. The models explain average annual household water use per district as a function of a set of explanatory variables. All models will include a price variable since the main objective is to quantify the influence of water tariffs on residential water demand.

5.3.1 Variables Used

Water use was hypothesized to be linearly related to a set of explanatory variables. The general equation is:

$$Q = a + b_1X_1 + b_2X_2 + \ldots + b_nX_n \qquad (5.1)$$

Where X_n are the explanatory variables and b_n are the variable coefficients. The coefficients are obtained from regression analysis. This model is a static model since water consumption in a given year is not assumed to be related to water consumption of the previous year. It is also assumed that there is an instantaneous adjustment by customers to new prices. The list of all variables employed during the regression analyses are defined in Table 5.2.

Table 5.2. Model Variables

Variable	Definition
Q	Average annual household water consumption per district (m^3)
Inc	Average annual real household income per district (000's $BBD)
IncDev	Deviation of annual income of district from average annual income of all districts (000's $BBD)
AP	Real average price ($BBD per m^3)
MP1	Real marginal price (price of lower block) ($BBD per m^3)
MP2	Real marginal price (as defined in section 5.2.3) ($BBD per m^3)
Pdum	Price dummy
Rain	Annual rainfall (mm)
RainDev	Deviation of rainfall from historical mean (mm)
Temp	Average annual temperature (^{0}C)
D_n	District dummy (n= 1 to 6)
Billing	Frequency of billing dummy
IncHigh	High income dummy
IncMed	Medium income dummy
IncLow	Low income dummy
Inc/AP	Income divided by average price
Inc/MP1	Income divided by marginal price (lower block)
Inc/MP2	Income divided by marginal price (as defined in section 5.2.3)
GDP	Real GDP growth (%)
Drought1	Drought dummy (drought if rainfall < historical mean)
Drought2	Drought dummy (drought if rainfall < (historical mean – 1 stdev))
Drought3	Drought dummy (previous year was a drought year (rain < historical))
Drought4	Drought dummy (previous year was a drought year (rain < (historical – stdev))
Drought5	Drought dummy (previous 2 years were drought years (rain < historical)
Drought6	Drought dummy (previous 2 years were drought years (drought if rain< (historical – stdev))
Wet1	wet season in previous year was dryer than normal (rain < historical mean)
Wet2	wet season in previous year was dryer than normal (rain < historical mean - stdev)

Note: All real values use 2001 as a base year; stdev = one standard deviation

Water consumption employed in the regression analysis was described in section 5.2.1. It is the average annual household consumption (m^3) for each district. Income was also explained previously and defined as the average annual household income for each district expressed in thousands of BBD$ (2001 prices). IncDev is defined as the difference between a district's average income and the average income of all districts. A positive value for IncDev indicates that the district in question is wealthier than the average district; a negative value means the opposite. Water consumption is believed to be positively related to IncDev.

The average price as explained in section 5.2.3 is the average monthly water price faced by all households in a district expressed in BBD\$/m^3. Two different marginal price specifications were tested in the models. First, it was assumed that the majority of households use an amount of water that puts them in the lower block of the two-block tariff structure. Hence, the marginal price in this case is simply the price of the lower block. The second specification, MP2, is the actual marginal price faced by the household as defined in section 5.2.3. In addition, a price dummy to test the effect of the change in tariff was also tested. It takes on a value of 1 in 1992 (when customers were faced with a new tariff), and 0 otherwise.

The influence of rainfall on water demands was tested using two different variables: 1) total annual rainfall, and 2) deviation of annual rainfall from the historical rainfall. Water consumption is hypothesized to be negatively related to total annual rainfall. The deviation of rainfall from the historical mean indicates if rainfall was above or below the norm. If rainfall during a year is above average, water demands during that year are expected to decrease. Alternatively, dummy variables can be used to express drought conditions. Two definitions of drought were used in the models: 1) drought if rainfall in a given year is less than the historical mean rainfall, or 2) drought if rainfall in a given year is less than one standard deviation below the historical mean. The Drought1 dummy variable takes on the value of 1 when the first definition of drought exists and 0 otherwise. Similarly, Drought2 takes on the value of 1 if the second definition of drought is true and 0 otherwise.

Water consumption in a given year may also depend on the rainfall conditions of the previous years. This was tested by including four different variables, Drought3 to Drought6. Water consumption may be related to the previous wet season being dryer than normal. Barbados obtains the majority of its water supply during the wet season which lasts from mid June to November. If the wet season is dryer than usual, the available supply for the following dry season will be lower. It is hence anticipated that water demands the following year will decrease because of, among other things, conservation efforts, outages and water restrictions. Wet1 and Wet2 are dummy variables employed to express that the wet season was dryer than normal. These variables are summarized as follows:

Drought3: 1, if previous year was a drought year (drought if rain < historical average)
0, otherwise

Drought4: 1, if previous year was a drought year (drought if rain < (historical average – stdev))
0, otherwise

Drought5: 1, if previous 2 years were drought years (drought if rain < historical average)
0, otherwise

Drought6: 1, if previous 2 years were drought years (drought if rain < (historical average – stdev))
0, otherwise

Wet1: 1, if wet season in previous year was dryer than normal (i.e. rainfall in wet season < historical mean rainfall in wet season)
0, otherwise

Wet2: 1, if wet season in previous year was dryer than normal (i.e. rainfall in wet season < (historical mean rainfall in wet season – 1 stdev))
0, otherwise

Temperature is usually positively related to water use. However, the average annual temperature was neglected from the models since it remains more or less constant during the study period.

The difference in water consumption in a district may vary for reasons other than income, price and climate. The number of persons per house, lot size, age of household members are some variables that play a role in determining demand. This type of data was not available so dummy variables were used to distinguish consumption between districts (D_1 to D_6). The following designations were made, using Hoytes Village as the base case:

D1: 1 for Orange Hill, 0 otherwise

D2: 1 for Bagatelle, 0 otherwise

D3: 1 for Prospect, 0 otherwise

D4: 1 for Sandy Lane, 0 otherwise

D5: 1 for Fitts Village, 0 otherwise

D6: 1 for Sunset Crest, 0 otherwise

Another variable that has been shown to affect water demand is the frequency of billing. Here, a dummy variable (Billing) was used to distinguish between monthly and quarterly billings. Customers switched from quarterly to monthly billing in 1994. Hence, the billing dummy variable takes on the value of 1 from 1994-2001, and 0 otherwise.

Dummy variables were also used to distinguish between water use for high, medium and low income districts. Although similar to an income variable, these dummy variables incorporate effects other than income, such as lifestyle choices. The districts were classified as follows:

IncHigh (high income dummy variable):
1 for Sandy Lane, 0 otherwise

IncLow (low income dummy variable):
1 for Orange Hill, Hoytes Village, Prospect and Fitts Village, 0 otherwise

Note that for medium income districts (Sunset Crest and Bagatelle), both income dummy variables become zero (i.e. IncHigh =0, IncLow =0).

The interaction between income and price may also explain water use rather than the individual effects of these two variables. Income was divided by price and tested to see if it plays a larger role in explaining demand. This variable basically represents the proportion of income that is used for purchasing water. It is hypothesized that the higher this ratio, the more water is demanded.

5.3.2 Results

Models were developed using ordinary least squares analysis. Many regressions were conducted using combinations of the variables described in the previous section. Several of the variables were shown to be insignificant. This section will present the most acceptable residential demand models.

A) Final Models

The final selection of the most suitable models was based on four criteria in the following order: 1) compliance with theory, 2) model significance (F-test), 3) variable significance (t-test), and 4) R^2. The multiple coefficient of determination (R^2) measures the proportion of the total variation in household water demand that is explained by the regression model. It is the ratio between the expected variance and the total variance. The t-test is used to check if the regression coefficients are significantly different from 0. That is, the t-test indicates whether or not to include a variable in the model. Generally, an absolute t-value greater than 2 is satisfactory. The F-test evaluates the significance of the regression equation as a whole. The larger the value of the F-statistic, the more likely it is that the independent variables affect the value of the dependent variable. The t-values are shown in brackets below the variables. Moreover, the models were selected based on the signs of the coefficients. If the signs of the coefficients are not as expected by theory, then the model is rejected.

The first acceptable model describes water demand as a linear function of income and the average water price:

$$Q = \underset{(2.1)}{106} + \underset{(13.6)}{8.5\,(\text{Inc})} - \underset{(-2.1)}{36.8\,(\text{AP})} \qquad (5.2)$$

$R^2 = 0.69$

The signs of all the coefficients are as expected. Income has a positive effect on water demand, while the price of water has a negative one. The t-values show that all coefficients are significantly different from 0. Other variables were added to this model but no satisfactory results were found.

The next model describes water use as a function of income divided by average price:

$$Q = \underset{(2.61)}{56.8} + \underset{(15.5)}{17.4}\ (\text{Inc/AP}) \qquad (5.3)$$
$$R^2 = 0.7$$

Inc/AP represents the proportion of income that is used for purchasing water. It is believed that the higher this ratio, the more water is demanded. This is indeed what is obtained in model 5.3. The coefficient of Inc/AP is positive thus indicating that as income increases and price decreases, water demand increases.

The next model obtained is similar to model 5.3 except that it uses the marginal price of water instead of the average price. As mentioned in the previous section, two different marginal price specifications were tested. Regressions using MP2, the real marginal price faced by the household, did not produce any satisfactory results. One reason may be attributed to the fact that many households use less than the minimum amount of water that is less than the amount at which the customer is faced with an increasing-block rate structure. Hence, the marginal price for these customers is 0 since they pay a flat rate. Therefore, it is not surprising that no adequate responses to price change were obtained by using MP2 since many of the users perceive no marginal price. MP2 would be the better price specification under a purely block-rate tariff structure. In contrast, MP1, the price of the lowest block in the two-step rate structure, was found to have a significant impact on water demand.

$$Q = \underset{(0.72)}{20.7} + \underset{(12.7)}{13.5}\ (\text{Inc/MP1}) \qquad (5.4)$$
$$R^2 = 0.63$$

Other variables such as rainfall, billing frequency, drought dummy variables were added to the above models but no satisfactory results were obtained, suggesting that income and price are the two most important variables in determining household demand in Barbados.

The final model uses the income level dummy variables instead of the average household income. The income level dummy variables indicate whether a district is considered as a low, medium or high income district. Households in high income districts are expected to consume the most water since in general they earn more money, have larger gardens, own more cars and water using appliances, etc. Similarly, household from low income districts are anticipated to consumer the least amount of water. The final models is:

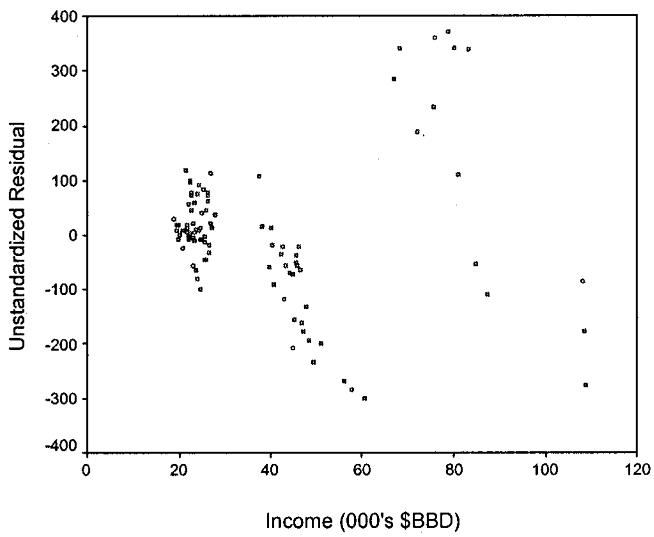
$$\underset{(1.8)}{Q = 353} + \underset{(23.1)}{573\ (\text{IncHigh})} - \underset{(-3.8)}{66.1\ (\text{IncLow})} - \underset{(-2.3)}{22.6\ (\text{AP})} \qquad (5.5)$$

$R^2 = 0.9$

The coefficient of IncHigh says that households in the high income districts, such as Sandy Lane, consume on average 573 m^3 more water per year than those in medium income districts based on lifestyle factors. Households in the low income groups (Orange Hill, Prospect, Hoytes, Fitts Village) tend to use 66 m^3 less water per year than those in medium income districts. Based on the data, the average annual consumption for low, medium and high income districts are 224 m^3, 296 m^3 and 870 m^3 respectively. Compared to medium income districts, low income groups use 70 m^3 less water per year and high income groups use close to 500 m^3 more water per year. However, it is important to note that consumption for high income groups is based only on consumption for Sandy Lane. Consumption for other high income districts would clearly improve the analysis. As expected, the average price of water is inversely related to water demand according to this model (coefficient = -22.6).

Once the final models were selected, tests for correlation and heteroscedasticity were undertaken. No correlation was found between any of the variables included in the above models. However, all models did show signs of non-constant error variance (heteroscedasticity). Therefore, regression coefficients obtained from ordinary least squares analysis will not produce the best results. Diagnostics for heteroscedasticity was achieved by plotting the model residuals (actual value – predicted value) against any one of the variables. These types of plots are easily performed with most statistical software. Plots of residuals versus income showed the greatest indication of non-constant error variance (Figure 5.7). As income increases, so does the variance in residuals. This is typical of studies employing household income. There tends to be greater variance in consumption for high-income families than for low-income families.

a) Model 5.2



b) Model 5.3

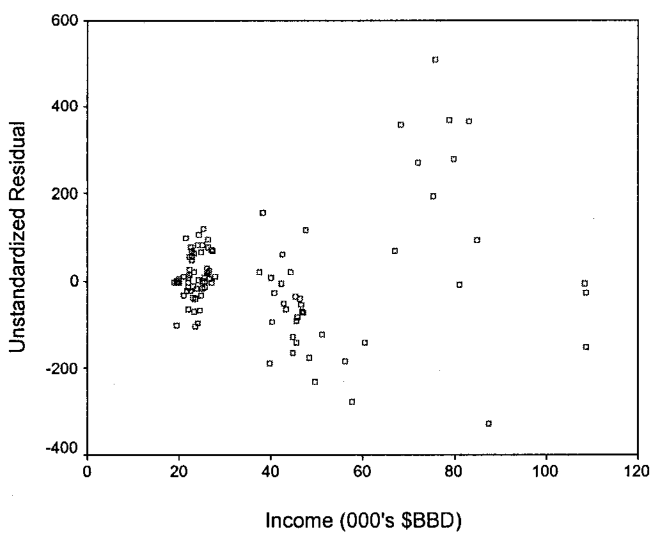


Figure 5.7. Tests for Heteroscedasticity

Heteroscedasticity can be dealt with by conducting what is known as a Weighted Least Squares (WLS) regression. The WLS process is discussed in Draper & Smith (1998), and

Montgomery & Peck (1992). In WLS, the deviation between the observed and expected value of the dependent variable is multiplied by a weight chosen inversely proportional to the variance. More weight would thus be given to observations that exhibit less variance such as low income households in our case. Unfortunately, WLS did not produce any significant changes; that is, non-constant error variances were still present. Generally, correction for heteroscedasticity only slightly modifies the regression results. Therefore, the models stated above will be employed even though no correction for heteroscedasticity was achieved.

It is also interesting to know the relative weight of each explanatory variable to the average annual household water consumption. This is accomplished by comparing the value of each term at the mean of the explanatory variable to the value of consumption at the means of all the explanatory variables. For example, using model 5.2, the average annual household consumption over all districts at the means of the explanatory variables is:

$$Q = 106 + 8.5(\text{Inc}) - 36.8(\text{AP})$$
$$Q = 106 + 8.5\ (38.6) - 36.8\ (2.69) = 335\ \text{m}^3$$

The relative weight of income to Q is therefore: [(8.5 x 38.6)/335] x 100% = 98%
The relative weight of the average water price to Q is: [(36.8 x 2.69)/335] x 100% = 30%
Similarly, the relative weight of the model constant is: [106/335] x 100% = 32%

The relative weight of all explanatory variables to Q is shown in Table 5.3 and details of the calculations and means of the explanatory variables are presented in Appendix E.

The relative weight calculation provides an insight into which model variables are more important in determining water demand. According to model 5.2, household income is more significant in determining water demand than the price of water. From models 5.3 and 5.4, it can be concluded that the relative income (i.e. income divided by price) explains most of the household water use. As shown in Table 5.3, the relative weight of Income/Price in models 5.3 and 5.4 are 83% and 94% respectively.

Some interesting observations can be drawn by looking at the relative weights of the variables in model 5.5. As displayed in Table 5.3, the relative weight of the price variable increases as income decreases (5% for high income districts, 21% for medium income districts and 28% for low income districts). Hence, according to the relative weight calculations, the price of water is more important in determining water demand for low income households than for high income households. This is because, for the same increase in water price, water bills for low income households will make up a greater portion of their income than for high income households.

B) Elasticity

Elasticity is a measure of the response of water demand to changes in the explanatory variables. It is used as a tool to understand the effect of policy changes on future water demands. Water price is the only explanatory variable included in the final models that can be controlled and modified by water policy makers. Hence, only the effect of water prices will be explored.

Price elasticity is commonly obtained by two different methods:

$$P.E.(1) = b_{price} * (P_{mean}/Q_{mean}) \quad (5.6)$$

$$P.E.(2) = (\%\text{ change in } Q)/(\%\text{ change in } P) \quad (5.7)$$

P.E. is the price elasticity, P is the price of water, Q is the water demand, and b_{price} is the coefficient of price in the regression model. The second equation is usually calculated by holding all other variables at their mean values. The price elasticity of all models is shown in Table 5.3.

Elasticities in models 5.2 and 5.5 were calculated using equation 5.6. Elasticities in models 5.3 and 5.4 were found using equation 5.7 because of the way the variables are specified. In these models, the variable included is income divided by price. Therefore, using equation 5.6 would tell us the elasticity of (income/price) and not price.

Table 5.3 Model Results

Model 5.2 (t-values) relative weight	*Q* = 106 + 8.5 (Inc) – 36.8 (AP) (2.1) (13.6) (-2.1) 100% = 32% + 98% - 30%	R^2 = 0.69	F-value = 107	Price Elasticity = -0.29
Model 5.3 (t-values) relative weight	*Q* = 56.8 + 17.4 (Inc/AP) (2.61) (15.5) 100% = 17 % + 83%	R^2 = 0.7	F-value = 241	Price Elasticity = -0.81
Model 5.4 (t-values) relative weight	*Q* = 20.7 + 13.5 (Inc/MP1) (0.72) (12.7) 100% = 6% + 94%	R^2 = 0.63	F-value = 162	Price Elasticity = -0.93
Model 5.5 (t-values) relative weight (High Income) relative weight (Medium Income) relative weight (Low Income)	*Q* = 353 + 573 (IncHigh) - 66.1 (IncLow) – 22.6 (AP) (12) (23.1) (-3.8) (-2.3) 100% = 40% + 65% - 5% 100% = 121% - 21% 100% = 158% - 30% - 28%	R^2 = 0.9	F-value = 291	Price Elasticity = -0.18

The results show price elasticity to range between –0.18 and –0.93. The lowest value observed is from model 5.5. This model states that residential water demand is a function the average price and the income level of the district. Actually, a regression using only the income level dummy variables reveals that 89% of the variation in consumption is explained by this variable. Hence, the addition of price to this model did not significantly modify the results. The income dummy variables still explain most of the variation. As a result, price elasticity may be small because more weight is given to the dummy variables. This conclusion can also be drawn by looking at the relative weight of the price variable to water use. As shown in Table 5.3, the average annual household water consumption (*Q*) is highly related to the price variable (or price effect variable) except for model 5.5, where the contribution of AP to *Q* is much smaller than the contribution of the income level dummy variables. Therefore, according to model 5.5, the income level dummy variable is more important in determining residential water demand.

Model 5.2 gives a price elasticity that is in the middle range of all models (-0.29). This model explains water use as a function of the average annual household income and the average price of water. The price elasticity may be lower than that obtained from models 5.3 and 5.4 because income has a greater effect in explaining water use than the price of water, as illustrated by its contribution to *Q* (98%). In summary, both models 5.2 and 5.5 indicate that income/lifestyle is a greater factor in determining household water demand than price, particularly when the price of water is relatively low. This is because the price of water is too low to influence water use, especially non-essential water uses, of higher income households.

Models 5.3 and 5.4 give the highest price elasticity values (-0.81 and –0.93). These models explain water use as a function of income divided by price. These elasticity values seem quite high, considering that water prices have not increased significantly over the past years.

Most studies in the U.S. found that price elasticity ranges from -0.2 to -0.7. Some researchers found that price elasticities from pooled data tend to fall in the higher end of this range (Danielson, 1979). Wong (1973) demonstrated that customers obtaining water from groundwater sources are more responsive to price changes than customers using surface water sources since groundwater tends to be more expensive. The results of the current models, on average, fall within these estimates. The high values for price elasticity may be attributed to the use of pooled data and because of the dependence on groundwater sources. In addition, Moncur (1987) found that including dummy variables in the regression models lowers the price elasticity. Model 5.5 includes two dummy variables and hence may be causing the low price elasticity.

Price responsiveness is believed to vary based on the income level. Some researchers have shown that low income households are more price responsive than high income households (Renwick and Green, 2000). This is because water bills for low income customers usually represent a larger portion of the household income. However, some have argued the contrary, that is, higher income households are expected to be more responsive to price changes. High income customers are in a position of being able to reduce their water consumption due to non-essential uses, whereas opportunities to reduce consumption are limited for low income customers. Water demand for low income customers is therefore expected to be more inelastic. To compute price elasticity for high income districts (Sandy Lane), elasticity is estimated at the mean income of the group. Similarly, price elasticity of the low income groups was found by holding income constant at the mean income of this group. The results are shown in Table 5.4.

Table 5.4. Price Elasticity for High and Low Income Groups

Model	High Income (mean income: 83 8500 BBD$, standard deviation: 13940 BBD$)	Low Income (mean income: 23 670 BBD$, standard deviation: 1745 BBD$)
5.2	-0.11	-0.51
5.3	-0.92	-0.72
5.4	-0.96	-0.89
5.5	-0.06	-0.25

Two of the models demonstrate that low income households are slightly less responsive to price changes than high income households (models 5.3 and 5.4). In contrast, according to models 5.2 and 5.5, low income customers are much more responsive to price changes. That is, for the same increase in price, low income households would decrease their water consumption more than higher income households. This situation would be normally occur if low income households already pay a greater percentage of their income to purchasing water than high income households. One way to verify the results is to calculate the proportion of a household's budget that is devoted to water bills. The average monthly water bill for each district from 1987 to 2001 was calculated from the consumption data. The water bills were converted to real 2001 dollars and compared to income (salaries and wages). The results are displayed in Figure 5.8.

The highest percent of income devoted to water bills (excluding sewerage) is in Fitts Village, a low income district. In contrast, middle income districts (Sunset Crest and Bagatelle) pay the smallest percent of their income to water. Overall, low income districts spend about 2.5% of their income on purchasing water, medium income districts pay about 1.7%. and high income districts pay 2.4%. It is difficult to accurately say who pays more for water, but based on our sample, we can see that low income groups pay more or less the same percent of their income as high income districts. A greater sample of households from other districts of various income levels is needed to improve these results.

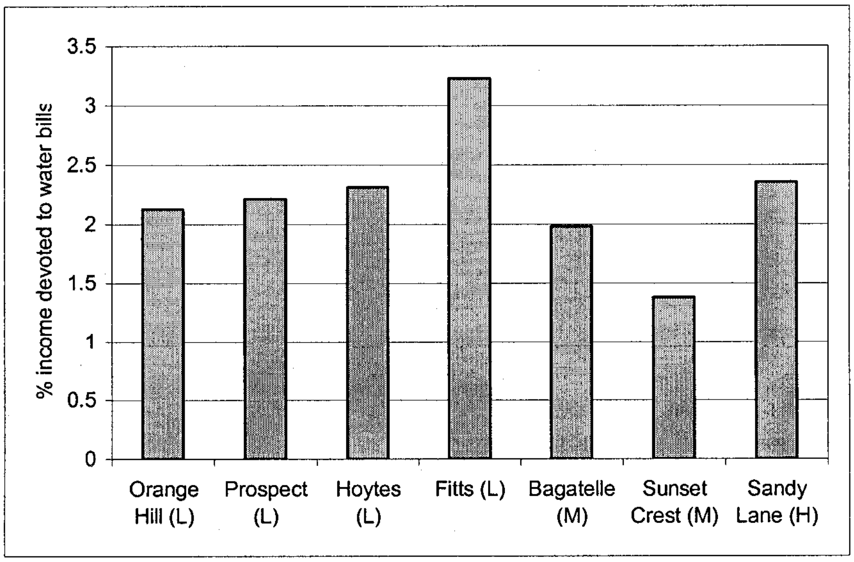


Figure 5.8. Water Bill as a Percent of Income

It is also important to note the effect of income on water demand. Although income is not a water policy variable, it still plays a large role in explaining demand. Income elasticity was estimated in the same manner as price elasticity (Table 5.5). Results indicate that water demand increases with income.

Table 5.5 Income Elasticity by Models

Model	Elasticity
5.2	0.98
5.3	0.81
5.4	0.94

All models produce high income elasticity values. These high values confirm the results presented in Table 5.3 that water use is highly dependent on income. For example, the relative weight of income according to models 5.2 is 98%, whereas the relative weight of price is 30%.

5.4 Concluding Remarks

The residential water demand models developed from the sample data indicate that the price elasticity of water demand is significantly different from 0. Hence, price can be used as a tool to control and reduce residential water demands in Barbados. The price elasticities derived from the developed models can be used by policy makers and the Barbados Water Authority to predict the impact of changing real water prices on future residential water demands and on revenues from the sale of water. This will be further explored in the following chapter.

Income was shown to have a greater impact on residential water demand than the price of water when both these variables are acting separately. The income dummy variable, which represents the difference in lifestyle choices between districts, was found to explain a greater percentage of water use than the price variable. These observations suggest that the difference in household consumption between districts is primarily attributed to the differences in household income and lifestyle choices. This is because the real price of water in Barbados has not changed significantly during the study period and remains too low to influence water use by higher income groups.

Price elasticities vary greatly between the models developed and therefore it can be concluded that the results are sensitive to changes in model specification. However, the expected signs and statistical significance of the variables show that the models behave well when the specification is changed. The various models can be assumed to give the possible range within which the actual elasticities lie.

Caution must be taken when interpreting the model results. Problems concerning the design of the models include the level of aggregation and the presence of missing data, inaccurate meters, high outliers and heteroscedasticity. In addition, model calibration was based on small water price changes. These factors affect the reliability and accuracy of the residential demand models.

The data was aggregated by district and by year. In doing so, the models aggregate the individual behaviour of customers within a district. However, water demand in a district is not constant between households. Income also varies greatly within a district, especially in higher income districts. Moreover, the monthly variation in water demand cannot be explained by these models. This is important especially in a place like Barbados where there are two distinct seasons in a year. Furthermore, the aggregation of the data in time and space greatly reduces the sample size. If monthly data for all of the sample households was available for fifteen years, a total of 24 480 data points would have been included. Instead, a sample of 7 cross-sections for 15 years was available giving a sample size of only 105.

There were many months during the study period where household consumption was missing, particularly prior to 1994. Missing monthly consumption data was replaced by the mean consumption of the particular month. This assumes that a customer is using on average the same amount of water at a particular month over the time period. However, a household's consumption in January 1987 may be quite different from that of January 2000.

No income data was available prior to 1996. Assumptions were needed to obtain values for household income prior to 1996. It was suggested that the change in income follows the change in real GDP. However, other factors may also influence changes in income.

Errors in meter reading also affect the outcome of the models. The results of the 1994 Water Metering Study showed that only about half of the meters to be accurate at all flow rates. It was also concluded that meters are less accurate at low flow rates (90% level of accuracy). On several occasions, the recorded monthly consumption of a household in the collected data was zero. Sometimes monthly consumption would be far greater during one month compared to all the other months. These readings may be outliers and customers with such erratic consumption patterns were avoided.

The price variation observed in the collected data may be too small to extrapolate to future impacts of large price changes. Real prices changed modestly during the sample study. The price elasticity derived from the models reflects the change in water demand to small changes in water prices. Hence, it is difficult to predict what would happen if prices were to change dramatically.

Further work would be needed to improve the results. The first step would be to collect more data. Additional customers from the 7 districts would be helpful. In addition, more customers from other districts, especially from high and medium income districts, are needed. Data on household demographics, education, water-using devices and lot size by district would truly improve the results. These would have to be collected using house to house surveys. Nevertheless, the results obtained do give useful information for policy makers. Price was found to reduce residential water demand. The next chapter will look at some of the policy implications of the model results.

Chapter 6. Policy Implications for Water Demand and Revenue Generation

Water pricing is an important demand management tool that policy makers can use to control future water demands especially in water scarce countries such as Barbados. Several water demand models were developed explaining residential water use in Barbados as a function of a set of explanatory variables. From the models, it can be concluded that water tariffs do have an impact in reducing water demands. The degree of this impact, however, varies between models. This chapter will explore the implications of the model results discussed in the previous chapter. The impact of future changes in water price will be investigated with a focus on water demand reduction and revenue generation. The impact of tariff changes will be achieved by comparing future residential water demands under different price change scenarios with future residential water demands under the current water tariff.

6.1 Method Description

The results from the previous chapter can be applied to estimate the effect of different water rate structures on controlling residential water use as well as increasing revenues from the sale of water. The method employed makes direct use of the residential demand models presented in the previous chapter. Future water demands and bills under seven proposed water rates are predicted from the demand models and compared to future water demands and bills under the current price structure.

In order to predict water demands, assumptions regarding changes in the model variables, such as income, are needed. Four different income change scenarios were assumed. The different scenarios will be described later.

The three models employed to estimate future water demands are:

Model 5.2	$Q = 106 + 8.5\ (\text{Inc}) - 36.8\ (\text{AP})$
Model 5.3	$Q = 56.8 + 17.4\ (\text{Inc/AP})$
Model 5.5	$Q = 106 + 573\ (\text{IncHigh}) - 66.1\ (\text{IncLow}) - 22.6\ (\text{AP})$

Model 5.4 (see chapter 5) was excluded from the analysis. This model assumes that most customers use an amount of water that would put them in the lowest block of an increasing block rate structure. However, this assumption is more difficult to make under the proposed tariffs described later.

The models were used individually to estimate and compare future residential water demands from 2003 to 2025 based on the current rate structure and seven proposed rate structures. Future demands were obtained based on 4 different scenarios with varying income growths. Table 6.1 displays how changes in water demands and water bills are obtained using Method I. For demonstration purposes, rate 1, model 1 and scenario 1 are employed. These calculations are performed for all three models, four scenarios, seven rate structures and seven districts. The following sections will explain the different rate structures and scenarios used in the analysis.

Table 6.1. Procedure to Calculate Predicted Changes in Water Demand and Revenue

	Model 1 (scenario 1)					
	Water Demands (m^3)			Water Bills ($)		
year	current rate	rate 1	difference (%)	current rate	rate 1	difference (%)
2003	PX1	PY1	((PY1-PX1)/PX1)*100	PU1	PV1	((PV1-PU1)/PU1)*100
2004	PX2	PY2	((PY2-PX2)/PX2)*100	PU2	PV2	((PV2-PU2)/PU2)*100
2005	PX3	PY3	((PY3-PX3)/PX3)*100	PU3	PV3	((PV3-PU3)/PU3)*100
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
2025	PXn	PYn	((PYn-PXn)/PXn)*100	PUn	PVn	((PVn-PUn)/PUn)*100
			average difference			average difference

6.2 Rate Structures

The impact of seven different rate structures on demand reduction and revenue generation were analyzed. The new rates are all increasing block rates but with different numbers of blocks (Table 6.2). Both prices and consumption ranges of the blocks vary between rate structures. Block divisions and prices of the different rate structures are modifications of the BWA's proposed rate and the current rate. Increasing block rates are used here since they promote water conservation. They also ensure that a minimal amount of water is provided at low unit prices. The intent is to verify if these different rate structures can be used as policy tools to confront the increasing problems of water scarcity in Barbados and to improve the water utility's financial situation.

Table 6.2. Rate Structures

	Price (BBD$/m³)							
Amount (m³)	current*	rate 1	rate 2	rate 3	rate 4	rate 5*	rate 6*	rate 7
0								
1								
2								1.5
3								
4								
5		3	1.5	1.5	3			
6								
7								
8								
9								
10								
11								3
12								
13							3	
14								
15								
16								
17				2.12	4			
18								
19	1.5	4	2.12					
20						3		
21								4
22								
23								
24								
25								
26								
27								
28				6	6			
29								
30		6	6				6	6
31								
32								
33								
34								
over 34	2.12					6		

* Includes a 20$ minimum charge for those using less than 13m³ of water in a month. For those using more than 13 m³ of water in a month but less than the consumption at which the next block starts, their water bill is equal to either 1.5$ (current rate) or 3$ (rate 5 or 6) multiplied by their total monthly consumption.

Rate 1: Barbados Water Authority proposed tariff

The rate structure in Barbados has not changed since 1991. Based on suggestions from previous studies, the Barbados Water Authority proposed to change the tariff in 1997 in order to encourage the efficient use of water as well as to improve its financial status. The proposed tariff was introduced in Chapter 4. It consists of a three-step block rate structure. The rate structure charges 3 BBD$/m^3 of water for customers using less than 10 m^3 of water in a month, 4 BBD$/m^3 of water for those using between 10 m^3 and 25 m^3 of water in a month and 6 BBD$/m^3 for any monthly consumption above 25 m^3. The proposed change in price has not yet been approved primarily due to political obstacles. The change in price has been put on hold for many years awaiting the approval of the Fair Trading Commission, which is responsible for reviewing and approving water tariff modifications (Mwansa, 1999).

Unlike the current structure, the proposed structure eliminates the minimum charge of BBD$20 for those who use less than 13 m^3 of water in a month. The minimum charge actually penalizes really low water users. For instance, a customer using 10 m^3 of water in a month will end up paying an average price of 2$/m^3, whereas one using 13 m^3 will pay an average price of 1.5$/m^3.

Rate 2: Rate structure 2 is similar to the Water Authority's proposed rate but prices for low water users are not as high. This rate structure focuses more on penalizing only those who use more than 25 m^3 of water in a month. This structure also benefits those who use less than 10 m^3 of water in a month. These customers will pay an average price of 1.5$/m^3 as opposed to 3$/m^3 under rate 1 or at least 2$/m^3 under the current rate.

Rate 3: Rate structure 3 is a slight modification on rate 2. The only difference is that the change from the first to second block occurs at a consumption of 13 m^3 and the change from the second to third block occurs at 20 m^3. Basically, this rate structure provides water at very little cost to those customers using less than 13 m^3. In addition, the third block starts at a consumption of 20 m^3, as opposed to 25 m^3 (rates 1 and 2). Hence, this rate tries to discourages monthly water use over 20 m^3.

Rate 4: Rate structure 4 is a combination of rate 1 and rate 3. It uses the same prices as rate 1 but the same consumption blocks as rate 3. Customers using less than 13 m^3 of water in a month will be charged 3$/$m^3$, those using between 13 m^3 and 20 m^3 will be charged 4$/$m^3$, and those using more than 20m^3 will be charged 6$/$m^3$. This rate is expected to have the greatest effect in reducing residential water demands for all districts especially medium and high income districts.

Rate 5: Rate structure 5 is similar to the current rate structure. The minimum charge of 20$ for those using less than 13m^3 of water in a month is still in place. However, prices of the two consumption blocks are much greater. The price of the two blocks are 3 $/$m^3$ and 6 $/$m^3$ respectively. Consumption for all districts under rate 5 is expected to be lower compared to consumption under the current rate.

Rate 6: Rate structure 6 is a modification of rate 5. The only distinction is that the change in price occurs at 25 m^3 instead of 34 m^3. Hence, customers will be discouraged to use more than 25m^3.

Rate 7: The last rate structure uses a 4 step increasing block rate. This rate provides a minimum of 5 m^3 of water for 1.5 $/$m^3$. The World Bank states that a minimum water use level of about 1.5 m^3 per person per month is required. The amount of 5 m^3 provides enough water for the average household in Barbados. Customers pay 3$/$m^3$ if they use between 5 m^3 and 15 m^3, 4$/$m^3$ if they use between 15 m^3 and 25 m^3, and 6$/$m^3$ if they use above 25 m^3.

6.3 Forecasting Scenarios

Three different water demand models are used to estimate and compare future water demands and water bills. However, assumptions regarding changes in model variables are needed to estimate future water demands. Water prices will change according to the different rate structures described above. Average household income will vary according to four income growth/decrease rates.

The four income growth (decrease) rates assumed during the forecast period were 5%, 2%, 0% and –1%. The income variable used in the models is a function of the real change in GDP, that is, current GDP minus inflation. The 5% growth assumes that GDP will always be greater than inflation. The 2% change is the actual change in real GDP observed from 1987 to 2001. The 0% income growth rate assumes that GDP and inflation will be equal. Finally, the 1% decrease supposes that inflation will actually be greater than GDP growth during the forecast period.

6.4 Demand Reduction

The effect of the seven proposed rate structures designed to reduce water demands were evaluated. For each rate structure, future water demands for the seven districts were estimated for all 4 income growth scenarios using the three models individually ($PY_{i,m,n}$ [refer to Table 6.1]). Future water demands were also estimated based on the current rate structure in Barbados ($PX_{i,m,o}$ [refer to Table 6.1]). The overall change in demand per rate structure was calculated as follows:

- For each scenario (1 to 4), calculate the percent change in consumption in each district for every model and year from 2003 to 2025

$$C_{i,m,n} = ((PY_{i,m,n} - PX_{i,m,o})/\ PX_{i,m,o})*100 \qquad (6.1)$$

- For each scenario, calculate the average change in consumption in each district for every model from 2003 to 2025

$$\hat{C}_{i,m,n} = \Sigma[((PY_{i,m,n} - PX_{i,m,o})/\ PX_{i,m,o})*100]/23 \qquad (6.2)$$

- For each scenario, the average change in consumption per district over the three models is:

$$C_{i,n} = \Sigma(\hat{C}_{i,m,n})/3 \qquad (6.3)$$

- The overall change in consumption per district over the four scenarios and four models is:

$$C_i = \Sigma(C_{i,,n})/4 \qquad (6.4)$$

- For each rate structure, the average change in consumption over all districts is:

$$C = \Sigma(C_i)/7 \qquad (6.5)$$

Where i = 1 to 7 (districts), m = 1 to 3 (models), n = 1 to 4 (scenarios), o = initial scenario (current rate structure)

The results are displayed in Table 6.3. The table lists the overall change in consumption for each rate structure over the three models (equation 6.5), the average change in consumption per district (equation 6.4) and the range of average change in consumption per district. In brackets is the income level of each district (low, medium, or high).

Table 6.3. Predicted Reduction in Water Demand (%)

	Percent Change in Consumption							
	Orange Hill (low)		Hoytes (low)		Prospect (low)		Fitts (low)	
rate	range	mean	range	mean	range	mean	range	mean
1	-15 to -36	-27	-15 to -38	-27	-15 to -38	-27	-15 to -38	-27
2	-2 to -12	-7	-2 to -14	-8	-2 to -14	-8	-2 to -14	-8
3	-3 to -13	-7	-3 to -13	-9	-3 to -15	-8	-3 to -16	-9
4	-13 to -40	-26	-14 to -37	-26	-14 to -37	-26	-14 to -37	-26
5	-10 to -34	-21	-12 to -32	-21	-12 to -32	-21	-12 to -32	-21
6	-10 to -35	-21	-12 to -32	-22	-12 to -32	-22	-12 to -32	-22
7	-9 to -34	-21	-10 to -31	-20	-10 to -30	-20	-10 to -31	-20
	Sunset Crest (medium)		Bagatelle (medium)		Sandy Lane (high)		Average	
rate	range	mean	range	mean	range	mean	rate	all districts
1	-13 to -43	-25	-13 to -42	-26	-7 to -45	-23	1	-26
2	-3 to -25	-13	-3 to -24	-13	-6 to -36	-18	2	-11
3	-6 to -29	-17	-6 to -27	-16	-6 to -40	-20	3	-12
4	-13 to -43	-26	-13 to -42	-26	-8 to -47	-24	4	-26
5	-9 to -36	-20	-9 to -36	-20	-6 to -37	-19	5	-21
6	-9 to -38	-22	-9 to -38	-22	-7 to -42	-21	6	-21
7	-10 to -38	-22	-10 to -37	-22	-7 to -43	-21	7	-21

The greatest reduction in consumption is obtained from rate structures 1 and 4. Rate 1 is the Barbados Water Authority's proposed rate. Rate 4 is almost identical to rate 1 except that the maximum consumption of each block is changed. Moreover, the mean reduction in water use by district is fairly constant under these two water tariffs. For instance, the average decrease in water demand under rate 4 is 26% for all districts except for Sandy Lane (24%).

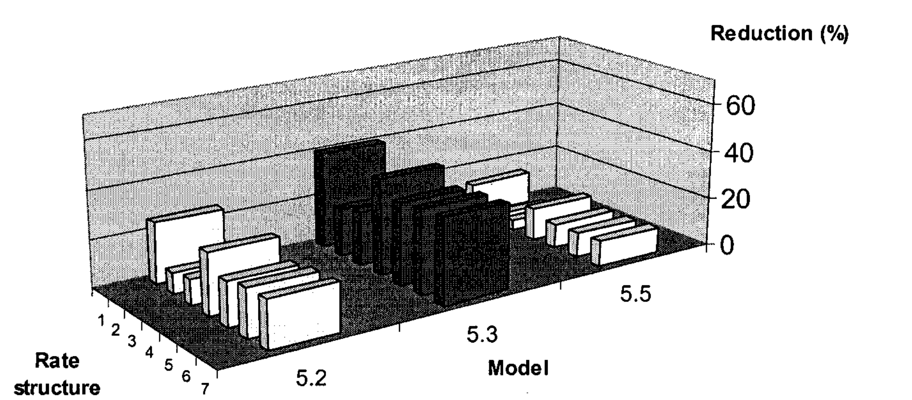
Rate structures 2 and 3 had the least impact in reducing residential water demands. This is expected since prices are lower in these two rate structures. The difference between these two rates is the maximum consumption at which prices increase. Rate structure 3 had a slightly greater impact in reducing demands from middle and high income districts. This is because in rate 3, customers using more than 20 m^3 of water in a month pay 6$/$m^3$ whereas in rate 2, this price applies to those using more than 25 m^3 of water per month.

Rate structures 5 and 6 are similar to the current rate in that they include a minimum charge of 20$ for those using less than 13 m^3 of water in a month. However, prices in each block are significantly higher than current prices. The only difference between rates 5 and 6 is the consumption value at which the second price block is applied. In rate 6, high water users are those who use more than 25 m^3 of water in a month as opposed to 34 m^3 in rate 5. Hence, the mean decrease in consumption from high and middle income districts should be greater under rate 6. This is indeed what is observed but the difference between both rates is minimal.

Rate 7 uses a four block pricing system. This tariff structure ensures that a minimum amount of water needed for survival is provided at very little cost. Also, customers using more than 15 m^3 will be charged more. Therefore, this rate tries to encourage customers not to use more than this amount. The overall reduction in consumption over all districts from rate 7 is 21%, similar to the values obtained from rates 5 and 6. However, low income districts should decrease their consumption a little more under rate 7 than under rate 5 or 6. This is indeed what happens as displayed in Table 6.3.

There is a wide range of values for the average reduction in water demand per district and rate structure. For example, customers in Orange Hill (low income) are predicted to reduce their water consumption from 9% to 34% under rate 7. Under rate 2, these same customers are expected to reduce their consumption from only 2% to 12%. These differences are largest under rates 1 and 4 (highest prices) and smallest under rates 2 and 3 (lowest prices). These disparities can be explained by taking a closer look at the three water demand models.

As revealed in the Figure 6.1, the difference in predicted consumption reduction differs between the three models. Model 5.5 gives the smallest decrease in water consumption and model 5.3 predicts the greatest decrease in water consumption. Both results are consistent with the price elasticities obtained in Chapter 5, -0.18 (model 5.5) and -0.81 (model 5.3). According to model 5.3, customers are very responsive to price changes and therefore their water consumption should decrease considerably when prices increase. In contrast, model 5.5 states that customers are much less responsive to price changes. Hence, their water consumption should decrease minimally when faced with greater prices. Model 5.2 predicts a consumption reduction in between the two other models, also consistent with its price elasticity (-0.29). All models show that the greatest reduction in water demand is achieved from rates 1 or 4.



	1	2	3	4	5	6	7
□ 5.2	25	9	10	25	18	19	19
■ 5.3	40	20	22	40	34	35	35
□ 5.5	13	3	4	13	10	10	10

Figure 6.1. Consumption Change by Model and Rate Structure

Real price changes experienced by the customers in the study period were quite small. Prior to 1991, residential customers paid 1.2$/m^3 for consumption below 50 m^3, and 1.7 $/m^3 for consumption above 50 m^3. After 1991, customers using less than 34 m^3 of water were charged 1.5$/m^3, an increase of only 25%. Under rate 1, however, the change in the average price paid by customers using less than 10 m^3 of water would be 200%

greater than under the current rate. All seven proposed rate structures will result in increases in water prices much greater than previously observed. The models were developed using much smaller changes in water prices and the price elasticities obtained from the models may not be necessarily applicable to great price increases such as in rates 1 and 4. This is especially true for models 5.2 and 5.5 because of the manner in which the variables were defined. These models explain residential water demand as a function of income (or proxy for income) and average price of water, as opposed to the other model that uses income divided by price. Large price changes will have a greater effect according to model 5.2 and 5.5 since, for the same price increase, more weight will be given to the variable AP (average price) as opposed to Inc/AP (income/price).

The reduction in consumption is not necessarily the same between income groups. Some of the proposed rate structures focus more on penalizing high water users while others target all customers equally. Figure 6.2 gives an insight on how different income level groups will behave under the seven proposed rate structures. Low, medium and high income districts will more or less reduce their consumption by the same amount under rates 1, 4, 5, 6 and 7. However, a greater variability in consumption reduction is observed under rates 2 and 3. Here, high income districts will display the largest reduction in water use followed by medium income districts. Reduction in water use in low income districts under rates 2 and 3 will be minimal. This pattern is expected since in rates 2 and 3, low water users are faced with low prices whereas prices increase tremendously for high water users.

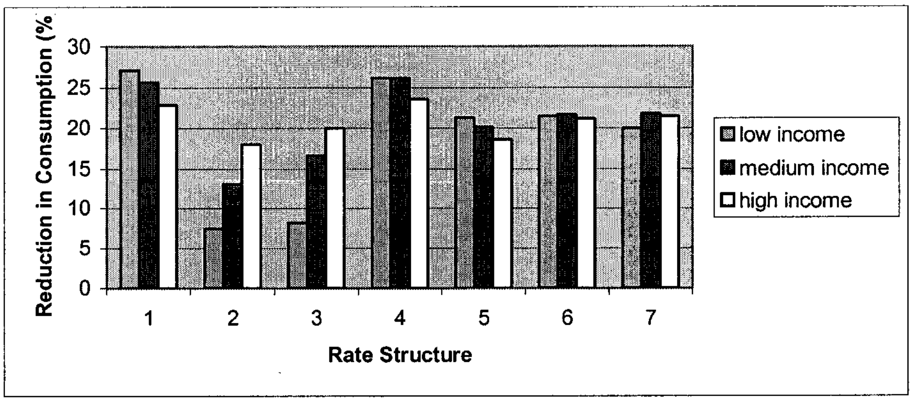


Figure 6.2. Consumption Change by Income Group and Rate Structure

6.5 Revenue Generation

The Barbados Water Authority obtains most of its operating revenue from the sale of water. However, water prices have not changed since 1991. In the past six years or so, the BWA has been faced with increasing financial problems and has been lobbying for an increase in water tariffs. The developed water demand models can be employed to estimate the impact of the various rate structures on generating revenues. The same procedure used to calculate changes in consumption was used to compute estimated changes in water bills. Future monthly water bills for each district under new tariffs were compared to future water bills under the current tariff. Table 6.4 presents the computed average change in water bills for each rate structure and district. The range in predicted changes in water bills by district and rate structure is also presented. These values show the wide range of results obtained from the three different water demand models.

Table 6.4. Predicted Revenue Generation (%)

	Percent Change in Water Bills							
	Orange Hill (low)		Hoytes (low)		Prospect (low)		Fitts (low)	
rate	range	mean	range	mean	range	mean	range	mean
1	20 to 78	44	19 to 78	47	19 to 78	46	19 to 78	47
2	4 to 15	11	4 to 18	13	4 to 17	12	4 to 18	12
3	4 to 16	12	5 to 22	14	5 to 21	14	5 to 21	14
4	19 to 73	42	18 to 73	45	18 to 73	44	18 to 73	45
5	14 to 64	36	14 to 64	38	14 to 64	38	14 to 64	38
6	14 to 64	36	14 to 64	39	14 to 64	38	14 to 64	39
7	13 to 56	34	12 to 56	36	12 to 56	35	12 to 56	36
	Bagatelle (medium)		Sunset Crest (medium)		Sandy Lane (high)		Average	
rate	range	mean	range	mean	range	mean	rate	all districts
1	13 to 75	34	12 to 90	61	8 to 135	83	1	52
2	5 to 49	20	5 to 57	29	5 to 112	69	2	24
3	7 to 60	39	7 to 67	41	6 to 121	75	3	30
4	13 to 93	61	12 to 93	63	9 to 139	86	4	55
5	10 to 68	46	9 to 68	47	6 to 113	69	5	45
6	10 to 69	49	10 to 73	51	7 to 127	78	6	47
7	10 to 71	50	9 to 75	52	7 to 129	79	7	46

As expected, all new rate structures will result in increases in average water bills over all seven districts and therefore more revenue to the water utility. Rates 1, 4, 5 and 6 and 7 all estimate very large increases in water bills (45% to 55%). Water bills under rates 2 and 3 are predicted to be roughly 27% greater than water bills under the current tariff.

For low income groups, expected changes in water bills will be much smaller under rates 2 or 3 than under the other four rate structures. For instance, water bills for customers in Hoytes (low income) are anticipated to increase by about 14% under rate 2 or 3 compared to about 40% under the other rate structures. For customers in Prospect (low income), water bills are predicted to increase by 13% under rates 2 or 3 and by roughly 40% under the other tariffs. If the water utility is reluctant to raise prices for low income districts, then rates 2 and 3 are most suitable. Water bills for middle income districts are also expected to be lower under rates 2 or 3. This large variation in predicted water bills is not present for customers in Sandy Lane (high income). This is because a price of 6$/m^3 is applied to high water users in all of the suggested rate structures.

As was the case for demand reduction, there exists a large variation in the predicted changes in water bills between the three models. For example, water bills for customers in Sandy Lane (high income) under rate 1 are predicted to vary from an increase of 8% to 135%. These variations are a result of the large range in price elasticity between the three water demand models (-0.18 to -0.81).

6.6 Equity Considerations

The previous section looked at the possible changes in water bills under alternative water rates. To assess the effect of the rate structures with respect to equity it is important to look at what percentage of income the water bills would take. For each year during the forecast period (2003-2025), the predicted water bill was divided by the average monthly income of the average customer in a district. The average income will vary according to the four real GDP growth scenarios described in section 6.3. Table 6.5 shows the average percent of monthly income devoted to purchasing water during the forecast period according to the seven alternative rate structures.

The results indicate that all seven proposed rate structures will result in water bills taking approximately the same portion of income. Rates 2 and 3 will actually result in slightly lower values. Overall, the percent of income devoted to water will be greater under the proposed rate structures than under the current rate. It was shown in the previous chapter that currently, water bills derived from the collected sample take up roughly 1.2% of monthly household income.

Table 6.5. Average Percent of Monthly Income Used for Purchasing Water

Rate Structure	Water Bill/Income
1 (BWA)	3.0
2	2.4
3	2.5
4	3.0
5	2.8
6	2.8
7	2.8

Since the overall percent of income used for water is roughly the same under the seven rates, it is more useful to look at the effect of water bills according to income level. Figure 6.3 shows that households from high income districts (Sandy Lane) are predicted to always pay a greater portion of their income to water. Interestingly, customers from middle income districts, such as Bagatelle and Sunset Crest, will most often pay the smallest portion of their income to purchasing water. Hence, rate structures may need to be modified to take this into account. The average monthly household consumption for Sunset Crest and Bagatelle is about 23 m^3 to 28 m^3. Therefore, water tariffs should try to penalize consumption of this magnitude. For instance, in rates 3 and 4, the price of the second consumption block can be raised. Alternatively, in rates 1 and 2, the consumption value at which the third block appears can be decreased to $20m^3$ or less.

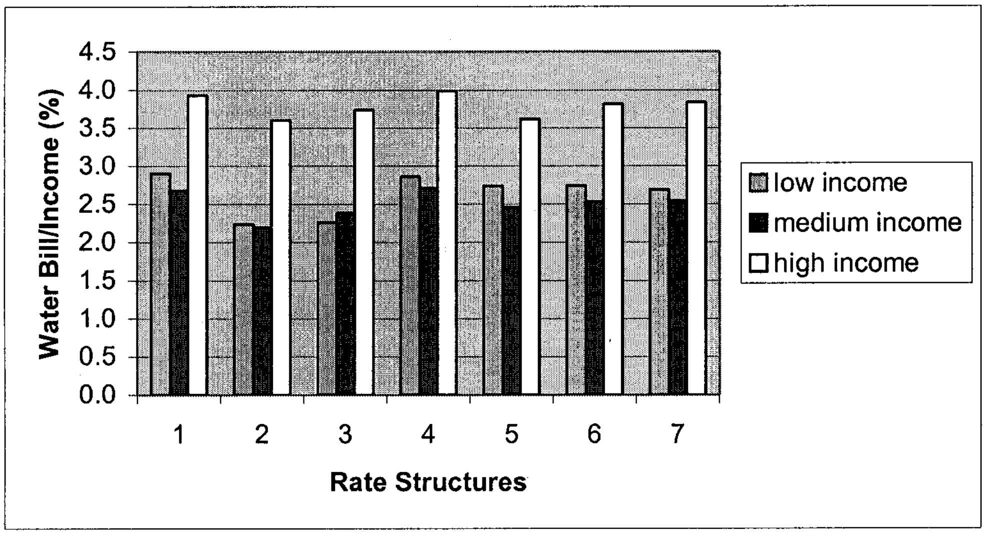


Figure 6.3. Average Percent of Monthly Income Used for Purchasing Water by Income Level

6.7 Summary

The effect of seven alternative rate structures on demand reduction, revenue generation and equity were considered. The results show that all suggested rates can be used to reduce residential water demands and increase revenues.

It is difficult to say which of these new tariffs is most suitable in Barbados. The choice depends on the desired level of demand reduction and revenue increase. Moreover, equity considerations must be taken into account to make the implementation of a new rate structure more acceptable. Table 6.7 summarizes the results of all rate structures.

If the goal is to achieve the greatest amount of reduction in residential water use, then rate 1 or 4 is preferred. A substantial amount of reduction in water demand can still be achieved from tariffs 5, 6 or 7. If the goal is to increase the water utility's revenues from the sale of water, then rate 1, 4, 5, 6 or 7 is suggested. If the goal is to charge high income households a greater portion of their income for water than low income households, then rate 2 or 3 is most desirable. The last column in the table displays the sum of the stars. If all three criteria (demand reduction, revenue generation, and equity) are all given the same weight, then rate 1 or 4 is the best rate structure.

Table 6.6. Selecting an Appropriate Rate Structure

rate	Demand reduction	Revenue generation	Difference between water bill of high and low income households (percent of income)	Sum of stars
1	***	***	**	8
2	*	*	***	5
3	*	*	***	5
4	***	***	**	8
5	**	***	*	6
6	**	***	**	7
7	**	**	**	6

*** maximum, ** average, * minimum

There exists a great variability between computed results depending on which water demand model is employed. The results are therefore quite sensitive to model specification. Consumption and revenue change between models is affected by the price elasticity. The price elasticities obtained from the models vary from –0.18 to –0.81. Moreover, the developed models describe how a residential water demand varies according to small price changes. These models may not perform well under large price increases such as the ones proposed by the seven rate structures. Nevertheless, trends and useful observations may be extracted from the results.

6.8 Concluding Remarks

Water pricing can be used to promote the conservation of water resources. Higher prices give signals to customers to reduce their wasteful habits. Pricing can also be used to generate revenue from the sale of water. Water pricing becomes a necessity in a water scarce region like Barbados which has been experiencing more frequent water supply shortages. Increasing tariffs can also be used to improve the Barbados Water Authority's financial status. Demand models can be employed to estimate the effect of alternative water rate structures on demand reduction and revenue generation. This can aid policy makers in deciding which water rate structure is best suited to the needs of the water utility, paying customers and the environment.

The approach employed to study the effect of several different rate structures uses the developed aggregate water demand models to forecast future demands. It was predicted that the BWA's proposed rate structure would result in an average decrease in residential water demand of 26% and an average increase in water bills of 52%.

Assumptions regarding changes in explanatory variables, such as income, are required when forecasting residential water demands using the method described previously. Therefore, the results may not be accurate since it is impossible to predict future socioeconomic conditions with certainty.

The method employed deals with relatively large price increases compared to previously observed price changes. If the sampled customers were faced with large price increases in the past, then the developed water demand models and the derived price elasticities would have probably been different. Therefore, the developed demand models are best suited for examining small price changes. Most of the proposed rate structures presented in the previous sections will result in price increases outside the range of previously observed price changes. The models would improve as more data on changes in water demand under greater changes in water prices are collected.

Chapter 7. Metering

Chapter 5 presented the developed residential water demand models and derived price elasticities. Chapter 6 discussed how these results can be used to assess the effect of different water pricing polices on demand reduction, revenue generation and equity considerations. The development of water demand models and the study of the impact of various rate structures can only be achieved with reliable and sufficient metering records. This chapter will take a closer look at the importance of metering. An overview of metering in Barbados will also be presented.

7.1 Benefits of Metering

As water becomes a scarce resource, it is crucial to get the water demand-supply balance to an acceptable position. Water demand management attempts to control the competing water demands to match the available supplies most often by changing the consumers' behavior with respect to water use. Vital to better demand management is the issue of metering. This section will look at the most important benefits of metering.

A) Quantifying and Understanding Water Use

A key component of demand management is the understanding of the factors determining water demand. This is an integral part of the design of policy measures that focus on controlling or influencing water demands such as raising water prices. Models can be developed to assess the impact of water policy changes. However, knowledge of households' water use patterns is required. This information can only be obtained from the use of water meters. Meters allow for an accurate account of how much water is actually being supplied and consumed. Household consumption can be read regularly to provide a long time-series of consumption records. These consumption records can then be used as the dependent variables in any econometric water demand models.

B) Developing Pricing Policies

Effective pricing policies can promote the conservation of water and ensure the equitable distribution of water bills. The installation of meters permits the development of more creative pricing policies such as increasing block or seasonal rate structures. These types of rate structures require an accurate account of how much water is being used by customer class and by season. With the use of meters and volumetric pricing schemes, customers are pressured to use less water in order to reduce their water bills. A reduction in demand will lower system operating costs and decrease water and wastewater capital requirements.

In the long run, metering, without an increase in price, provides no incentive to reduce water consumption. In the short run, on the other hand, water consumption tends to decrease when flat rate customers become metered. This decrease in consumption is due to the belief of most customers that their water bills will increase when their use is measured with meters. However, these customers soon realize that they can consume the same amount of water as they used to without any significant increase in their water bills. As a result, consumption tends to increase some time after the installation of meters if the rate structure does not change.

C) Controlling Water Leakage

A major problem with many distribution systems is the high volume of water leakage. Leakage is due to aging systems and a lack of maintenance. Estimates of leakage in the Caribbean range from 30% to 70%. Reducing the volume of water lost in the distribution network will help towards achieving a balance between water demand and supply. Unfortunately, the lack of meters makes the task of controlling and quantifying system leaks very difficult. Therefore, the implementation of meters improves leakage control by providing an accurate account of how much water is lost in the distribution network and, most importantly, where the loss is occurring.

In summary, meters are essential to the design of creative pricing structures that promote the conservation of water. Reduction in water usage will result in a decrease in the utility's operating expenses and may postpone the need of system capacity expansion. Household consumption data obtained from metering records is crucial to the development of water demand models. Meters are also essential to help quantify and control system leakage.

The benefits of metering should be compared to the costs of purchasing and installing meters. Costs of ongoing maintenance must also be considered. Putting a monetary value to these costs is feasible. On the other hand, benefits of metering are more difficult to quantify. However, benefits, such as the conservation of water resources, will greatly increase if metering is accompanied by a substantial increase in water prices. The next section will examine the history of metering in Barbados.

7.2 Metering in Barbados

Metering of water in Barbados first started in the late 1960's after Barbados became independent. Meters were first installed where customers had off-standard plumbing fittings or because they felt it more economical. In the early 1970's, it was decided that all new stone houses would be metered. An attempt was also made to meter all non-domestic customers. By 1978, about 18% of all accounts were metered with 8% of all residential customers and 70% of all commercial customers metered. In 1982, a new regulation was enforced that required that all dwellings with a floor area exceeding $239m^2$ to be metered. At that time, the domestic customers who had meters were mostly those with a new or recently renovated house. The switching of existing customers from fixed-rate to metered-rate schedules was uncommon.

In 1994, a metering study was conducted by R.M. Loudon Limited to give recommendations to the Barbados Water Authority for a water metering program. The Barbados Water Authority was committed by agreement with the Inter-American Development Bank to install 40 000 new meters from 1994 to 1996. By 1996, 30 % of all domestic customers were metered and all commercial and industrial customers were metered.

In 1997, the Government approved a universal metering program. The intention of the program was to meter all customers on the island in order to facilitate the measuring and controlling of water consumption. However, private well owners lobbied and were allowed to be responsible for the installation of their own meters (Mwansa, 1999). The metering of private wells was not as successful as the metering of domestic customers.

The first part of the metering program consisted of installing 40 000 new meters funded by a BBD$2 815 600 loan from the Inter-American Development Bank. The second part consisted of adding another 20 000 meters on the island using the Barbados Water Authority's own funds and in-house plumbing crews. Figure 7.1 shows the metered customers as a percent of the total number of customers from 1981 to 2001. Prior to the universal metering program, only 30% of the total customers were metered. In 2001, almost 94% of the customers on the island were metered.

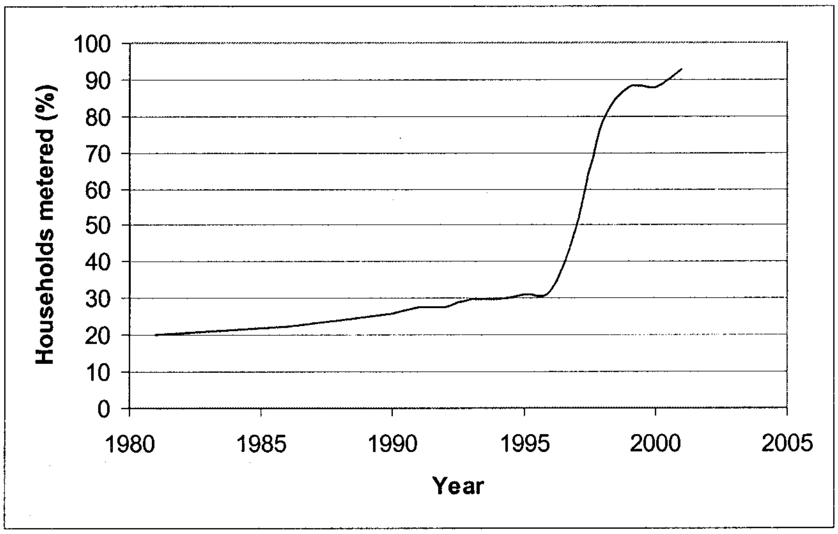


Figure 7.1. Metered Customers

The metering program was completed in 2001 and cost about US$ 3 million. There was an immediate reduction in demand soon after the program commenced. Figure 7.2 shows that the water pumped from groundwater sources decreased during the universal metering program. In 1996, 58.8 x 10^6 m^3 of water were pumped from groundwater sources compared to 51.6 x 10^6 m^3 in 2000, a decline of 12%. As mentioned earlier, newly metered customers tend to reduce their consumption shortly after becoming metered. This decline is in part psychological since consumers fear that their water bills will substantially increase. The average water bill for non-metered customers in Barbados typically ranges from BBD$13.33/month to BBD$53.55/month. The average monthly bill for metered customers is BBD30$, based on an average domestic metered consumption of $20m^3$/month. Hence, on average, water bills for metered and non-metered customers are similar. Therefore, household consumption for newly metered customers is expected to increase once they realize that their bills are more or less the same as before.

The decrease in water pumped form groundwater is also an economic response to slightly higher prices faced by some metered customers, such as very low and high water users. For example, the smallest monthly bill for a flat rate customer is BBD$13.33 compared to BBD$20 for metered customers. The greatest monthly water bill for non-metered customers is BBD$53.55. Under metered rates, monthly bills for high water users, such as customers in Sandy Lane who consume on average 65m^3/month, can exceed BBD$100/month.

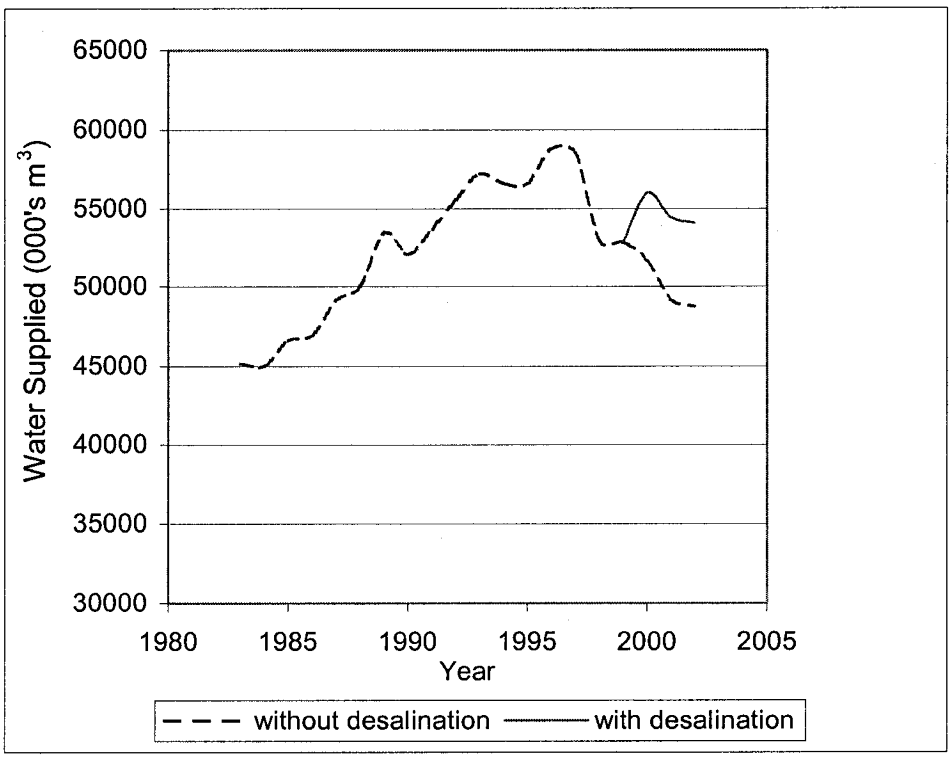


Figure 7.2. Water Production

The water pumped from groundwater continued to decline from 2000 to 2002 but this can be attributed to the construction of a new desalination plant that provided a new source of water supply. The plant supplied 4.4 x 10^6 m^3 of water in 2000 and is now responsible for 10 % of the water in the distribution system.

The universal metering program in Barbados allowed for the development of a detailed consumer database. The database can provide useful information regarding households' water consumption patterns and their water bill payments. This type of information is essential for the development of water demand models such as the ones presented in Chapter 5. The design of a more efficient, effective and equitable rate structure can be facilitated with the availability of the consumption database. Metering information will also help to quantify how much water is being lost in the distribution network. Previous estimates for leakage range from 40% to 60%. These estimates were based on surveys and some metered records. A recent study conducted by McGill students using complete island-wide metering records showed that water leakage is approximately 35% of the total amount supplied.

7.3 Concluding Remarks

With growing populations and increasing standard of living, it becomes more challenging to find a balance between the supply and demand for water especially in water stressed countries. Water demand management measures, such as pricing and metering, can be used to try and achieve this balance by controlling or influencing water demands. However, information regarding water consumption is essential for the development, implementation and analysis of demand management policies. This type of information can only be obtained from metering records.

Barbados has been faced with major water shortages over the past decade. The Government recognized that water demand management should be given greater emphasis to achieve a balance between the water demands and the limited supplies. A universal metering program was initiated in 1997 to try to quantify and control water consumption on the island. There was an immediate reduction in water supplied demonstrating that metering can be used as a means of controlling consumption. However, this decrease may be attributed to the fear of larger water bills for those switching from non-metered to metered rate. However, prices did not change during the metering program and metered customers soon realized that their bills did not increase substantially as anticipated. Hence, per-capita consumption has been on the rise in recent years. Therefore, in the long-run, metering alone is not effective in changing people's consumption behaviour. Metering must be used in conjunction with appropriate pricing mechanisms to provide an incentive to conserve water.

Metering allows for an accurate account of water consumption that leads to a better management of the resource. Water policy makers in Barbados can now accurately determine where the supplied water is going to. Metering also facilitates the detection of water leaks. The location and magnitude of water leaks in Barbados' public supply system can now be more easily determined and hence repaired.

Chapter 8. Conclusions

In many regions of the world, it is becoming more difficult to meet the competing water demands, especially in times of drought, by relying solely on supply-side measures. Water demands are pushing existing supplies to their limits and costs of new supplies are increasing tremendously. Financially, water utilities are having difficulty in maintaining, operating and expanding their water distribution networks and treatment facilities. The supply-side approach, which relies predominately on structural measures, also gives the impression that water is plentiful and therefore gives no incentive to customers to change their consumption habits.

Water resources management has been slowly shifting away from the era of meeting demands by simply developing new supplies. The considerations of policies that focus on the demand for water have recently been given more attention. Water demand management attempts to balance the supply of and demand for water by influencing (or controlling) water use. The demand-driven approach tries to improve the sustainable use of water so that future generations can benefit from this resource as well.

Water demand management becomes a necessity in a water scarce island such as Barbados. This densely populated island, with low water availability ($<1000m^3$/capita), has been having difficulty in assuring a 24 hr supply of water to all its customers. In addition, water demands cannot be met during drought years without affecting the water quality through irreversible saltwater intrusion. The Barbados Water Authority's operating revenues cannot keep up with its increasing expenses. The lack of maintenance of the aging distribution network is resulting in substantial water losses. Moreover, most customers do not perceive the severity of the water problem in Barbados and continue to use wasteful amounts of water. Without any strong actions and will, the water situation in Barbados will further deteriorate.

This research analyzed the potential of two demand management measures, water pricing and metering, to influence and reduce residential water demands in Barbados. The effect of water price on residential water demand was achieved by developing several water demand models. The demand models were developed from a sample of 136 households from seven different districts in St-James. The average annual household consumption over each district was modeled as a function of a set of explanatory variables. Many regression analyses were conducted using combinations of variables but only four significant econometric demand models were finally chosen. The table below summarizes the results of applying regression analysis.

Table 8.1. Residential Demand Models

Equation	R^2	Price Elasticity
5.2 $Q = 106 + 8.5\,(Inc) - 36.8\,(AP)$	0.69	-0.29
5.3 $Q = 56.8 + 17.4\,(Inc/AP)$	0.70	-0.81
5.4 $Q = 20.7 + 13.5\,(Inc/MP1)$	0.63	-0.93
5.5 $Q = 353 + 573\,(IncHigh) - 66.1\,(IncLow) - 22.6\,(AP)$	0.90	-0.18

Price elasticities between –0.18 and –0.93 were obtained, agreeing with the hypothesis that price has a positive effect in reducing water demands. Most studies conducted in the U.S. found price elasticities ranging from –0.2 to –0.7. Income elasticities between 0.81 and 0.94 were also obtained from the different models. The various models can be assumed to give possible range within which the actual price and income elasticity lies.

The elasticities obtained vary greatly between the developed models indicating that the results are sensitive to changes in model specification. Income was shown to have a greater impact on residential water demand than the price of water when both these variables are acting separately as in model 5.2. The income dummy variable was found to explain a greater percentage of water use than water price suggesting that the difference in household consumption between districts is primarily attributed to the differences in household income and lifestyle choices.

The price elasticity obtained from all four demand models is significantly different than zero. Therefore, water pricing policies can be used to promote the conservation of water resources. Changes in water prices can also be used to generate revenue from the sale of water thus improving the Barbados Water Authority's financial status.

The demand models presented in Table 8.1 were employed to estimate the effect of alternative water rate structures on demand reduction and revenue generation. This was achieved by using the developed aggregate water demand models to forecast and compare future demands under proposed and current rate structures. The analysis concluded that the Barbados Water Authority's 1997 proposed tariff change would result in a decrease of water consumption and an increase of revenue collected from the sale of water.

Caution must be taken when interpreting the results of the demand models. The data used to develop the models was aggregated by district and by year. In doing so, the models aggregate the individual behavior of customers within a district. It is therefore assumed that each household within the same district will, on average, behave in the same manner to changes in water prices. However, household characteristics within the same district, and hence household consumption, are not homogeneous. For instance, household income may vary greatly within a district, especially in higher income districts. In addition, other variables determining household water demand, such as the number of people per household and lifestyle choices, were not included in the analysis.

Monthly variation in water demand cannot be explained by the developed demand models since the data was aggregated on an annual basis. However, monthly consumption within a year is not necessarily homogeneous, especially in a place like Barbados where there are two distinct seasons in a year. In general, household consumption is greater during the dry season than the wet season.

There were also missing data and therefore assumptions regarding certain important variables were needed. Monthly household consumption was missing for some months during the study period, especially prior to 1994, and was replaced by the mean monthly consumption over the study period. Income information was more scarce and numerous assumptions were made. Income was assumed to be directly related to GDP change. The water demand models may have differed somewhat if no data was missing or if other assumptions were made.

The models were also developed using small and infrequent changes in real water price. The last nominal price change in Barbados occurred in 1991 when water prices increased by roughly 25%. This observed price variation may be too small to extrapolate future impact of large price changes. Most of the rate structures presented in Chapter 6 will result in price increases outside the range of previously observed price changes. The price elasticities derived from the models would have probably been different if the sample customers were previously faced with large price increases. Therefore, the developed demand models are best suited for examining small price changes. More data on changes in water demand under greater changes in water prices needs to be collected to improve the results.

The last chapter of this study looked at the impact of the Universal Metering Program in Barbados. There was an immediate reduction in water pumped from groundwater sources demonstrating that metering can be used as a means of controlling consumption. However, per-capita consumption has been on the rise in recent years. Therefore, without a change in water prices, metering alone will not be effective in changing people's consumption behaviour.

The Universal Metering Program completed in 2000 is a big step towards improving water resources management in Barbados. However, more steps are needed to assure the sustainability of the island's water resources. The use of appropriate pricing mechanisms will encourage consumers to rethink and change their water consumption habits. The 1997 proposed tariff change should be the Government's primary focus with respect to water. Other rate structures should be suggested and designed based on economic and equity principles. However, there is a general resistance and unwillingness to engage in pricing policy changes. Therefore, greater efforts must be made to educate people on the critical water issues facing Barbados. Water conservation should be encouraged and embedded in the minds of all Bajans. It is believed that a combination of demand-side and supply-side measures will lead to a more sustainable, efficient and equitable management of the island's water resources and will improve its water security.

Chapter 9. Recommendations for Future Work

The validity and reliability of the developed residential demand models would improve with more data. Water consumption data from additional households from each of the seven districts should be collected. Households from other districts should also be selected for the analysis, particularly from high and middle income districts since this research looked at only one high income district (Sandy Lane) and two middle income districts (Bagatelle and Sunset Crest).

Household income data was very difficult to obtain primarily for privacy reasons. This was overcome by getting a database that contains no information that pin points a particular customer. Unfortunately, this type of database does not allow for a household level analysis. Therefore, income was aggregated by district even though income may vary greatly between households within the same district. A household survey should be developed to acquire information on household income or proxies for income. In addition, the database did not contain income data for all customers in the seven selected districts. Income data was also only obtained from 1996 onwards since it was available in digital format. It would be very beneficial if income data prior to 1996 is collected, although it may be quite time consuming.

The method used to analyse the impact of price changes on future water demands relies on several GDP growth assumptions. It would be good to check if the Statistical Office of Barbados or other institutions have recently made any GDP projections. A more accurate GDP growth assumption would definitely improve the results.

The Universal Metering Program in Barbados was completed in 2000. However, only water production and consumption data up to 2002 was collected at the time of the study and hence only short term effects of the program was analysed. Consumption/ production after 2002 should be obtained to see if the program was beneficial in reducing wasteful water use in the long run.

It would also be interesting to compare Barbados' experience with water resource management to other Caribbean islands. What are the water problems and issues on other islands? How are they tackling these emerging problems? Are other islands also considering water demand management practices, such as pricing and metering? Can the developed models for Barbados be used for other islands? These are some interesting questions that I hope future researchers will answer.

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Appendix A: Groundwater Protection Zones

Zone	Definition of Boundary	Maximum Depth Of Soakaway Pits	Domestic Control Restrictions	Industrial Restrictions
1	300 day travel time	None allowed	No new houses or water connections No changes to existing wastewater disposal	No new industrial development No quarrying
2	600 day travel time	6.5 m	Septic tank of approved design Separate soakaway pits for toilet effluent and other domestic wastewater No storm runoff to sewage soakaway pit No new oil tanks	All liquid wastes to be dealt with as specified by the Barbados Water Authority
3	5-6 year travel time	13 m	As above for domestic wastewater. Petrol fuel or oil tanks to approved leak-proof design	Maximum soakway depth as for domestic wastes
4	Extends to all highlands	No limit	No restriction on domestic wastewater disposal Petrol fuel or oil tanks to approved leak-proof design	
5	coastline	No limit	No restrictions on domestic wastewater disposal. Siting of new fuel storage tanks subject to approval of the Barbados Water Authority	

Appendix B: Customer Database

Rate Schedule	Customer Number	Bill Date	Usage	Additional Usage	Bill Days	Parish
M1	165	19960103	31	0	28	St-James
M1	184	19960103	6	0	28	St-James
M1	222	19960103	39	0	27	St-Lucy
M2	231	19960103	52	0	30	St-James
M1	450	19960103	33	0	30	St-Lucy
M1	478	19960103	12	0	23	Christ Church
M1	517	19960103	36	0	35	Christ Church
M3	703	19960103	246	0	33	St-Michael

This table shows a part of the BWA's customer database. The database contains all the billing records from January 1996 to August 2002.

Rate schedule: The rate schedule identifies the customer type (i.e. domestic, commercial, etc.). The different rate schedules are: (M1) metered domestic, (M2) commercial and industrial, (M3) hotels, (M4) government and schools, (M5) BWA, (M6) Port Authority. Flat rate bills are coded based on the amount paid based on property value. The rate schedules range from 040 to 160.

Customer Number: Each bill has a number associated with it identifying the customer. Note that the customer numbers shown in the table above do are not correspond to an existing customer.

Bill Date: This indicates the date the bill was sent.

Usage: This is the recorded water consumption from meters during the billing period in cubic meters. Consumption for unmetered customers is 0.

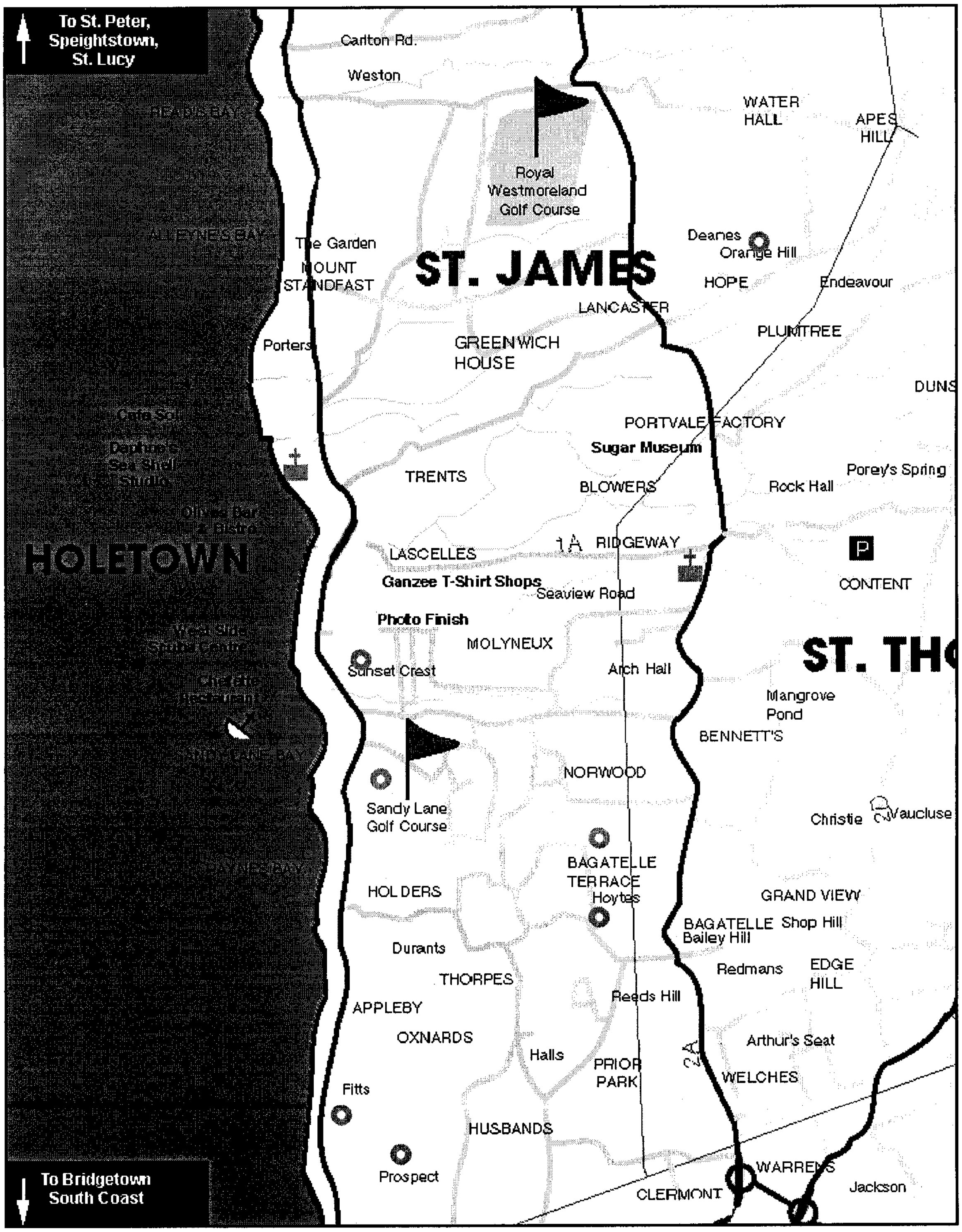
Additional Usage: Meters are not read on a continuous basis. The BWA estimates the water that would have been consumed based on previous monthly consumption or standard seasonal peaks. This estimate is then recorded under the *Usage* column. The actual usage is obtained the next time the meter is read and is again recorded in the *Usage* column. Additional usage is the difference between the total usage recorded from the meter and the estimated usage.

Bill Days: This indicates the number of days over which the customer's usage is being recorded.

Parish: Identifies the parish of residence of a customer

Appendix C: District Locations

(source:http://www.funbarbados.com/ourisland/maps/holetown.html)



Districts used in the analysis

Appendix D: Data Tables

D.1 Average Annual Household Water Consumption (m^3)

yr	Orange Hill (L)*	Hoytes (L)	Prospect (L)	Fitts (L)	Sunset Crest (M)	Bagatelle (M)	Sandy Lane (H)
1987	174	250	189	259	273	364	814
1988	171	157	205	218	299	336	1051
1989	156	191	268	244	201	363	1085
1990	162	188	227	257	228	355	829
1991	248	275	92	310	208	344	918
1992	176	278	162	284	260	387	880
1993	175	231	180	252	232	378	938
1994	162	244	201	254	206	316	810
1995	190	240	184	290	209	339	1035
1996	195	302	172	294	214	327	1058
1997	210	292	173	272	244	395	704
1998	214	252	195	318	233	412	669
1999	201	224	206	259	215	362	850
2000	192	234	275	302	236	349	780
2001	189	240	184	316	223	374	659

* L (low income district), M (medium income district), H (high income district)

D.2 Average Real Annual Income (thousands of BBD$)[1]

year	Orange Hill (L)*	Hoytes (L)	Prospect (L)	Fitts (L)	Sunset Crest (M)	Bagatelle (M)	Sandy Lane (H)
1987	22.9	25.9	25.6	26.3	46.9	44.1	78.9
1988	23.2	26.3	26	26.6	47.5	44.7	79.9
1989	24.1	27.3	27	27.7	49.4	46.5	83.1
1990	23.5	26.6	26.3	27	48.2	45.4	81.1
1991	21.9	24.8	24.5	25.1	44.8	42.2	75.4
1992	19.4	22	21.7	22.3	39.8	37.4	66.9
1993	19.8	22.4	22.1	22.7	40.6	38.2	68.2
1994	20.9	23.6	23.3	24	42.8	40.2	71.9
1995	22	24.9	24.6	25.3	45.1	42.4	75.9
1996	22.9	25.9	25.6	26.3	46.9	44.1	78.9
1997	20.8	25.1	25.5	23.3	46.8	39.9	84.8
1998	18.9	22.9	21.9	21.5	50.9	46.1	109
1999	19.8	23.4	22.3	22.8	60.4	45.4	108
2000	19.5	24.3	22.6	22.4	56.1	43.3	109
2001	20.1	25.6	22.5	24.3	57.5	45.8	87.4

1.base year = 2001
* L (low income district), M (medium income district), H (high income district)

D.3 Real Average Water Prices (BBD$ per m^3)[1]

year	Orange Hill (L)*	Hoytes (L)	Prospect (L)	Fitts Village (L)	Sunset Crest (M)	Bagatelle (M)	Sandy Lane (H)
1987	2.15	5.38	2.40	2.92	6.50	1.88	1.91
1988	2.06	6.77	1.42	2.62	2.19	2.15	2.09
1989	2.00	4.34	3.54	3.71	2.48	2.07	1.85
1990	2.21	3.05	3.33	2.71	2.64	2.68	2.11
1991	1.71	1.51	2.64	2.55	1.98	2.36	1.74
1992	2.81	1.94	3.26	3.04	3.40	3.94	2.22
1993	2.46	1.90	2.60	3.39	3.50	1.88	2.46
1994	2.63	2.04	2.12	3.61	3.96	3.14	2.66
1995	2.56	1.92	2.87	3.10	3.40	2.93	2.09
1996	2.75	1.90	3.31	2.99	3.15	2.31	2.46
1997	2.23	1.86	2.72	2.49	2.70	1.76	1.92
1998	2.24	1.91	2.59	2.43	2.94	1.79	2.36
1999	2.53	2.33	2.26	2.35	2.89	2.21	2.50
2000	2.64	2.40	2.54	2.51	2.19	1.88	2.02
2001	2.37	2.18	2.96	2.42	2.44	1.76	2.23

1.base year = 2001
* L (low income district), M (medium income district), H (high income district)

D.4 Real Marginal Water Prices (BBD$ per m^3)[1]

year	Orange Hill (L)*	Hoytes (L)	Prospect (L)	Fitts Village (L)	Sunset Crest (M)	Bagatelle (M)	Sandy Lane (H)
1987	0.32	0.45	0.38	0.53	0.40	0.76	0.71
1988	0.33	0.40	0.53	0.76	0.49	0.73	0.96
1989	0.36	0.49	0.45	0.52	0.52	0.77	1.02
1990	0.38	0.46	0.39	0.56	0.62	0.84	1.02
1991	0.56	0.92	0.45	0.70	0.60	0.93	1.08
1992	0.71	1.17	0.67	1.03	0.80	1.32	1.58
1993	0.63	1.19	0.32	1.01	0.77	1.37	1.62
1994	0.56	0.98	0.65	0.88	0.69	1.15	1.47
1995	0.68	1.05	0.62	0.98	0.68	1.23	1.57
1996	0.79	1.20	0.69	0.96	0.80	1.29	1.55
1997	0.88	1.23	0.78	1.06	0.86	1.53	1.67
1998	0.86	1.08	0.75	1.10	0.90	1.56	1.58
1999	0.85	1.05	0.91	1.02	0.86	1.48	1.65
2000	0.85	0.93	0.77	1.10	0.96	1.48	1.75
2001	0.90	1.09	0.92	1.11	0.99	1.51	1.77

1.base year = 2001
* L (low income district), M (medium income district), H (high income district)

D.5 Average Annual Rainfall (mm) at the Caribbean Institute of Meteorology and Hydrology Station

year	rain (mm)
1987	1373
1988	1561
1989	1078
1990	1676
1991	1321
1992	1303
1993	1043
1994	1029
1995	1253
1996	1294
1997	1038
1998	1396
1999	1449
2000	1100
2001	1101
2002	842

D6. Real GDP Change

year	Real GDP Change (%)
1987	6.33
1988	1.29
1989	3.95
1990	-2.41
1991	-6.99
1992	-11.3
1993	2.01
1994	5.41
1995	5.53
1996	3.97
1997	2.69
1998	9.15
1999	3.47
2000	3.53
2001	2.31

Appendix E: Relative Weight of Model Variables

E.1 Variable Statistics

Variable	Mean	Standard Deviation	Definition
Q	335	229	average annual household consumption per district (m^3)
Inc	38.6	21.8	average annual real household income of district (000's $)
AP	2.69	0.37	real average price ($)
(High Income)	2.17	0.27	
(Med Income)	2.7	0.55	
(Low Income)	2.81	0.37	
Inc/AP	16.0	11.1	income divided by average price
Inc/MP1	23.4	13.8	income divided by marginal price
IncHigh	0.14	0.35	high income dummy variable
IncLow	0.57	0.5	low income dummy variable

Note: All real values use 2001 as base year and all prices are in Barbados Dollars

E.2 Relative Weight of the Explanatory Variables

Model 5.2: $Q = 106 + 8.5\,(\text{Inc}) - 36.8\,(\text{AP})$

$$Q \text{ (at mean)} = 106 + 8.5\,(38.6) - 36.8(2.69) = 335\ m^3$$

$$\text{Contribution} = \frac{106}{335} + \frac{8.5(38.6)}{335} - \frac{36.8(2.69)}{335} = 32\% + 98\% - 30\%$$

Model 5.3: $Q = 56.8 + 17.4\,(\text{Inc/AP})$

$$Q \text{ (at mean)} = 56.8 + 17.4\,(16) = 335\ m^3$$

$$\text{Contribution} = \frac{56.8}{335} + \frac{17.4(16)}{335} = 17\% + 83\%$$

Model 5.4: $Q = 20.7 + 13.5\,(\text{Inc/MP1})$

$$Q \text{ (at mean)} = 20.7 + 13.5\,(23.4) = 337\ m^3$$

$$\text{Contribution: } \frac{20.7}{337} + \frac{13.5(23.4)}{337} = 6\% + 94\%$$

Model 5.5 : $Q = 353 + 573\ (IncHigh) - 66.1\ (IncLow) - 22.6\ (AP)$

High Income

$Q = 353 + 573 - 22.6\ (AP)$

Q (at mean) $= 353 + 573 - 22.6\ (2.17) = 877\ m^3$

Contribution $= \frac{353}{877} + \frac{573}{877} - \frac{22.6(2.17)}{877} = 40\% + 65\% - 5\%$

Medium Income

$Q = 353 - 22.6\ (AP)$

Q (at mean) $= 353 - 22.6(2.7) = 292\ m^3$

Contribution $= \frac{353}{292} - \frac{22.6(2.7)}{292} = 121\% - 21\%$

Low Income

$Q = 353 - 66.1 - 22.6\ (AP)$

Q (at mean) $= 353 - 66.1 - 22.6\ (2.81) = 223\ m^3$

Contribution $= \frac{353}{223} - \frac{66.1}{223} - \frac{22.6\ (2.81)}{223} = 158\% - 30\% - 28\%$