Integrating Water Resources Management - Analysis of the St. Thomas, U.S. Virgin Islands, Water Market

by

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Abstract

The purpose of this thesis is to contribute to the understanding of the water resources management of the St. Thomas water market. By applying the framework for Integrated Water Resources Management, the actual water resources situation in the island was analyzed. This framework requires meeting three criteria: economic efficiency in water use, environmental and ecological sustainability, and equity in the access to water for all the population.

The study includes the assessment of available water supply and water demand by use, and the evaluation of alternative and feasible supply options to augment freshwater resources. Three potential main supply strategies for freshwater supply were identified and compared based on: 1) economic efficiency in water use, 2) environmental and ecological sustainability, and 3) equity in the access to water for all people.

Four integrated strategies for future development and management of water resources in the island were recommended: 1) Gradually phasing out desalination based on distillation as the main strategy of water supply. This supply can be replaced with distributed reverse osmosis desalination and by importing water by submarine pipeline from Puerto Rico. 2) Gradually expanding the distribution system to the entire population, applying the funds saved by shifting to more cost-effective and sustainable freshwater supply alternatives. 3) Developing water trading policies within the island as well as with neighboring islands. 4) Improving accountability for available water supplies, which is a basic need for water managers and planners informed decision making.

Thesis Supervisor: Dennis McLaughlin
Title: Professor of Civil and Environmental Engineering

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To my wife and my son for their support: Judy and Martin.
To my advisors for their insight: Prof. Dennis McLaughlin, Prof Peter Rogers, Dr. Pete Shanahan, Daniele Lantagne and Prof. Eric Adams.
To the people of the US Virgin Islands.

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Abbreviations used throughout the thesis

RWC Rainwater Catchments

R/O Reverse Osmosis Systems

WAPA Water and Power Authority

DPW Department of Public Works

DPNR Department of Planning and Natural Resources

IWRM Integrated water resources management

USVI United States Virgin Islands

1. Introduction

Dealing with water scarcity has been the historical rule in the US Virgin Islands (USVI). The combination of extreme events (hurricanes and floods) and the lack of holistic planning in infrastructure have conditioned the US Virgin Islands population to a state of constant drought.

Because of annual rainfall–102 centimeters (40 inches) concentrated during the hurricane season between July and November (Donahue and Johnston, 1998)–and due to low capture and storage in the small basins and limited aquifers, water conservation is of critical concern for the population and requires constant attention by the water resources managers and planners.

Available water supply comes from three systems:

- Catchments of rainwater with cistern storage.
- Saltwater conversion (desalination).
- Groundwater wells (mainly in St. Croix, because of contamination and different type of geology in the St. Thomas main aquifers).

Due to the high cost of water from desalination, the daily average per capita water consumption is substantially less than the US average, totalizing 190 L/day per capita (OIA, 1999).

It is difficult to analyze the islands as a whole, because each island is substantially different. St. Thomas is the center of tourism and commerce associated with it, St. Croix is the industrial center, and St. John is mainly a natural reserve with low population. The scope of this study will be focused on the island of St. Thomas. In this island, it must be added to the local water demand, the pressure on this resource from tourism demand. The peak population of this island in high tourism season is estimated by some authors to be around 130,000 persons, a figure that almost triples the permanent population (Donahue and Johnston, 1998).

Focusing on St. Thomas island research has been done on:

- Available water supply.
- Water demand by water use.
- Evaluation of alternative and feasible supply options that can augment water resources.
- Identification of the existing and alternative supplies, with the potential to provide the water quantity and quality required for St. Thomas.
- Comparison of the main potential supply strategies for St. Thomas, taking in consideration economic, environmental and equity criteria.
- Finally, paths for future development and management of water resources in the island are discussed.

In order to conduct this research information from the different stakeholders in water resource planning was considered. The actual stakeholders in the water market are WAPA (Water and Power Authority, responsible for generating and supplying electricity and desalinated water), DPW (Department of Public Works, responsible for, among other public works, wastewater collection, treatment and disposal), and DPNR (Department of Planning and Natural Resources, responsible for controlling and enforcing potable water and wastewater permits, codes and regulations, through DEP Division of Environmental Protection). Understanding the position and interrelation between the major stakeholders regarding water resources is crucial for evaluating the particular dynamics of the water market.

Representatives of all these major stakeholders have been interviewed in order to establish a datum during the month of January of 2003. Care has been taken to maintain quantities accurate and in the proper order of magnitude for comparisons and recommendations included in this work. The estimates of water supply and demand on which this study is based can be improved with surveys and with a greater geographical breakdown of the available information. It is to be noted that because of the multiple sources and the need for estimation in some sensitive parameters, some amounts can be debatable.

1.1.Why Integrating Water Resources Management?

"Integrated Water Resources Management–IWRM–is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000).

IWRM is a powerful tool to face the challenges presented by the USVI water resources sector development. It provides a framework to the process of managing and developing water resources, land uses and other related resources. IWRM gives a holistic approach to the rules and constraints that should apply to all participating sectors in the water related issues, in order to achieve economic and social welfare, without affecting ecosystem sustainability. A rational balance between the use of the water resource, and the protection and conservation of the resource should be achieved.

To take into account social, natural and economic conditions three criteria should be addressed: economic efficiency in water use, environmental and ecological sustainability, and equity in the access to water for the population.

Three fundamental complementary elements should be encouraged and developed as part of effective water resources management:

- The enabling environment, as a framework.
- The institutional roles at each level and representing every stakeholder.
- The management and development instruments, as a useful "tool-box" for implementing IWRM.

1.1.1. The actors of water resources management

a) Government, as enablers, setting the framework for private action. It is important that government can retreat from its old role of providing services, and can assume successfully the role of regulating the services that can be operated by private companies, users associations and other non-governmental organizations (NGO's). Another crucial task should be to adopt the full-cost pricing of water use and related services, and to implement policies of subsidies to individuals. Government must also support and regulate the water market, and must provide or ensure the necessary funding for crucial water resource development that cannot be assured by the private sector.

b) Institutions of users, industry, and all other non-governmental organizations. These institutions should be integrated in a fashion that will give all the "stakeholders" representation and relative weight by means of participatory institutional mechanisms. Communities and NGO's should play a fundamental role in watershed action programs, groundwater aquifer management organizations, local-level action for natural disasters, monitoring quality of water, pest control, drought relief, and conservation.

c) Private sector, as provider of water services for people, drinking water and wastewater treatment. The other crucial role of the private sector is as provider of capital, in the form of investment or financing water related infrastructure works. It is of an extreme importance that the government could adequately regulate the "rules of the game" so that the private sector can be developed in a timely and efficient manner. These rules can be implemented by adopting water full-cost pricing as a key incentive.

d) Institutions for monitoring, and following up on the development of action plans, bringing technical assistance where needed. Another role of these agencies should be to leverage financial assistance for projects that exceed local capital markets possibilities (either private or public) (Global Water Partnership, 2000).

Water is a resource that has no frontiers, and many neighbor islands can play an important role in water augmentation.

One of the contributions that IWRM can give is to help in the definition of a practical set of water management techniques that can be a useful guideline for the St. Thomas case analysis:

- Water resource assessments: availability and demand.
- Communication and information systems.
- Water allocation and conflict resolution.
- Regulatory instruments comprising direct controls, economic instruments (fees, prices, charges, etc.) and encouraged self-regulation. Regulatory instruments should be inspired on three basic principles:
  - User pays.
  - Polluter pays.
  - Subsidize the good, tax the bad.
- Technology
  - Technological advance towards sustainability.
  - Research and development in technology.
  - Guidelines for technology assessment.
  - Choosing the optimal technology for a given particular context.

2. Historical and economical background focused on the water situation

For a better understanding of the actual water situation in this U.S. territory a chronology of relevant key events is presented. The water situation is embedded in the greater social, economical and political picture of the islands. Moreover, it is not possible to analyze the water market without taking into account all this information. It is important to note that institutionally the islands are a young autonomous territory. Only since 1970, the locals have elected their own governor. As with every other institution in the islands, the ones of the water sector are young and striving to find their maturity.

In the past fifty years, the history of water resources development in the islands can be summarized as follows. Until 1960, hillside rainfall catchments and dug wells composed the major sources of water supply. Rainwater harvesting was the source of water for most rural and urban domestic supplies. As a proof of the importance of this practice, in 1964, the Legislature of the US Virgin Islands passed a law that required as mandatory for all new residential, commercial or industrial buildings to have a minimum cistern storage related to the surface of the roof. In 1955 as population started to grow, water began to be barged from Puerto Rico as a supplement to the water resources available. In the 1960's and early 1970's population grew rapidly (see figs 2.1 and 2.2) because of the shift in the economic activity of the island. In this period the economy that has been traditionally based in agricultural production, shifted dramatically. The new economy was based in tourism and industry. This continuous growth in population (see fig 2.1) provoked an unprecedented stress on the available water resources. In 1960 the population was 32,100 and it rose in 1975 to 85,800 (USGS, 1987).

To mitigate water scarcity in 1964 the first desalination plant began production. Its operation was under the charge of the Virgin Islands Water and Power Authority (VIWAPA). The initial production doubled the capacity of the existing supply system based in rainwater catchments and groundwater extraction (USGS, 1987).

In the 1970's water production by seawater conversion continued to be expanded. However, at the end of that decade, due to aging equipment and lack of maintenance, a water crisis appeared again in the island horizon. These problems added to periods of drought, over-pumping of wells, failures in the distribution systems, and a lack of adequate storage capacity determined that rationing of water had to be applied in order to mitigate its frequent shortages. In 1979, barging from Puerto Rico was started again (USGS, 1987).

In 1981-82, the VIWAPA expanded its desalination capacity by 2.5 MGD on St. Thomas and by 1.25 MGD on St. Croix, ending the need for rationing. But, although supplies have been improved, water demands were not fully satisfied (USGS, 1987). In the last two decades and as it can be seen in the population trends, population growth has decreased (fig 2.1), and in the last decade negative growth has been registered. Not much has been invested in the expansion of the water system. The efforts made were concentrated towards more efficient operation of the existing system. If the population trends forecasted in the 1980's (156,000 inhabitants by the year 2000) would have been materialized, a water crisis will be at its climax today in the islands. The fact that the actual population is only of 108,000 (US Bureau of the Census, 2000) has mitigated the lack of meeting the planned goals in the water resources sector.

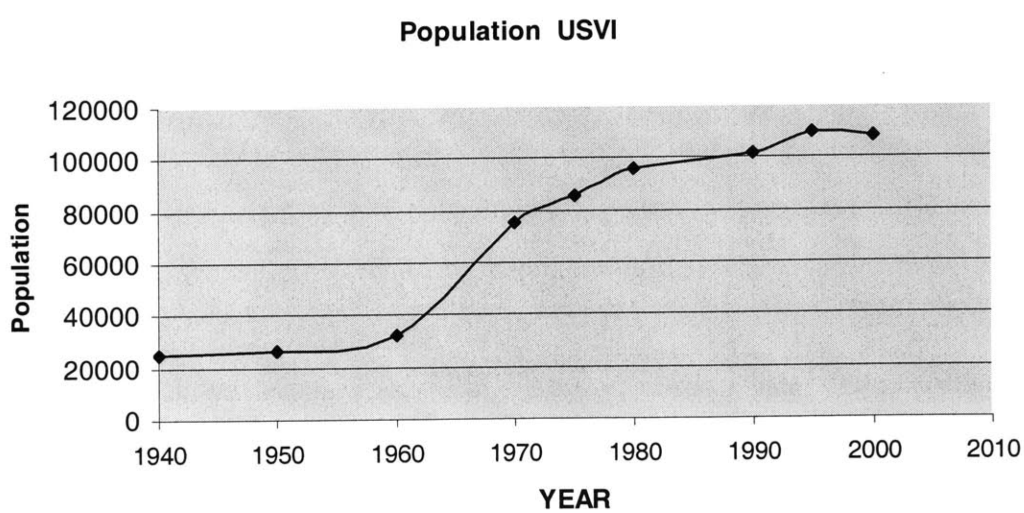

Figure 2.1
(Data taken from the US Census Bureau, 2002 and OIA, 1999)
Total Permanent Population

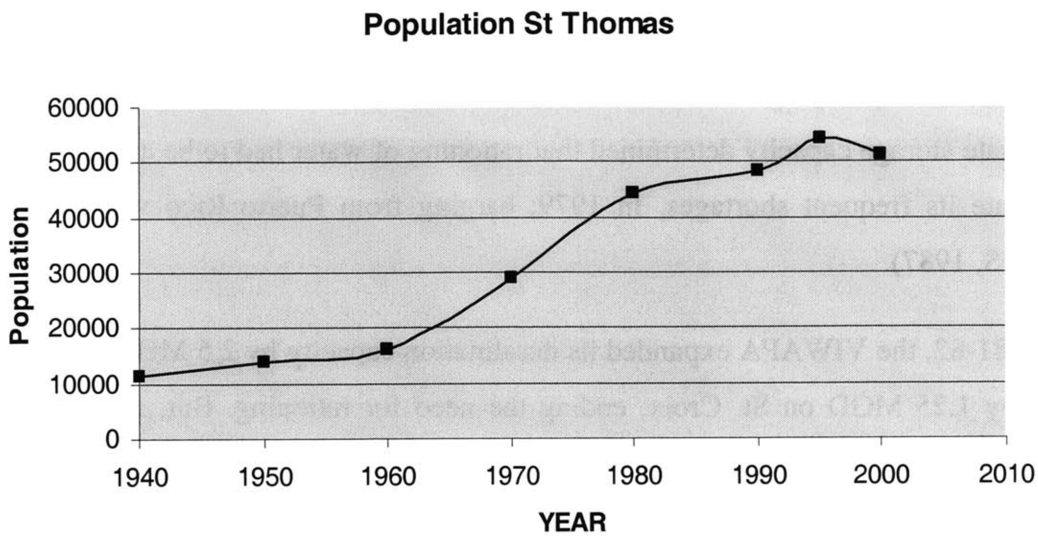

Figure 2.2
(Data taken from the US Census Bureau, 2002 and OIA, 1999)
Total Permanent Population St. Thomas

3. Water Related Infrastructure

3.1.1. Water System

The WAPA (Water and Power Authority) manages the desalinization plants and the distribution system, which covers the more populated subdistricts of St. Thomas. Given that the costs of saltwater conversion are significant, the system integrity and the efficiency of metering operations are of crucial importance (OIA, 1999).

Currently, water distribution rehabilitation and replacement projects are in progress as part of a territory-wide water program on St. Thomas and St. Croix.

Almost every big resort as well as main industries has their own private seawater conversion units, mainly using reverse osmosis (R/O) technology to convert seawater to drinking water.

St. Thomas

More than 50% of the population relies solely on roof catchments and water cisterns for potable water (Table 3.1). When rainfall is scarce or cistern capacity is small, there are companies that deliver water by truck from the desalination facilities or from private wells.

The remaining population relies on desalination or a combination of desalinated water and water catchments. The demand on the WAPA distribution system ranged between 11.20 and 13.24 MLD (2.96 and 3.50 MGD) and supplies the town of Charlotte Amalie and the east end of the island (OIA, 1999).

Desalination facilities can produce 16.85 MLD (4.45 MGD) using seawater and waste heat from the electric power plant for the conversion of water (OIA, 1999). The distribution system consists of 3,400 metered connections on 80 km (50 miles) of water mains. The system has seven boosters pump stations and an approximate storage capacity of 50 ML (13.21 MGal). Funding has been provided for plant expansion through the issuance of water bonds.

In addition, a saltwater flushing system used to serve the Fire Main Water supply in Charlotte Amalie. This was a great advance in water conservation policies. Mainly because of lack of maintenance, this system has seriously deteriorated. This has resulted in electrolysis along the potable water lines, causing disintegration of the pipes. Today it is no longer in use.

One of the main problems that still face the water distribution system is of losses mainly due to system leakage (OIA, 1999). In 1998, those losses were reduced to 45 percent from the 65 percent that was registered in 1988. Ninety percent of total system loss is accounted for these system leaks. All piping is being replaced with PVC, because of the corrosive nature of the soils.

St. John

In 1990 a desalination plant of 587,000 LPD (155,000 GPD) capacity began operation, eliminating the barging from St. Thomas of 50 percent of St. John's water supply needs (OIA, 1999). This facility is complemented with an elevated storage reservoir with an attendant pump station. Water service has been provided to the residents of Coral Bay. Storage capacity has been doubled in 1995 from 2.27 to 4.54 million liters (0.60 to 1.20 million gallons).

St. Croix

Groundwater is added in this island as part of the pubic supply. The daily water demand is approximately 12.11 MLD (OIA, 1999). The desalinated water production is of 14.00 MLD (3.70 MGD), and a maximum of 1.89 MLD (0.50 MGD) extracted from all active wells. The distribution system has 224 km (140 miles) of mains, 6 primary booster pump stations, and 87 ML (23 MG) of storage capacity. It is crucial to control water losses and leaks due to the high cost of water production.

Table 3.1
Population source of water, sewage disposal and
percentage of water purchased from vendor
(Datum taken from the US Census Bureau-2002)

Relevant Datum	St Thomas	St John	St Croix	Total
Total Population	51,181	4,197	53,234	108,612
Source of Water (% of housing units)				
Public System	24.40	3	25	24
Public System and Cistern	19.00	14	26	22
Cistern, tanks, drums only	55.40	81	45	52
Public standpipe	1	2	4	2
Other source				
Sewage disposal (% of housing units)				
Public Sewer	57	16	49	52
Septic tank or cesspool	40	78	47	45
Other means	3	7	4	3
Purchased	34	50	32	34
Not purchased	66	50	68	66

3.1.2. Wastewater System

Wastewater treatment plants and sewage collection systems are installed in the three islands. Private residences use individual septic systems, and some hotels use small private treatment plants, that in both cases are not connected to the public systems. The discharge of effluent is made to either an inland stream or the ocean. The towns of Charlotte Amalie on St. Thomas and Christiansted on St. Croix use saltwater sewage flushing systems as a potable water conservation measure. The Department of Public Works (DPW) manages and operates the public sewer systems on all three islands.

On January 19, 1996, the Government of the USVI signed an Amendment Consent Decree with EPA. This resulted in the scheduling of improvements to existing wastewater treatment facilities, as well as schedules for new ones to be constructed with strict penalties for failure to meet the deadlines and interim quantity and quality of effluent proposed.

St. Thomas

Individual septic tanks are the common wastewater disposal system for private residences (OIA, 1999). In addition, there are eight sewage treatment facilities, seven secondary plants, and an anaerobic pond located at the airport. The plants do not always attain secondary treatment discharge requirements.

Infrastructure deficiencies has been reported as follows "With regard to wastewater treatment on St. Thomas inadequate facilities, particularly on the East end and the Cyril E. King Airport, have been discharging poorly or untreated effluent into coastal water areas, causing damage to the marine ecosystem, lowering water quality levels, and endangering public health" (DPNR, 1991).

EPA approved a grant for the construction of a regional wastewater treatment plant at the solid waste landfill site located on the eastern end of the island (OIA, 1999). When finished, it will initially eliminate five existing plants, and later, a sixth.

Sewer line replacement for the island of St. Thomas is estimated at $20 million, including preparatory cleaning and inspection (OIA, 1999). The sewage lift stations are being provided with emergency generators.

St. John

The only area that is served by a secondary waste treatment plant is Cruz Bay (OIA, 1999). This facility is overloaded, does not meet interim effluent limits, and discharges into a nearby salt pond. There is project for a new secondary treatment plant that will replace this facility and discharge effluent through an ocean outfall, already finished in 1995. Sewer lines have been extended in 1995. Sewage lift stations are being provided with emergency generators.

St. Croix

The island relies on one primary wastewater treatment facility for servicing Christiansted and Fredericksted (OIA, 1999). The treatment plant discharges to the ocean. The sewage collection system consists of 140 km of gravity (mainly concrete pipes) and force mains with three major sewage lift stations and twelve feeder pump stations. These concrete pipes are suffering deterioration from hydrogen sulfide gas, which produces sulfuric acid. Due to deterioration of sewage pipes provoked by the combination of extended time of detention and the presence of sulfuric acid, occasional raw sewage bypasses had to be made to mitigate health hazards and environmental damage. The need of sewer line rehabilitation and replacement will demand an effort estimated in $30 million.

4. Key issues for Integrating Water Resources Management

Several water resources management issues are crucial for facing the challenges of the constrained St. Thomas water market. The following identifies issues as background to formulate a strategy.

4.1. Environmental consequences of separate operation of water supply and wastewater

Is it desirable to have two different entities operating water supply and water disposal?

In the case of the Virgin Islands, the fact that during the last decade's water supply was designed as dependant primarily on desalinated water affected the culture and the response to proper conservation of the environment (Donahue and Johnston, 1998). This, combined with a water supplier (WAPA) independent from the wastewater supplier (DPW), affects and conditions the final overall quality of water.

4.2. Reliability of public water system based in desalination. Frequency of extreme events.

Is it possible to operate a reliable water system based only in one supply strategy (desalination) in a place where the occurrence of extreme events is of high frequency?

In 1995, Hurricane Marilyn put the WAPA desalting facilities in St. Thomas out of operation for six weeks (Donahue and Johnston, 1998). This meant no water AND no power to operate cistern pumps at households for six weeks. This type of extreme event is of high frequency in this zone. The total public reserves of water for these periods of water scarcity, as shown in Table 4.1, span from 6 to 11 days of supply. Moreover, if we consider the declared leaks of the system (water not accounted for ascended in 1998 to 45 percent due to losses in the distribution system) this time will be cut at half in an emergency.

4.3. Water costs and prices in this market

How can proper prices on water be managed in a market with these characteristics?

Water demand exceeds the possible supplies (Donahue and Johnston, 1998). Ranging from the small cost of catchments of rainfall (with the dangerous water quality issues inherent to such a system) to desalination water costs there are some alternatives that must be analyzed, mainly to assure a basic and equitable water supply.

4.4. Health consequences derived of the system of rainfall water catchments

How can overall water quality be assured when catchments of rainfall is the main water supply for more than 70% of the population? As it is reflected in the datum of the last census, not much has changed in the distribution system of desalinated water. Although all of the taxpayers have been involved in one way or the other in the monies that are owed to the federal government, in part for desalination plant acquisitions. Nevertheless, the benefit of desalinated water only reaches a fraction of the population, as can be seen in Table 4.2.

Table 4.1

Available public supply.

(Partial datum taken from OIA, 1999).

Note: Daily per capita available public supply for St. Croix and St. John where taken over permanent population datum, and still are low figures compared to US standards

Available Public Supply (in MLD)	St.Thomas	St. John	St. Croix	Total
Desalination Plants Production (WAPA)	16.84	0.57	14.00	31.42
Groundwater			0.50	0.50
Storage Capacity (in ML)	189.25	4.54	87.06	280.85
Storage Capacity in days of non-plant operation	11.24	8.00	6.22	
Resident Population	51,181	4,197	53,234	
Adding Tourist Population to Residents	130,000.00	no datum	no datum	
Daily available Supply (L/cap/day)	129.56	135.28	263.07	

5. Water Supply on St. Thomas

5.1. Conjunctive use of harvested rainwater and desalinated water

General information has been given in the introduction on the water resources of the three main islands that compose the US Virgin Islands. Now a more thorough description of the water use and perspectives for water supply for the particular case of St. Thomas will be analyzed.

Many of the practices described pertaining to water use is common to the three islands as well as some of their neighboring Caribbean islands. "In most of the smaller islands of the Caribbean, there is no single natural source of water that may be used to satisfy the ever rising demand for consumption and sanitary purposes brought on mainly by increasing standards of living and visitors arrival. Mountainous terrain makes buildable land dear, and along with high evaporation rates make larger surface water impoundments impractical. Groundwater supplies are limited due to high runoff rates and little opportunity for recharge" (Smith, 1987).

In St. Thomas the only reliable and available water supply for all the population of the island, still in 2003, is rainfall water catchments (referred as RWC from now on). Although desalination is present in the island since 1962, it is not distributed throughout the island. Desalinated seawater is only allocated in urban areas and in places where population is denser in the island. Groundwater is used throughout the island but is only privately operated. Today and because of groundwater contamination it is not considered more than a last option complementary water resource. In the other hand almost all of the resorts in the island are basing their water supply in privately owned reverse osmosis systems (R/O from now on). The actual water use situation depends on the location of the tourist resorts that conditions the possibility of having or not public supply, ranges from total reliance on R/O system for all uses, to partial use of privately desalinated water for irrigation. Three resorts are using R/O systems with an input of brackish ground water, and the rest of them (around twenty-seven) use sea water as input (David Simons interview, DPNR officer, 2003).

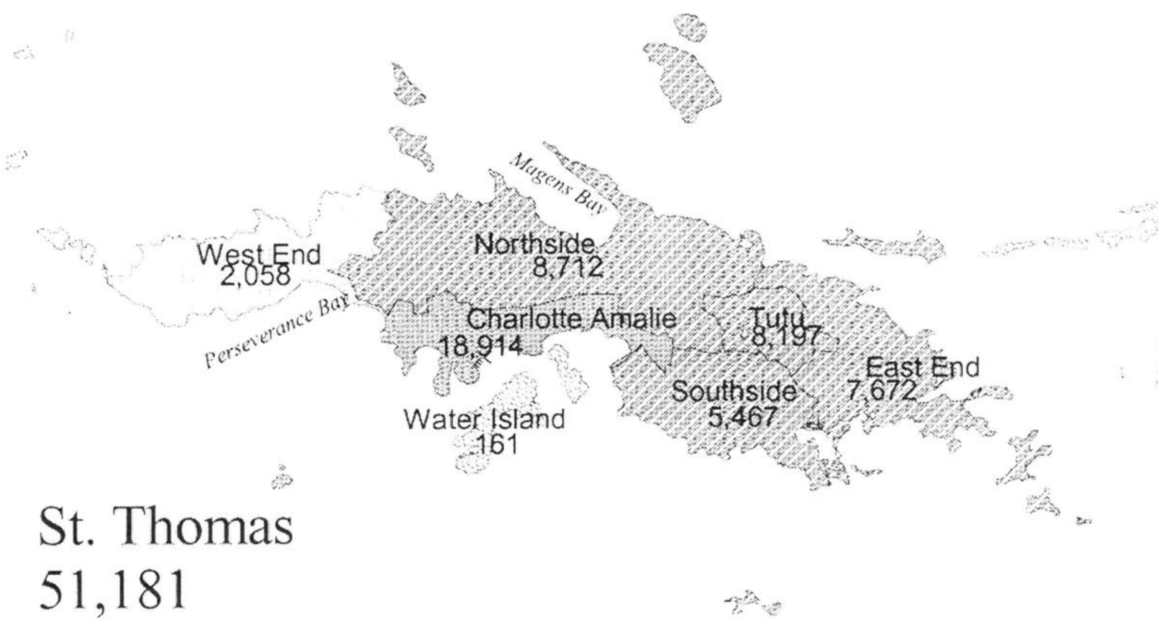

Figure 5.1
Key Map for subdistricts
(Source: US Census Bureau, 2002)

Table 5.1

Population, source of water, sewage disposal and percentage of water purchased from vendor by subdistrict for St. Thomas

(*) 161 persons living in Water Island were not considered as part of St. Thomas total population)

(Datum taken from the US Census Bureau, 2002)

	1 Charlotte Amalie Sub district	2 East End Sub district	3 North side Sub district	4 South side Sub district	5 Tutu Sub district	6 West End Sub district	Total for St. Thomas (*)
Total Population	18.914	7.672	8.712	5.467	8.197	2.058	51.020
Source of Water (% of housing units)							
Public System only	44	17	6	24	18	2	25
Public System and Cistern	36	7	8	13	15	4	20
Cistern, tanks, drums only	20	73	85	62	66	93	54
Other means	1	3	1	1	1	1	1
Sewage disposal (% of housing units)							
Public Sewer	90	29	19	48	80	20	60
Septic tank or cesspool	7	66	76	50	17	75	36
Other means	3	5	5	2	3	5	4
Water purchased from water vendor (% housing units at least once in year)							
Purchased	30	42	32	38	31	32	33
Not purchased	70	58	68	62	69	68	67

As shown in Table 5.1 the allocation of public system (desalinated water) does not cover more than the most populated areas, leaving the rest of the population with no other option than RWC. Of the permanent residents only forty five percent have access to public potable water (desalinated water), while sixty percent of the population has access to public sewer system. In an island of these geographic and topographic characteristics it is far more costly to develop and maintain a sewer system than to develop and maintain a water supply system, taking into account that desalination plants already exist and are in operation. Despite this fact and because of economic considerations, WAPA is not planning to extend its distribution throughout the island. On the other hand, DPW is working on extending the sewer system.

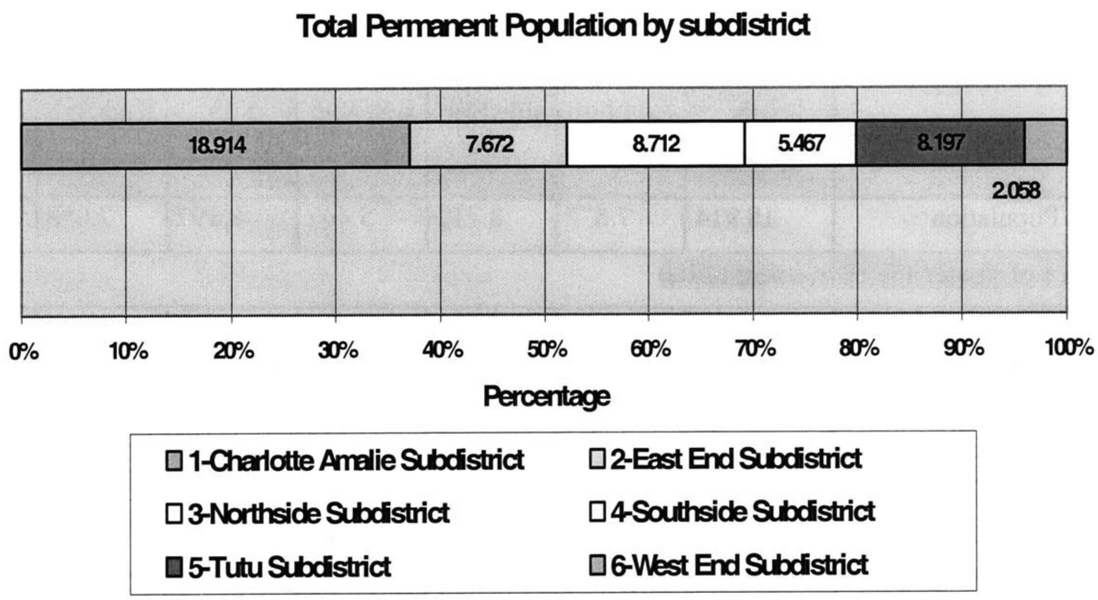

Figure 5.2
Total permanent population by subdistrict
(Data taken from the US Census Bureau, 2002)

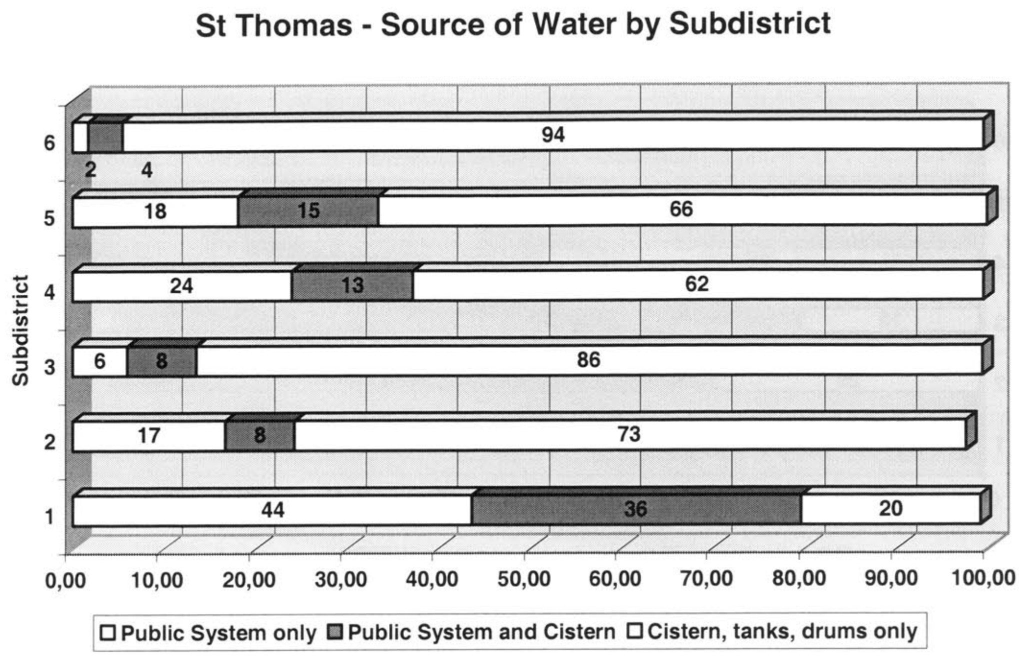

Figure 5.3
St. Thomas - Source of water by subdistrict
(Data taken from the US Census Bureau, 2002)
Note : subdistrict key is in Figure 4.1

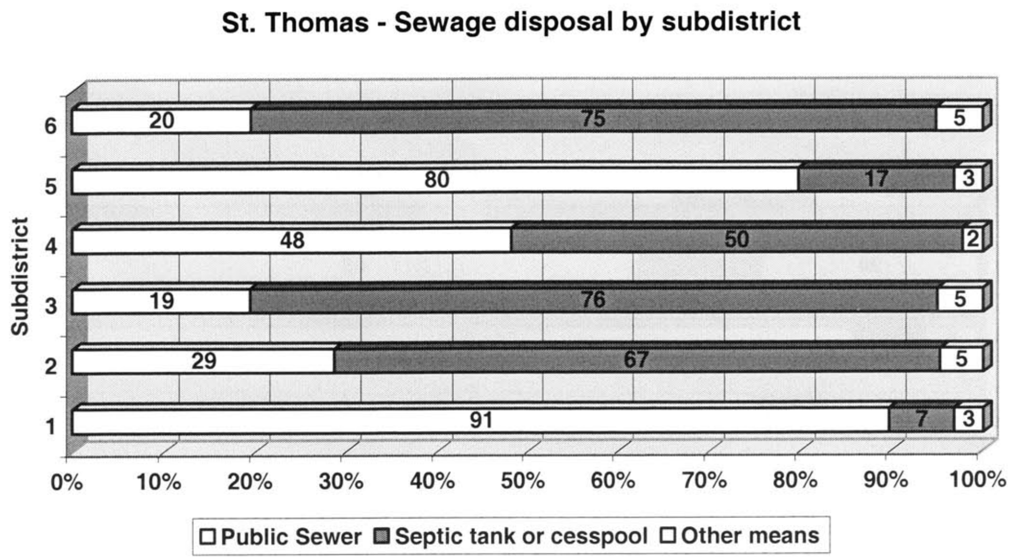

Figure 5.4
St. Thomas - Sewage disposal by subdistrict
(Data taken from the US Census Bureau, 2002)
Note : subdistrict key is in Figure 4.1

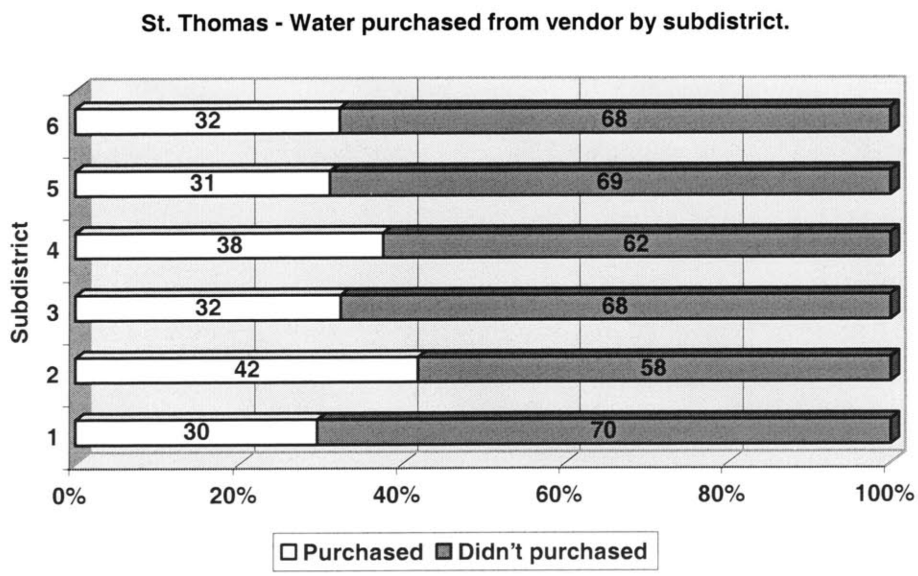

Figure 5.5
St. Thomas - Water purchased from vendor by subdistrict.
(Data taken from the US Census Bureau, 2002)
Note : subdistrict key is in Figure 4.1

5.2. Available water supply

5.2.1. Definition of household types

Given the relative importance of residential use in the water resources management in the island, a classification of households is proposed for this analysis. The different types are defined according to the household available water supply as has been discussed in the previous subsections.

- **Household Type A:** Household that is supplied only from the WAPA public main
- **Household Type B:** Household that is supplied by a combination of public system and RWC.
- **Household Type C**: Household that is only self-supplied by means of RWC.

5.2.2. Catchments of rainwater with cistern storage (RWC)

Determining a proper and representative estimate of the total available water supply is not an easy task, mainly because of lack of datum.

GIS or aerial/satellite photograph analysis can give us an exact estimate of rainwater rooftop surface available area for catchments. By measuring the total available roof area of the different buildings that by US Virgin Islands law are required to have rooftop catchments with cistern storage (according to table 5.2), we can come to a good estimate of RWC. The difficult part of the calculations would be to incorporate in the RWC available supply rainfall patterns. Such calculations should be made using stochastic analysis.

Table 5.2 contains the standard of the USVI building code that sets the requirements for the mandated cistern size of a household. Actually, the application of this code grants exemptions to households that are supplied from WAPA's public system.

Table 5.2
RWC (rainwater catchments in household)
required by the USVI building code for household types B and C

Type of Structure	Required cistern size (gal per square foot of roof area)
Single story dwelling	10.00 g/ft^2 (407.85 l/m^2)
Multistory dwelling	15.00 g/ft^2 (611.77 l/m^2)
Churches and warehouses	4.5 g/ft^2 (122.00 l/m^2)
Other buildings	Exempted

For the purpose of this thesis, the RWC supply has been estimated according to the housing units surveyed by the US Bureau of the Census (2002). This estimate will leave out commercial and other sites that are not included in household type of construction.

Total occupied housing units 19,458.
Median rooms= 3.9 r
Estimated surface per room = 12 m^2
Annual rainfall average for St. Thomas = 102 cm

Total area of potential catchments:

$$A_{RWC} = 19{,}458 \times 3.9\ r \times 12\ m^2 = 910{,}634\ m^2$$

Assuming that all the houses are single unit dwellings, a potential rough total available cistern capacity for households can be calculated as:

$$S_{RWC} = 910{,}634\ m^2 \times 0.407\ m^3/m^2 = 371{,}402\ m^3 = 371.4\ ML$$

This number should be the ideal total capacity if all household units comply with local regulations. An average daily available supply can be calculated from this capacity.

The method chosen involves calculating the yearly capacity according to the average monthly rainfall for St. Thomas. According to Ruskin (1996), the following formula can be applied to the Virgin Islands in order to determine the size of the cistern. Using this formula, we can have another rough number of the storage capacity potential of the RWC for households

$$Cw = 0.01 \times RA \times CA \times RE$$

Cw = water harvested in m^3

RA = rainfall input in cm

CA = catchments area in m^2

RE = runoff efficiency depending on the roof averaged at 0.85

$$Cw = 0.01 \times 102\ cm \times 910{,}634\ m^2 \times 0.85 = 785{,}519\ m^3 = 0.786\ ML$$

This calculation yields a figure that is 113 percent of the government mandatory requirements for cistern capacity.

For a simple household unit of 78 m^2, the total cistern needed will be

$$Cw = 0.01 \times 102\ cm \times 78\ m^2 \times 0.85 = 67.62\ m^3 = 67{,}626\ L$$

But according to the building code the total required cistern for this household will be (using table 5.2):

$$Cw = 407.85\ L/m^2 \times 78\ m^2 = 31{,}812.3\ L = 31.8\ m^3$$

Due to the high contribution of the cistern to the overall cost of a house, in places that are served by the public system, like Charlotte Amalie, the 1995 building code admitted a reduction on the cistern capacity. Besides that, enforcement of the building code has not very strict during the past decade.

Ideally, this figure will be the total volume of water that households will have yearly. Because of the uneven rainfall distribution pattern through the year as well as between years this particular figure is subject to uncertainty and it can be predicted stochastically and calculated on a monthly basis.

According to the data available, and having the number of inhabitants that lack public water supply system, we can calculate the available supply for Household Type C. Also the assumption that Household Type B will be using RWC for satisfying 70% of its needs is made. One last assumption to be made is that the actual household distribution corresponds to the population distribution.

Calculating the supply needed for Household Type C (54% of the population according to table 5.1) and the partial supply for Household Type B (20% of the population according to table 5.1), the total combined supply needed for these types of households, considering a demand of 190 lpcd will be of:

$$\mathbf{S_{RWC}} = 51{,}181\ c \times (0.54+0.20 \times 0.7) \times 190\ lpcd = 6{,}612{,}585\ lpd = 6.61\ MLD$$

This quantity can be met in regular years. For regular years, it is meant years in which no prolonged droughts occur.

5.2.3. Saltwater conversion (desalination)

5.2.3.1. Distillation of sea water supply (SWS)

According to the OIA (1999)

$$S_{SWS} = 13{,}240{,}000 \text{ lpd } (3{,}498{,}018 \text{ gpd}).$$

This value represents the theoretical limit of supply from WAPA under maximum capacity.

Household Type A includes also a low-income population that lives in government housing. According to data of the Virgin Islands Housing Authority (VIHA–a government owned company), in 1979 18% of the population lived in "projects" or community houses that where projected, constructed, financed and rented to low-income population by the government. Regarding water supply, these types of complexes are supplied from one metered connection to the public main. Then, internally the distribution is made into each unit. The particularity is that these types of users are "free-riders" of the public water system because WAPA sells water to the government and the government in turn does not meter internal consumption in each unit. In fact VIHA absorbs (subsidizes) the difference between the real water used and the proportion of the flat rent that the tenant is paying that pays the water bill. Today we can estimate that almost 9,000 people live in this type of housing units in St. Thomas. The public sector is by far the largest property owner in the island as well as the largest client for WAPA, although it is not the best client. Another consideration for water operation is that government in the past years and due to its high fiscal debt with the federal government (one billion dollars as of 1999) has not been honoring its debts with suppliers (like WAPA) on a regular basis.

A review of WAPA's Balance Sheets, from the unaudited five-year summary of operations (June 30, 1995 to June 30, 1999) under the concept of water sales is included as Tables 5.3 and 5.4.

Table 5.3
Annual WAPA Water Sales for St. Thomas in ML
Note: Information totals the three islands water supply.
Around 50 % corresponds to St. Thomas.

Water sales (ML)	1999	1998	1997	1996	1995
Residential	995,686	987,635	1,069,751	1,000,251	996,110
Commercial	1,612,607	1,713,326	1,860,301	1,327,324	1,442,093
Government	2,801,699	2,789,571	2,711,188	2,707,195	2,750,912
Other government	21,892	17,805	21,961	26,033	6,154
Standpipe	260,571	254,905	214,958	264,746	390,673
Total	5,692,455	5,763,242	5,878,158	5,325,548	5,585,941

Table 5.49-
Annual WAPA Water Sales for US Virgin Islands in MGal
Note: Information totals the three islands water supply.
Around 50 % corresponds to St. Thomas.

Water sales (MG)	1999	1998	1997	1996	1995
Residential	263,061	260,934	282,629	264,267	263,173
Commercial	426,052	452,662	491,493	350,680	381,002
Government	740,211	737,007	716,298	715,243	726,793
Other government	5,784	4,704	5,802	6,878	1,626
Standpipe	68,843	67,346	56,792	69,946	103,216
Total	1,503,951	1,522,653	1,553,014	1,407,014	1,475,810

It is to be noticed that in a water-constrained environment, 18% of the population that lives in public housing are not paying for the water they consume. This considerable fraction of the population is not developing a habit of water conservation practices. This behavior is subsidized by the government and has a clear irrationality from the point of view of water conservation principles.

Another crucial issue in understanding the water distribution pattern in the islands is the remarkable economic cross-subsidies that are embedded in the system. From tables 5.3 and 5.4 it can be appreciated as it was mentioned that government is the main client for WAPA.

Regarding water distribution for the island of St Thomas, it is not in WAPA's plans to expand the system to the areas with no service. WAPA's efforts are limited to maintaining and operating the existing system. The reason WAPA will not be expanding the distribution is because it is not a cost-effective supply (based on information collected through interviews with WAPA personnel).

5.2.3.2.Reverse osmosis supply (SWRO)

We must consider the installed capacity of SWRO in the resorts that are scattered throughout the coastal areas of the island, some of them having at least low season surplus of water, as they have generally designed their plants as either main or complementary to their peak occupation demand. The approximate number of resorts that are currently operating R/O plants is 30 for St. Thomas Island. The estimate for this water supply has been taken from the discharge permits of the resorts (DPNR, 2003).

The estimate will be of 150 lpcd (40 gpcd) by each bed available. It is also assumed that these resorts operate 2200 beds (more than half of the available tourist beds that are of approximately 3800).

$$S_{RO}' = 2200 \text{ c} \times 151 \text{ lpcd} = 332{,}200 \text{ lpd } (87{,}768 \text{ gpd})$$

The actual production ranges of these R/O plants go from 5000 gpd to the maximum permitted by DPNR (as of brackish water intake) of 20,000 gpd. Therefore, another way to calculate this figure will be:

$$S_{RO} = 30 \text{ c} \times 47{,}312 \text{ lpd} = 1{,}419{,}375 \text{ lpd } (375{,}000 \text{ gpd}).$$

This supply is private and is intended for internal use of the plant owner. In a scenario of water market practices, it is possible for some of these operators to be enticed by the possibility of allocating their surplus production at a convenient price to other users.

5.2.4. Groundwater supplies

The use of groundwater in St. Thomas is limited due to actual contamination as well as because of the aquifers' special geologic characteristics. Although fresh water wells are rarely used in St. Thomas today, they are an excellent source of brackish water with less salinity than sea water, requiring a less costly desalinization process than sea water. It can also replace actual non-drinking water uses that are being met with potable water that could be allocated into a more productive or crucial use.

DPNR is limiting the total water to be extracted from a well to 20,000 gpd. Assuming that the quantity of active wells in St. Thomas can be estimated as around 20 wells, groundwater could supply:

$$S_{GW} = 20 \text{ w} \times 75{,}700 \text{ lpwd} = 1{,}514{,}000 \text{ lpd } (400{,}000 \text{ gpd}).$$

Groundwater in the island cannot be considered a safe source of freshwater for direct human consumption, unless water quality control is monitored and assured, although some of the water vendors extract and purify this water.

5.2.5. Hauled water

Whenever Households Type C, resorts and stores run out of cistern water, the last resource for their water need is trucked water. Today around twenty different private water suppliers and water haulers operate in St. Thomas. They truck water from the WAPA standpipe at the plant at Krum Bay to the cistern that needs to be filled. This supply does not generate water, it is only an expensive allocation mechanism for what WAPA and rainwater cannot cover. Some of these water haulers also operate their service based in selling water extracted from wells. These particular suppliers also need to treat the groundwater extracted in their own facilities (usually R/O).

5.2.6. Total available water supply

Just for comparing the figures calculated for demand and the available supply, it is useful to analyze a rough supply number. As RWC available supply is a difficult number to grasp, interpolation should be made for this supply as a low figure from the actual demand that is being satisfied without buying "external" water in each household.

$$\mathbf{S = S_{RWC} + S_{SWS} + S_{RO} + S_{GW}}$$

$$S = 6{,}589{,}733 \text{ lpd} + 13{,}240{,}000 \text{ lpd} + 1{,}419{,}375 \text{ lpd} + 1{,}514{,}000 \text{ lpd}$$

$$S = 22{,}763{,}108 \text{ lpd } (6{,}014{,}031 \text{ gpd})$$

Table 5.5
Summary of water estimated supply for St. Thomas.

Water Supply	lpd	gpd
Rainwater	6,589,733	1,741,013
Desalinated	13,240,000	3,498,018
Estimated R/O	1,419,375	375,000
Groundwater	1,514,000	400,000
Total	22,763,108	601,4031

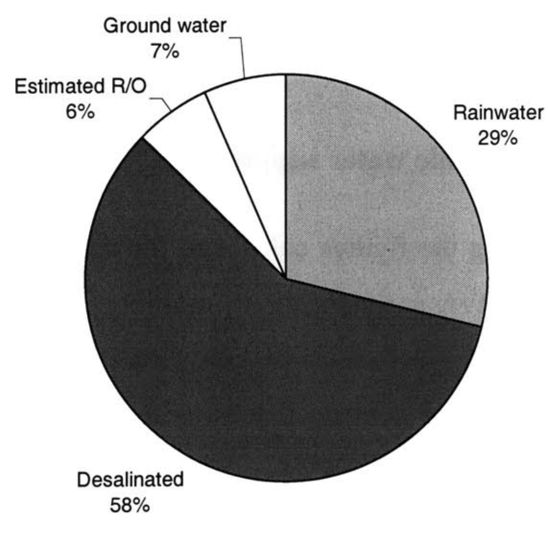

Figure 5.6
Summary of estimated water supply for St Thomas.
Percentage by source.

5.3. Analysis of the three different types of household in relation to water supply

5.3.1. Type A (HA):

A Type A Household is one that is supplied only from a public main (desalinated water from WAPA). WAPA charges a lower price for the first 3.785 m^3 consumed each month, and from then bills a surcharge of twelve percent as a penalty for excessive consumption. (See Section 6.2.)

The supply curve for this type will be as follows:

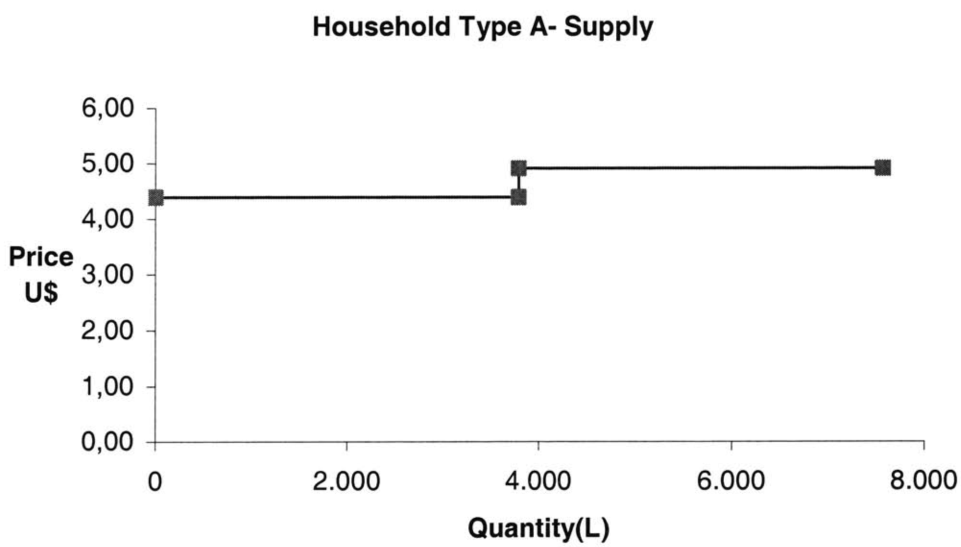

Figure 5.7
Supply curve for Household Type A
(Data from interviews with stakeholders and cited bibliography)

5.3.2. Type B (HB):

The Type B Household is one that is supplied by a combination of public system and RWC. First RWC is consumed and then water from the public main is used. In addition, a combined use can be presented depending on the strategy of each household.

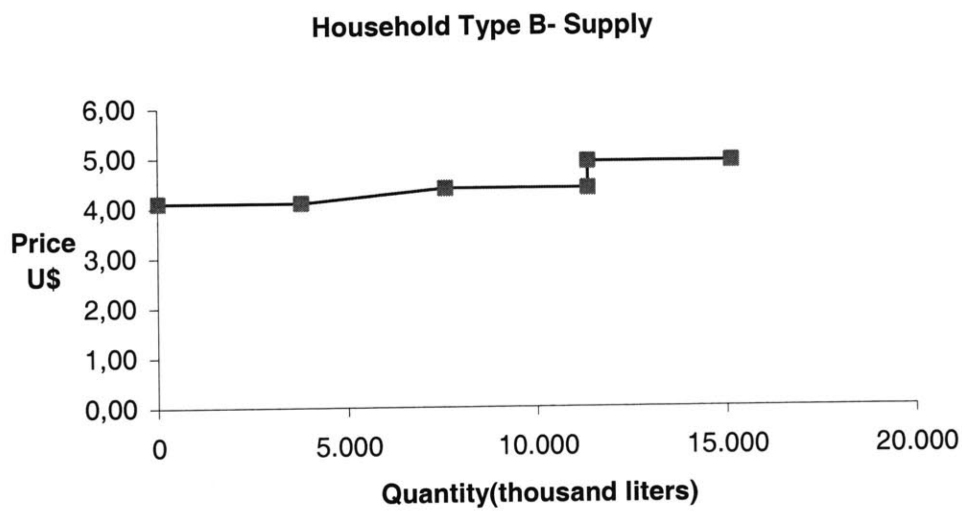

Figure 5.8
Supply curve for Household Type B
(Data from interviews with stakeholders and cited bibliography)

5.3.3. Type C (HC):

The Type C Household is one that is only self-supplied by means of RWC. After RWC water is finished, water should be hauled to fill the cistern (water hauled/trucking).

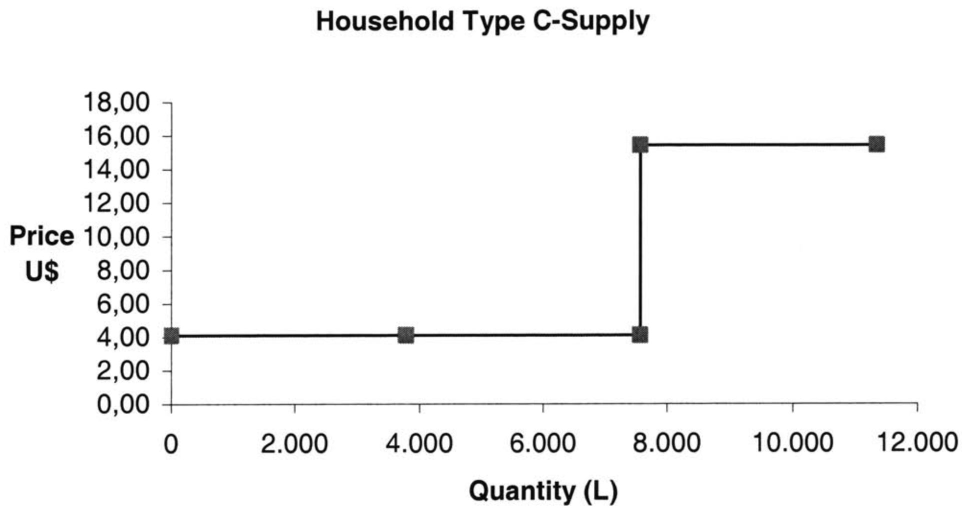

Figure 5.9
Supply curve for Household Type C
(Data from interviews with stakeholders and cited bibliography)

6. Water Demand

Water is allocated only for residential household and community uses (schools, hospitals, government), resorts and commercial demand. Water demands for irrigated agriculture and for industry are negligible in the island. Water demand can be classified and calculated as follows:

6.1. Household Demand

Not every household has the same access and possibilities of being supplied with the type of water they could demand. The difficulty to estimate a demand curve for a supplier lies in the rooted tradition of RWC in every household. Demand will be analyzed incorporating the demand of the population served by rainwater. The most important aspect of rainwater demand lies in that it is the means of supply for 74% of the population. We have three different types of households from the point of supply, and the available supply conditions the demand of each one.

- **Type A (HA):** Household that is supplied only from a public main (desalinated water from WAPA)
- **Type B (HB):** Household that is supplied by a combination of public system and RWC.
- **Type C (HC):** Household that is only self-supplied by means of RWC.

Local estimates of the average water demand on the island range from 110 to 230 lpcd (30 to 60 gpcd) (Peebles, 1979). Actual demand calculations based on the last census held in 2000 will take into account 190 lpcd (50 gpcd).

$$\mathbf{D_R} = 190 \text{ lpcd} \times 51{,}181 \text{ c} = 9{,}724{,}390 \text{ lpd } (2{,}569{,}122 \text{ gpd})$$

6.2. Tourism Peak Demand

Regarding the composition of the visitors' inflow, it must be noted that for St. Thomas approximately two thirds of them came by sea cruise and the rest by air. Sea cruise tourists have the particularity of having shorter stays and living mainly in their cruise ship environment. It is difficult to assign a number on their impact over water supply and wastewater generation. However, it can be assumed that the length of their stay is of one day and it can be assigned a consumption of 57 lpcd (15 gpcd) (Peebles, 1979).

The rest of the island visitors come by air and they account for the majority of tourism revenues. According to the latest available figures for tourism for the year 1997, the total visitors to the three islands were 2,100,000, and accounted for more than 60% of the US Virgin Islands gross domestic product. Breaking up this number, 24% of the tourists (505,880) had night stayovers and the remaining 76% (1,619,000) had one-day visits from cruises and yachts (mainly harbored in Charlotte Amalie, St. Thomas).

As was mentioned in Chapter 4, the peak population of this is estimated by some authors to be around 130,000 persons (Donahue and Johnston, 1998). According to this figure, and subtracting the actual total population, it can be considered at a peak day the presence of around 80,000 tourists in the islands, assuming that a portion of them will be staying overnight in the island and the rest will be just for the day, as it has been discussed in the introduction:

$$\mathbf{D_T} = 80{,}000 \text{ c } \times (0.24 \times 400 \text{ lpcd} + 0.76 \times 55 \text{ lpcd}) = 11{,}024{,}000 \text{ lpd } (2{,}912{,}549 \text{ gpd})$$

It is better to estimate peak demand on total visitors present in the island because by considering only hotel rooms declared will keep out of demand calculations visitors that will stay in unoccupied households and other means not accounted for in hotel room counts, which will yield a significantly lower demand.

If the estimation for tourist demand should be made considering the stayovers as only linked with the total rooms available, as it has been made in the Water Plan of 1979, a lower figure will result. The actual figure for tourist accommodations in the island of St. Thomas is of approximately 5,250 available rooms for visitors (Hotel Guide Express, 2003).

If we consider full occupation as 2.6 people per room, in high season, and a consumption of 757 lpcd (200 gpcd):

$$\mathbf{D_T}' = 5{,}250 \text{ r} \times 2.6 \text{ c/r} \times 757 \text{ lpcd} = 10{,}333{,}050 \text{ lpd } (2{,}730{,}000 \text{ gpd}).$$

The main point on considering D_T over D_T' for the demand estimation, is that D_T is more representative of tourist presence in the island, because not every tourist or visitor will be lodged at a hotel room, there are some visitors that will be staying in condominiums, time-shared apartments, private homes, etc.

6.3. School Demands

The school enrollment (population 3 years and over enrolled in school) in 2002 was 14,346, with an estimated average lpcd consumption of 57 lpcd (15 gpcd) (Peebles, 1979). School demand is thus:

$$\mathbf{D_S} = 57 \text{ lpcd} \times 14{,}346 \text{ c} = 817{,}722 \text{ lpd } (216{,}043 \text{ gpd})$$

6.4. Workforce Demand

The employed civilian population 16 years and over is 24,181 (US Bureau of the Census, 2002) with an average lpcd consumption of 38 lpcd (10 gpcd) (Peebles, 1979). Workforce demand is thus:

$$\mathbf{D_W} = 38 \text{ lpcd} \times 24{,}181 \text{ c} = 918{,}878 \text{ lpd } (242{,}768 \text{ gpd})$$

6.5. Hospitals Demands

The count of hospital beds on St. Thomas is 240 with an estimated average lpcd consumption of 757 lpcd (200 gpd) (Peebles, 1979). Hospital demand is thus:

$$D_H = 757 \text{ lpcd} \times 240 \text{ c} = 181{,}680 \text{ lpd } (48{,}000 \text{ gpd})$$

6.6. Irrigation, miscellaneous and other needs (bars, car-wash, Laundromats, etc.)

These demands were included by Peebles in his water plan for the US Virgin Islands (Peebles, 1979) but are impacted by the same proportion as the population growth coefficient (from 44,000 to 51,181, which yields a coefficient of 1.163). The water plan figure was 749,430 lpd (198,000 gpd) (Peebles, 1979). Current estimated demand is thus:

$$D_M = 749{,}430 \text{ lpd} \times 1,163 = 871{,}578 \text{ lpd } (230{,}274 \text{ gpd})$$

6.7. Declared public system unaccounted for water (UAFW leakage and illegal connections)

From an interview with Mr. Glenn Rothgeb, Assistant Director of WAPA, 15% of their water was cited as the actual figure for the UAFW. Taking into consideration the actual production of WAPA as 13,240,000 lpd (3,498,018 gpd)

$$D_U' = 13,240{,}000 \text{ lpd} \times 0.15 = 1{,}986{,}000 \text{ lpd } (524{,}703 \text{ gpd}).$$

This value of D_U seems to be optimistic. More pessimistic figures produced by the OIA for 1998 rose to 45% of UAFW in the public system. It is also obvious the efforts that WAPA made in the past few years for diminishing the UAFW. But it is possible that the actual figure will be higher than 15%. For calculation purposes, 25% of UAFW will be considered. On the visit and tour of the St. Thomas public water system, guided by Mr. Rodriguez Jiminian, I could check that the system is gradually being upgraded and a program of controls on 64 points of quality and pressure will in the near future get the values of UAFW. The standard for UAFW in this type of operation is usually 5% to 10%.

$$\mathbf{D_U} = 13,240{,}000 \text{ lpd} \times 0.25 = 3{,}310{,}000 \text{ lpd } (874{,}505 \text{ gpd}).$$

6.8. Total non-tourist related demand

This demand is considered more stable throughout the year, having smaller ranges of dispersion, but it must be considered that its peak will also be coincident with the tourism water demand peak.

$$\mathbf{D_{NT}}' = \mathbf{D_R+D_S+D_W+D_H+D_M+D_U}' = 9{,}724{,}390 + 817{,}722 + 918{,}878 + 181{,}680 + 871{,}587 + 1{,}986{,}000 = 14{,}500{,}257 \text{ lpd } (3{,}830{,}979 \text{ gpd})$$

Or

$$\mathbf{D_{NT}} = \mathbf{D_R+D_S+D_W+D_H+D_M+D_U} = 9{,}724{,}390 + 817{,}722 + 918{,}878 + 181{,}680 + 871{,}587 + 3{,}310{,}000 = 15{,}824{,}257 \text{ lpd } (4{,}180{,}781 \text{ gpd})$$

6.9. Total Peak demand including tourism demand

Tourism demand is highly seasonal and to calculate its demand, it must be taken into account statistical tourism data. Unfortunately the available data are not updated or are not geographically broken by island. To make a proper model of water demand it should be studied on a monthly basis or at least quarterly. One important issue to take into consideration is that the period of peak demand occurs in the dry season period. Therefore, it is of great importance the strategy of water reservoir that can be applied to the system year round. Reservoir in this particular case should be understood to be referring only to cisterns, either public, or private. No major reservoir or impoundment is meant (with the sole exception of salt ponds that can be last resource reservoir of saline or brackish water).

$$\mathbf{D' = D_{NT}' + D_T =}$$

$\mathbf{D'}$ =14,500,257 lpd + 12,128,000 lpd = 27,137,647 lpd (7,169,788 gpd)

Or

$$\mathbf{D = D_{NT} + D_T =}$$

$\mathbf{D}$ =15,824,257 lpd + 12,128,000 lpd = 27,952,257 lpd (7,385,008 gpd)

To check this estimation its value should be compared to the peak available WAPA demand of 13.24 MLD (4.498 MGD, which will cover for 47.4% of **D**), a figure that is consistent with the available census datum.

Table 6.1

Summary of water estimated demand for St. Thomas.

Units in liters

Water Use	Water Demand LPCD	Population Considered	Demand lpd	Total Demand l per day
Residential	190	51.181	9.724.390	
School	57	14.346	817.722	
Workforce	38	24.181	918.878	
Hospitals	757	240	181.680	
Miscellaneous (irrigation, other intensive)			871.587	
UAFW			3.310.000	
TOTAL LOCAL DEMAND				**15.824.257**
Tourism Peak stayovers	400	19.200	7.680.000	
Tourism Peak for the day	55	60.800	3.344.000	
TOTAL TOURISM RELATED DEMAND	At peak			**11.024.000**
TOTAL DEMAND				**26.848.257**

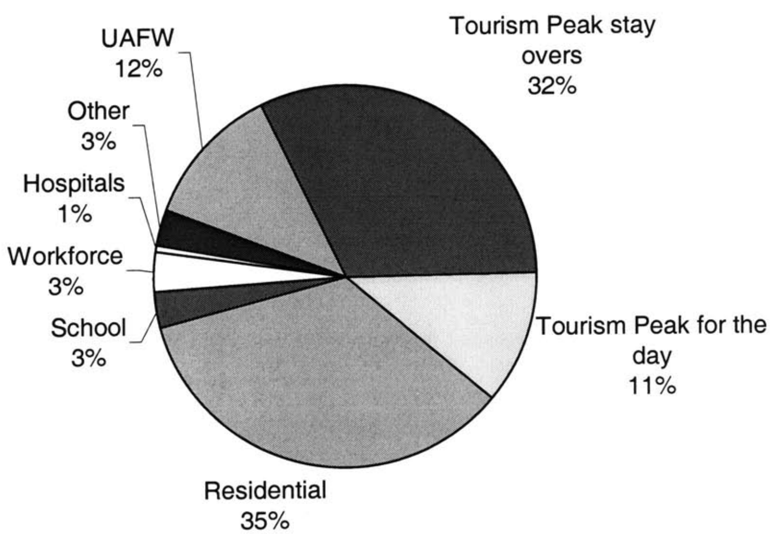

Figure 6.1

Water use from all sources of supply,

Total peak demand including tourism demand

7. Supply and Demand

7.1. Estimated Available Supply vs. Peak Demand

According to the calculations that have been made in the last two chapters, it is to be noticed that supply (S) and demand (D) are related as follows:

S = 22,763,108 lpd (6,014,031 gpd)

D = 27,952,257 lpd (7,385,008 gpd)

D-S = 5,189,149 lpd (1,370,977 gpd)

This value, D-S, represents the theoretical deficit in available supply during peak demand.

7.2. Estimated Available Supply vs. Local Demand

This can be representative of the low season in the island:

S = 22,763,108 lpd (6,014,031 gpd)

$\mathbf{D_{NT}}$ = 15,824,257 lpd (4,180,781 gpd)

$\mathbf{S - D_{NT}}$ = 6,938,851 lpd (1,833,250 gpd)

This value represents the theoretical available base local supply surplus in tourism low season.

It is clear from this summary that in order to provide for the local water demand and continue successful operations of the fundamental tourism industry at the same time, freshwater augmentation is a major concern.

8. Evaluation of alternative and feasible supply options that can augment the actual water resources

Based on the classification identified in the "Source Book of Alternative Technologies for Freshwater Augmentation" (UNEP, 1998), an analysis of chosen applicable technologies for St. Thomas will be enumerated. The main objective of this section is to discuss the alternative available technologies taking as a base the experience of typical high volcanic islands with similar characteristics as St. Thomas. The purpose of this evaluation is to provide an inventory that can be taken into account by the different actors to make informed choices in maximizing the resources of the island.

In this classification there are a subset of four groups of technologies that can be applied:

- Freshwater augmentation
    - RWC (rain water catchments)
    - Wells
    - Water importation
    - Submarine piping
- Water quality improvement
    - Desalination
        - Desalination by distillation
        - Desalination by reverse osmosis
- Wastewater treatment technologies and reuse
    - Wastewater reuse
    - Alternative dry sanitation
- Water conservation
    - Water resources planning and management in an integrated way.
    - Water conservation and protection measures

Table 8.1
Technologies for freshwater augmentation
St. Thomas summary

Technology Group	Technology	Actual Use	Past Use/ Phased out	For evaluation or improvement
Specific freshwater augmentation	RWC	Yes		Yes
	Wells	Yes		Yes
	Importation		Yes	Yes
	Submarine piping			Yes
Water quality improvement technologies	Desalination by distillation	Yes		Yes
	Desalination by reverse osmosis	Yes		Yes
Wastewater treatment technologies and reuse	Wastewater reuse			Yes
	Alternative dry sanitation			Yes
Water conservation	Water conservation and protection measures	Yes		Yes

Some of the technologies enumerated in table 8.1 have been applied in the past in the USVI, the rest of them should be considered as part of an evaluation of the overall water resources strategies to be discussed between the actors of this particular market.

A more extensive coverage will be given to freshwater augmentation technologies and water quality improvement technologies in the rest of the section. Water reuse and conservation should be analyzed in a broader specific analysis that exceeds the extension of this thesis effort. Nonetheless wastewater reuse and conservation are complementary measures that should be carefully considered by water planners in the St. Thomas market.

8.1. Specific Freshwater Augmentation Technologies

8.1.1. Rainwater Harvesting (RWC)

Extent of Use RWC is currently extensively applied in the island.

Operation and Maintenance Due to the simplicity of this technology, operation is not a concern. If the materials and the installation of these systems are carefully selected, and regular maintenance is practiced, this system can be of great use. The main concern is water quality.

Level of Involvement It is important to notice that the USVI experience in the matter is one of the most successful in the area. The main cause of the success of this system lies in the government regulatory participation since rainwater harvesting has been regulated in design for households. This successful policy should be sustained and enforced. RWC should still be enforced by law for all households.

Costs and prices The appropriate way of calculating the cost of RWC has been discussed in several local researches. Ruskin (1996) estimates that the cost of the RWC system consisting of the roof, the gutters, the rainwater pipes and the cistern costs from 25.5 to 39% of the cost of a house. The estimated cost by considering the monthly mortgage payment for an average house in St. Thomas gives the result according to the cited author of $5.28/month/1000 L ($20/month/1000 gal) also an estimation on its further maintenance is mentioned. Another publication (UNEP, 1997) gives a cost of $2-5/month/1000 L ($7.57-18.95/month/1000 gal) of water for

RWC. The real value will depend on different characteristics of each house. As the materials used for the different components, water consumed that will repay the construction investment before or after a certain period, water use habits and rainfall patterns.

Suitability This option is most suitable for islands where precipitation presents an even distribution year round, which as seen in previous sections is not the St. Thomas case.

Advantages This option represents a readily available source of water at the point of use. As it depends on household operation, this option does not involve public operation and management. It is an acceptable supplemental source.

Disadvantages This technology is climate dependant.. There is a high risk of contamination of water, mainly in the catchments area. Drought management in the case of St. Thomas is usually required in a household basis.

Further development of the technology Improvement of this well established technology at the household level should be routinely targeted by continuous education at the public level. This would be a joint task for the DPNR and the Department of Public Health (SIWIN, 1996).

8.1.2. Groundwater extraction (wells)

Extent of Use This option is extensively applied in the island but in decrease due to water quality considerations.

Effectiveness of the technology It must be noted that the USGS has made a groundwater assessment in the island on 1962 (USGS, 1962). As a result of that study a total amount of 396,300 lpd (1,500,000 gpd) was determined as available if the groundwater extraction can be maximized. This can be achieved after solving the serious contamination of the ground that is registered today in the island. A good example of this fact is the contamination in the most productive aquifer in the island, the Tutu wellfield. Reports produced by the DPNR from 1987 to 1990, indicated the presence of VOC's in the groundwater. Twenty two commercial, residential and public wells were contaminated with compounds such as tetrachloroethylene, benzene, 1,2-dichloroethylene, and trichloroethylene, supposedly since 1983. As a consequence of this several wells were shut and remediation had to be enforced (Donahue and Johnston, 1998).

Suitability In the case of St. Thomas, this source is limited as a reliable supply by both quantity and quality.

Advantages Although the discussed problems of contamination should be addressed and solved, groundwater can still present a significant source of supplemental water resources.

Disadvantages Groundwater utilization requires skilled and site experienced personnel, mainly because of the volcanic nature of the soil.

Further development of the technology Not much can be added to this well established technology. What should be taken into account in the St. Thomas case is the need for maintaining in the long term the actual policy of control of extraction and well head protection. More control over small wells (less than 1893 lpd or 500 gpm) should be implemented. This will make possible at least return to the levels of reliability of part of the baseline available supply for safe groundwater (SIWIN, 1996).

8.1.3. Importation using sea transport commonly referred as "Barging"

Technical Description Water conveyance is seen today as a last resource freshwater augmentation. The vessels or barges should be sized in order to have a capacity that will make transportation cost-efficient.

Extent of Use This alternative was extensively applied in the island in the past. The source from which water was conveyed was mainly Puerto Rico. As a paradox, today WAPA is targeting to increase its sales to the passenger cruises that dock in Charlotte

Amalie. Desalinated water is being exported rather than imported. This does not imply that water is not scarce in the territory, but rather that if WAPA plays by the market rules, as a revenue generating company, it should naturally target such clients whose characteristics are regularity in purchase and timely payment.

Operation and Maintenance Due to its cost, the efficiency in the operation of the barges is crucial. The more important fraction of this cost includes the infrastructures in port of destiny and port of delivery as well as the suitable size of the barge. Usual maintenance includes regular inspection and cleaning of tanks to keep water uncontaminated.

Level of Involvement Because of costs and volumes it is usually a resort of the government to decide on importing water in a particular case.

Costs and prices The cost varies from island to island, in the particular St. Thomas case, the last reported cost for barging water from Puerto Rico was reported as $4.65 per m^3 in 1985 (UNEP, 1998).

Suitability The only limitation is the need of proper infrastructure associated to the water handling during loading and unloading. Sources with adequate water resources at an economically feasible distance should be chosen. In the particular St. Thomas' case the source of conveyed water, in the past was Puerto Rico.

Advantages After hurricanes or severe droughts, it has the ability to provide emergency supplemental water supply.

Disadvantages Weather can have a negative impact on transportation efficiency. In addition, investment in an adequate distribution infrastructure is needed.

Cultural acceptability The wrong but rooted association of water with territorial sovereignty is the principal block for reliance from out of USVI importation (UNEP, 1998).

8.1.4. Submarine Pipelines

Technical Description Pipes are installed underwater to convey water to small and water-scarce islands, mainly from nearby continents or larger islands. It may be done by gravity flow or by pumping, depending on the extension and the layout characteristics.

Extent of Use It is not used today in the island. In the near future a pipe will connect St. Thomas and St. John in the Red Hook zone in the east end of the island. The principal limitation of the system has to do with the costs of engineering and maintenance. The best examples of this technology are in the oil offshore extraction industry. An example of a continuous pipe of 7.4 kilometers and at a depth of 850 m was installed in Ceiba oil field development (Everest Field, Gulf of Niger). The Island of Vieques is supplied with water from Puerto Rico with a submarine pipe built in 1979 (Peebles, 1979). Other cases of islands to which water pipes have been installed is Vetmanna Island in Iceland (14 Km in length, 1968), Seychelles 5 km (was damaged in a storm), Fiji, Hong Kong Island, Shangai, Lantau Island in Hawaii, Penang in Malasya (3.5 km), and Xiamen Island in China (2.3 Km).

Operation and Maintenance Operationally there is not much difference from a regular terrestrial pipeline. The only special requirement is the inspection of the pipeline in particular after storms. The elements that require special design are the anchors blocks that have to be carefully designed to avoid damage by tidal flows and storms.

Level of Involvement Because of the highly specialized engineering requirements for the use of this technology, the stage of feasibility studies should be carefully considered. The most important factors to consider in the design of the system are: the pipeline route, bathymetry (water depth), sea floor conditions and oceanic currents.

Effectiveness of the technology This technology is usually regarded as costly, and only suitable for short distances. Technology for this type of installation has been greatly improved by offshore oil extraction, and can be implemented today with more competitive costs. Continuous flexible pipelines are commercially available in a variety of length. The main experience for this technology should be taken from offshore oil platform installation. It is usual to deal with depths of up to 850 m, and pipes are produced between 2½ inches to 16 inches of internal diameter. The operating pressures of these pipes exceed that needed for this water service (around 5000 psi). Being that the oil refining industry is one of the main activities in St. Croix, technology and expertise for this type of technology would not be an impediment.

Suitability This technology is suitable when the distances between the island and the source of surplus water resources is such that it is economically feasible. In the case of St. Thomas in order to analyze the suitability of this technique, which is often regarded as possible for distances that do not exceed 2 to 5 km, an analysis will be made.

Advantages Once installed, the operational costs are minimal if operated by gravity-fed supply. The possibility of interconnectivity reduces dependence on desalination, and minimizes the environmental impact of the actual desalination production. This alternative can provide St. Thomas with a reliable and abundant alternative source. The costs that should be incurred by St. Thomas could be shared with Isla de Culebras and Isla de Vieques. In addition, Puerto Rico or investors from Puerto Rico, in its possible interest for selling water on a regular basis, can finance part of this project.

Disadvantages Initially the installation costs are high. This type of infrastructure is subject to damages during storms and tidal flows. Marine environmental impact should be carefully considered and evaluated..

Cultural acceptability As has happened with barging in the past, the fact of relying on off-island water source can stir some animosity. However, the fact that all of the vegetables fruits are barged from Puerto Rico is also another way of importing water from that place, and relying on the quality of their irrigation water supply.

Further development of the technology As pipe materials and installation techniques improve, mainly driven by the oil industry, this technology will become more cost effective and reliable.

As an example of the commercially available materials that can be adopted for this type of supply see fig 8.1.

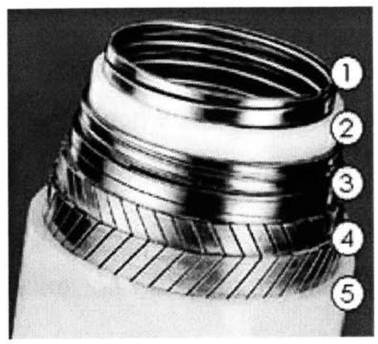

Figure 8.1
Continuous flexible pipeline
Source: NKT Flexibles

This particular pipe is an unbounded composite structure flexible pipe. The different layers are composed of:

1. Carcass: An interlocking structure manufactured from a metallic strip. The carcass prevents collapse of the inner liner and provides mechanical protection
2. Inner liner: An extruded polymer layer providing internal fluid integrity.
3. Pressure armor: A number of structural layers consisting of helically wound C-shaped metallic wires and/or metallic strips that provide resistance to radial loads.
4. Tensile armor: A number of structural layers consisting of helically wound flat metallic wires. The layers are counter wound in pairs. The tensile armor layers provide resistance to axial tension loads.

5. Outer sheath: An extruded polymer layer. The function is to shield the pipe's structural elements from the outer environment and to give mechanical protection.
6. Anti-wear layers (not shown).
   Non-metallic layers are incorporated in order to prevent wear and tear between the structural elements (NKT Flexibles, 2003).

Table 8.2
Approximate distance of underwater pipe lines connecting the islands

Section	Islands connected	Miles	Km
A	Puerto Rico-Isla de Vieques	8,00	12,80
B	Isla de Vieques-Isla de Culebra	9,00	14,40
C	Isla de Culebra -STT 1	1,00	1,60
D	STT 2	9,00	14,40
E	STT 3	2,00	3,20
Total		**29,00**	**46,40**

Pipe Sizing and Pump calculation for longest section STT2

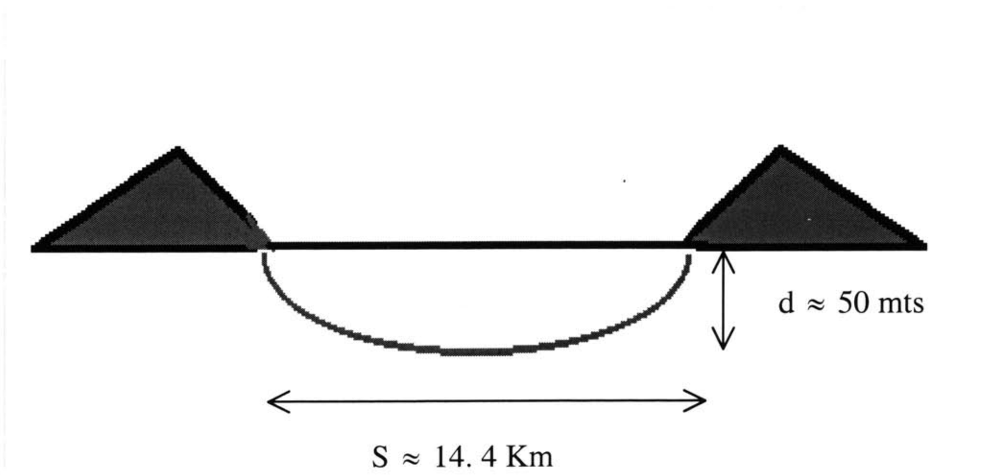

Figure 8.2
Section STT2 scheme

Idealizing the pipe as a catenary its total length can be calculated as :

$$L=\frac{d^2}{54\ S}+S=\frac{(50m)^2}{54\times 14{,}400\ m}+14400\,m\ =14400{,}003m$$

As the d term is negligible the calculations will be made with the values from table 8.1

1)Using the Bernoulli Theorem

$$z_1+\frac{10^5 p_1}{\rho_1 g_n}+\frac{v_1^2}{2g_n}=z_2+\frac{10^5 p_2}{\rho_2 g_n}+\frac{v_2^2}{2g_n}$$

2)As $\rho_1=\rho_2$ and $v_1=v_2$ and $z_1=z_2$

$$\frac{10^5}{\rho_1 g_n}(p_1 - p_2)=h_L$$

3) $$h_L=\frac{22.96KQ^2}{d^4}$$

$$R_e=\frac{dv}{\mu}\rho$$

$$v=\frac{21.22Q}{d^2}$$

$$Power\ needed\ (Kw)=\frac{QH\rho}{6116\times 10^3\times e_p}$$

Where

p = relative pressure
v = average fluid velocity
ρ = fluid (water) density
g = gravity acceleration
h_L = head loss due to fluid flow
K = resistance coefficient
Q = flow
d = interior diameter of the pipe
R_e = Reynolds number
μ = fluid (water) absolute or dynamic viscosity
H = Total head

4) 45° Elbows (assumed 2 un/100mts) to simulate sea bed irregularities

$$K = 16 \times ft \times 280 = 4480 \times ft$$

90° Elbows (assumed 1 un/1000mts) to simulate sea bed irregularities

$$K = 30 \times ft \times 15 = 450 \times ft$$

Check Valves 2

$$K = 100 \times ft \times 2 = 200 \times ft$$

Gate Valves 3

$$K = 8 \times ft \times 280 = 24 \times ft$$

Choosing a 14" (333.3 mm internal diameter) $ft = 0.013$

Where ft = friction factor in the zone of total turbulence

$$Kpipe = \frac{L}{D} \times ft = \frac{14,400}{333.3} \times ft$$

5) $d = 333.3$

$\rho = 998.2$

$\mu = 0.98$

$ft = 0.013$

6) $v = \dfrac{21.22 \times 400}{333.3^2} = 1.91$

$\text{Re} = \dfrac{333.3 \times 1.91 \times 998.2}{.98} = 6.48 \times 10^5$

$f = 0.0145$

7) $K = \dfrac{14400 \times 0.0145 \times 1000}{333.3} = 609$

$Ktot = 609 + (4480 + 450 + 200 + 24) \times 0.013 = 676$

8) $h_L = \dfrac{22.96 \times 696 \times 10,000^2}{333.3^4} = 130m$

9) $H = 130mts$

$$Power\, needed = \frac{10000 \times 130 \times 998.2}{6116 \times 10^3 \times 0.7} = 304\, Kw \approx 395HP$$

(Crane, 1992)

Where f represents the friction factor

Pipe and pump first option:

$$\phi \;=\; 14" = 355.6\,mm$$

Pump

$$H = 150\,m = 15\,bar$$

$$Power = 400\ HP$$

Second Choice: Another choice of pipes that will be recommendable is to have two or more pipes for increased reliability.

$$\phi \;=\; 2\times 10" = 2\times 273\,mm$$

This will result in a difference in pressure drop in the section of

$(0.084 - 0.081)\dfrac{bar}{100m}\times 14,400m$ =0.05 Bar (negligible difference)

Pump

$$H = 150\,m = 15\,bar$$

$$Power = 2\times 153Kw \approx 2\times 205HP = 410\ HP$$

(Crane, 1992)

Third option: The third alternative proposed has to do with reducing costs of installation.

Summary of proposed layout for submarine piping :

Table 8.3
Summary of layout of underwater pipelines and pump stations connecting the islands

Section	Islands connected	Miles	Km	Max Depth m
PS1	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi)			
A	Puerto Rico-Isla de Vieques	8.00	12.80	18.30
	Use existing /projected interconnected island main			
PS21	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi			
B	Isla de Vieques-Isla de Culebra	9.00	14.40	54.00
	Use existing /projected interconnected island main			
C	Isla de Culebra -STT 1	1.00	1.60	
PS3	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi			
D	STT 2	9.00	14.40	54.45
AV	Air Valve			
E	STT 3	2.00	3.20	
Total		**29.00**	**46.40**	

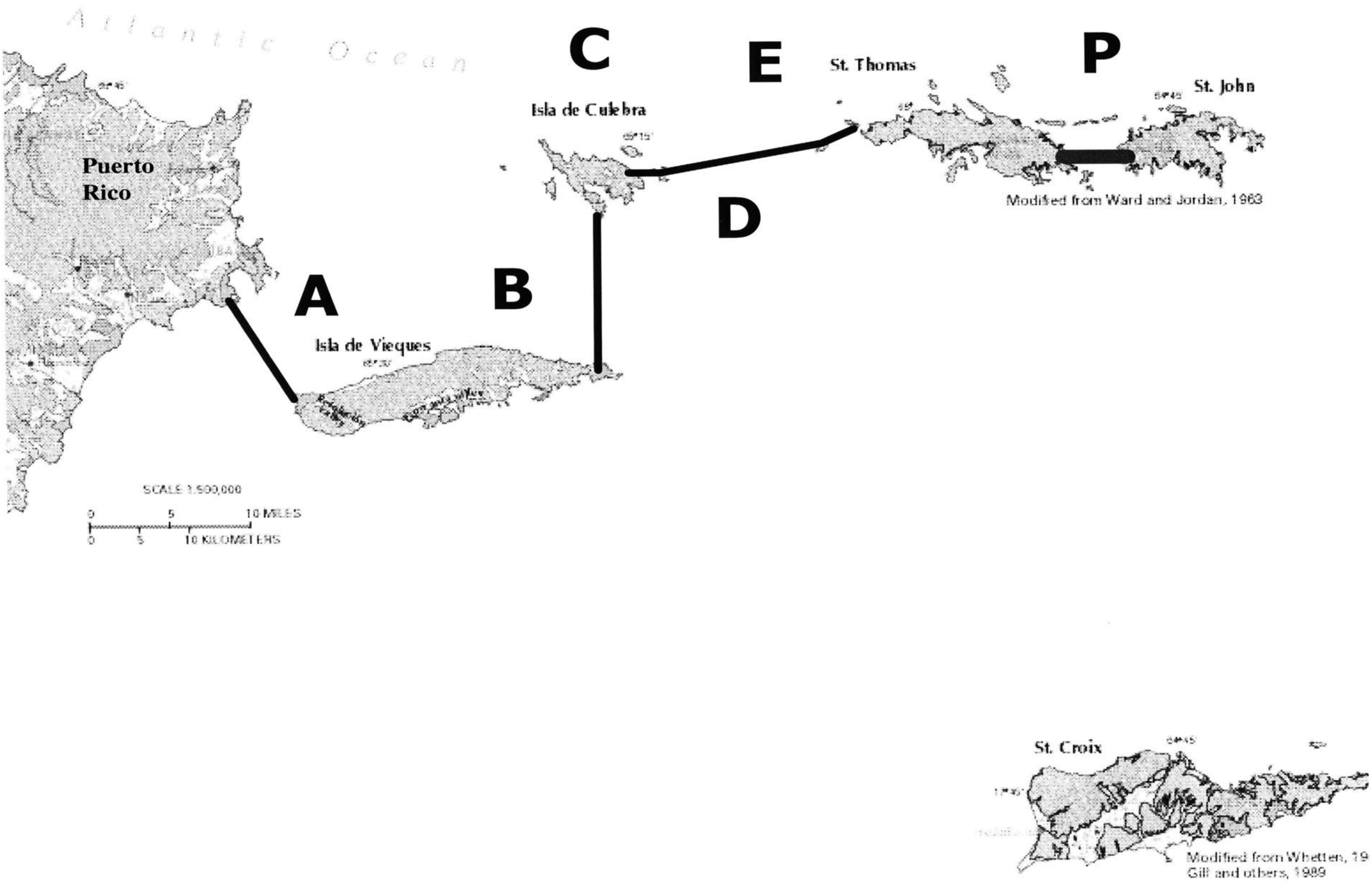

Figure 8.3
Pipeline from Puerto Rico layout

Cost estimation:

Table 8.4
Summary of costs 2x10" pipe

Section	Islands connected	m	Cost/m ($ 2003)	Total ($ 2003)	Pump cost ($2003)
PS1	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi)				200.000,00
A	Puerto Rico-Isla de Vieques(2 pipes of 10")	12800	885	11.328.000,00	
VIE	Use existing /projected interconnected island main				
PS21	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi				200.000,00
B	Isla de Vieques-Isla de Culebra(2 pipes of 10")	14400	885	12.744.000,00	
CUL	Use existing /projected interconnected island main				
C	Isla de Culebra -STT 1 (2 pipes of 10")	1600	885	1.416.000,00	
PS3	2 Pumps 10,000 lpm @ 15 bar(2650 gpm @218 psi				200.000,00
D	STT 2(2 pipes of 10")	14400	885	12.744.000,00	
AV	Air Valve				5.000,00
E	STT 3(2 pipes of 10")	3200	885	2.832.000,00	
Total		**46400**		**41.064.000,00**	**605.000,00**
					41.669.000,00

Table 8.5

Summary of costs 2x8" pipe

Section	Islands connected	m	Cost/m ($ 2003)	Total ($ 2003)	Pump cost ($2003)
PS1	2 Pumps 10,000 lpm @ 40.5 bar(2650 gpm @589 psi)				200.000,00
A	Puerto Rico-Isla de Vieques(2 pipes of 8")	12800	630	8.064.000,00	
INL 1	Use existing /projected interconnected island main				
PS21	2 Pumps 10,000 lpm @ 40.5 bar(2650 gpm @589 psi)				200.000,00
B	Isla de Vieques-Isla de Culebra(2 pipes of 8")	14400	630	9.072.000,00	
INL 2	Use existing /projected interconnected island main				
C	Isla de Culebra -STT 1 (2 pipes of 8")	1600	630	1.008.000,00	
PS3	2 Pumps 10,000 lpm @ 40.5 bar(2650 gpm @589 psi)				200.000,00
D	STT 2(2 pipes of 8")	14400	630	9.072.000,00	
AV	Air Valve				5.000,00
E	STT 3 entering West side (2 pipes of 8")	3200	630	2.016.000,00	
Total		**46400**		**29.232.000,00**	**605.000,00**
					29.837.000,00

The inland pipe on Isla de Vieques and Isla de Culebras has not been considered as part of the cost of this installation. It is the understanding of the author that the new or resized pipe needed to connect the two submarine pipes in each island can be considered and built as part of the main distribution system of these two islands, and for their own usufruct. The first objection that can be made to this point of view has to do with water quality, and risk of contamination. It is also obvious that constant monitoring in the entrances to each of the submarine pipes to each of the islands should be designed, for water quality and salinity.

No system is perfect, there are trade-offs to be analyzed in each of the presented options. The decision does not lie only in the economic issues of the proposed alternative supplies. Cultural, social and regional issues should be taken into account. One favorable point is that the pipelines are connecting two islands that belong to the same country.
The other obvious and easiest pipeline connection between islands is linking by submarine pipe the USVI and The British Virgin Islands (St. John –Tortola). What can flow between these two islands is desalinated water (Reverse Osmosis). The prices that are paid in Tortola are not as different as the prices paid in St. John. The legal aspects will be different in this case, as the water is flowing through a national boundary.
The other aspect to mention is that by the location of St Croix and also due to the depths of the sea bed involved, it is out of reach for these type of technologies.

8.1.5. Water Quality improvement technologies

8.1.5.1.Desalination

Technical Description Desalination is a process for separating the salt contained in saline water, with the objective of producing water that has low content of total dissolved solids (TDS). Under desalination, several different processes are included:

8.1.5.1.1. Desalination by distillation

Technical Description Desalination is based in reproducing the hydrological natural cycle of sea water. Through the vaporization of sea water (by a combined process of heat and pressure differential), this vapor is then condensed to form fresh water. Three types of thermal units have been developed in the market: MSF (Multi Stage Flash), MED (Multiple effect distillation), and Vapor Compression. The units in St. Thomas are a modernized version of the MED type of plants, the HTME (Horizontal type multiple effect).

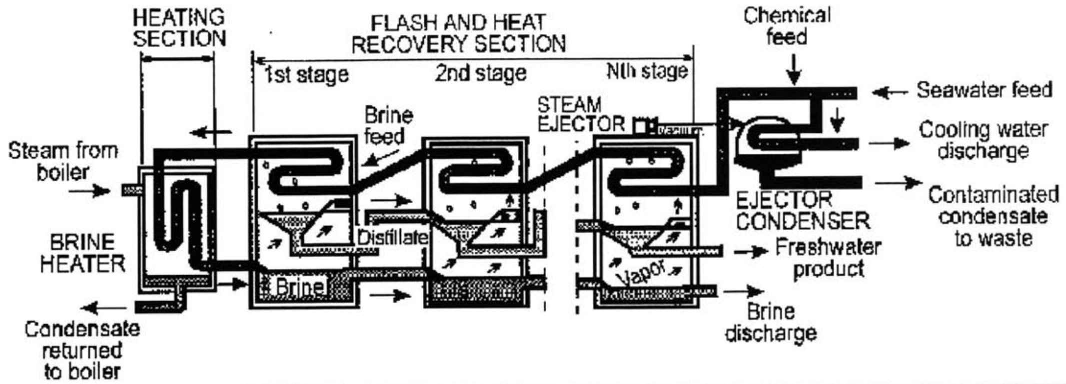

Fig 8.4
Multi Stage Flash (Distillation MSF Process)
Source: (SIWIN, 1996)

Extent of Use Desalination is currently extensively applied in the island as the main public strategy of water supply.

Operation and Maintenance Of the possible types of desalination technologies the actual process applied in St. Thomas is the one that requires larger and complex units. It also makes sense only in the case they are operated in conjunction with electrical generating plants.

Level of Involvement The use of this type of units requires a considerable application of funds for its purchase and its operation and maintenance.

Costs and prices Capital costs of this type of units ranges from $1000 to $2000 per m^3/d (UNEP, 1998). Costs reported by WAPA vary within each island; for St. Thomas WAPA cost for production and distribution ranges from $1.85-2.11/1000 L ($7–8/1000 gal).

WAPA sells water to consumers at the following rates:

- Residential users:

For the first 1000 gal per month: $16.58/1000 gal

After the first 1000 gal per month: $18.58/1000 gal

- For commercial users:

$16.58/1000 gal.

Effectiveness of the technology The measure of the efficiency of this type of technologies is given by the amount of water produced per unit of steam delivered to the plant.

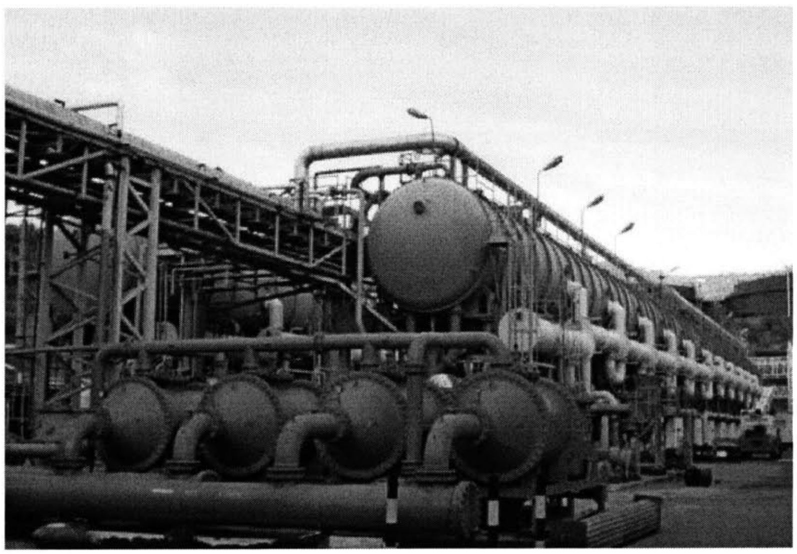

Fig 8.5
Desalination Plant, Krum Bay, St. Thomas

Suitability It has the advantage of being suitable to every climate.

Advantages In the St. Thomas case, distillation is already a well developed and proven technology. Of all the desalting processes it is the one that can operate better with poor quality of feedwater.

Disadvantages It is the most capital intensive of the desalination options. It has high infrastructure, operation and maintenance costs. It is totally dependant on steam generated by an electric plant. The reliance on fossil fuels for its operation, will probably condition the introduction of sources of renewable energies in the St. Thomas energy market.

Environmental impact From the aquatic point of view, discharge of brine is one of local effects. For our analysis we will consider the energy consumption per volume of water as an air pollution indicator.

Further development of the technology Although technological improvement is possible, this technology is mature, and no further advances in the distillation processes are expected in the near future.

8.1.5.2. Desalination by reverse osmosis

Technical Description This system comprises four different processes:

- Pre-treatment of the incoming seawater or brackish water.
- Pressurization of the saline water against the membrane.
- Membrane separation in which dissolved salts are retained and water flows through the membrane.
- Post treatment stabilization

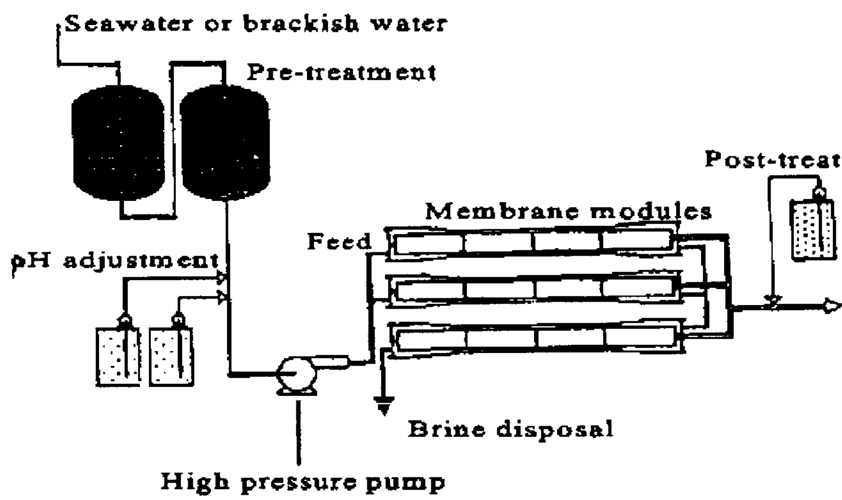

Figure 8.6
Elements of the reverse osmosis desalination process
Source : UNEP, 1997

Extent of Use R/O is currently extensively applied in the island by resorts.

Operation and Maintenance Operation of the units is easier than in distillation. Although the personnel in charge have to be trained in a wide range of preventive maintenance, like instrument calibration, pump adjustment, chemical feed inspection and adjustment.

The most important maintenance routine is to keep the membrane free of salts or suspended materials that can clog it. Membranes should be changed every three to five years, and they represent about one third of the cost of the plant.

Level of Involvement The level of involvement depends on the scale of the plant. As facilities become larger, producing water for a whole community will require community acceptance and financing.

Costs The capital costs for treating brackish water range from $250 to $750 per m^3/d, and for seawater it ranges from $800 to $1250 m^3/d (UNEP, 1998). Water costs for desalination were referred by Seven Seas Company (provider of this equipment for resorts and also for WAPA) between $1.05 to $2.44 per m^3 ($4-9.25/1000 gal).

Effectiveness of the technology This type of technology has been in constant improvement in the last decade. It has been proven a very effective technology for Caribbean seawater.

Suitability The suitability of this technology depends on the characteristics of the incoming brackish/seawater. If the intake is carefully chosen and maintained free of pollution the process will be effective.

Advantages The wide ranges of sizes and modularity of R/O plants allows for a flexible and scalar system. The design is simple, and because of this simplicity, they are ideal for use as emergency alternative supplies. As there are many options in the market, the replacement components for operation are readily available and prices are balanced.

Disadvantages Membranes have to be carefully maintained in order to avoid suspended solids to clog them. It requires constant attention by skilled personnel.

Environmental impact From the aquatic point of view, discharge of brine is one of local effects. For our analysis we will consider the energy consumption per volume of water as an air pollution indicator.

Further development of the technology This technology for the range of supply necessities that St. Thomas has is developing at a fast pace. Improvement in pretreatment and intake filtration, as well as new membranes design that can work at lower pressures will increase the efficiency and cost-effectiveness of this particular technology.

9. Comparison of the three potential main supply strategies for freshwater supply and augmentation

As it has been discussed in previous sections, of all the sources of augmentation, only distillation (the actual strategy), reverse osmosis desalination and submarine piping can provide on continuous basis water in the quantity and quality needed. As we have seen in the introduction, the analysis in an IWRM framework of these options should be made taking into account three different elements: 1) economic efficiency in water use, 2) environmental and ecological sustainability, and 3) equity in the access to water for all people. An evaluation of these three principles follows.

9.1. Economic analysis of the main supply alternatives

This analysis will be done for the purpose of fair comparison, with the operation data of WAPA for the year 1995. The alternatives of R/O and submarine piping will be calculated for supplying the peak supply of distillation water that WAPA's plant in Krum Bay, St. Thomas can supply at peak operation.

9.1.1. Submarine piping benefit/cost analysis

Assumptions

Value of commercial KWh 1 KWh=0.14 (WAPA 2003)

Personnel average wage \$22,222/yr (Male full-time median income 1999 US Bureau of the Census totaled \$29,309).

Capital costs For a 14,000 m^3/d supply and according to the range quoted in Section 8.1.4, the costs for the two chosen alternatives have been considered. The detailed capital costs are expressed in tables Table 8.4 and 8.5.

Production costs The production cost of ground-water in Puerto Rico was considered at 0.5 $\$/m^3$. Considering an annual import of 2.900,000 m^3 per year (roughly the 1995 WAPA production for the year 1995 in St. Thomas), the total production amount to be paid for water provision in Puerto Rico has been calculated to be of \$1,450,000.

Operation and maintenance Electric Energy represents the primary operating cost. For the 10-inch diameter installation, the pumps will need 930 KWe for continuous operation (8,146,800 KWh annually). For the 8-inch diameter installation, the pumps will need 2838 KWe for continuous operation (24,860,880 KWh annually). To this electricity cost, 1/50 of the capital cost was added as maintenance of the pipe and pumps. The last item added to this O&M cost was the wages of the staff needed for pump operations.

Staffing level For each of the pump stations two persons as staff is needed. We will take for our calculations 6 persons for a 14,000 m^3/d demand, operating the three pump stations..

Administration Costs are the same as the data from WAPA (1999). All of the operating expenses, production cost of water distributed, operations and maintenance, customer service, administrative and general expenses, depreciation and amortization, interest expenses, interest income and allowance funds, have been taken from the unedited balance sheets of WAPA from 30 Jun 1995 to 30 Jun 1999.

Depreciation of equipment Based on a lifespan of the pipe and pump stations of 50 years, 1/50 of its value per year has been considered as the depreciation amount.

Sales To keep the consistency of the analysis the sales revenues are considered to be the same as the WAPA FY99 for St. Thomas throughout the years 1 to 50.

Inflation and interest over capital They have not been considered in the calculations for simplicity.

Four different alternatives have been run.

First Alternative: WAPA operates the pipe and fully finances the construction of dual parallel flexible pipe of 10-inch diameter (2x10").

Second Alternative: WAPA operates the pipe and fully finances the construction of a dual parallel flexible pipe of 8-inch diameter (2x8").

Third alternative: The water seller in Puerto Rico, and/or possible users in Isla de Culebra and Vieques, pays for half of the cost of the works. Work consists in 10–inch diameter dual pipe alternative.

Fourth alternative: The water seller in Puerto Rico, and/or possible users in Isla de Culebra and Vieques, pays for half of the cost of the works. Work consists in 8–inch diameter dual pipe alternative.

Detailed calculations for each alternative are included in APPENDIX A.

Table 9.1

Summary of costs and sales, submarine pipe alternative

Source of quoted capital costs flexible pipe manufacturer (2003)

Description	Submarine Pipe 2*10"	Submarine Pipe 2*8"
Capital Costs for Capacity of 14 MLD(14000 m3/d)		
Max Capital Cost- 2 pipes of 10" (Source manufacturer of Flexible Pipe)	41,669,000.00	
Min Capital Cost- 2 pipes of 8" (Source manufacturer of Flexible Pipe)		29,837,000.00
Operating Expenses (Annual) $	8,494,316.02	10,320,273.22
Production cost of water distributed	1,450,000.00	1,450,000.00
Operations and Maintenance	2,147,999.32	4,210,596.52
Customer Service	619,663.04	619,663.04
Administrative and General	2,163,069.09	2,163,069.09
Depreciation and amortization	833,380.00	596,740.00
Interest expense-income-allowance funds	1,280,204.56	1,280,204.56
Operating Revenues (WATER SALES) $	13,666,538.89	13,666,538.89

9.1.2. Desalination by distillation benefit/cost analysis

Assumptions

In this particular case, the values will be the actual balance values of WAPA water production for the year 1994. As this data is not presented separate for each of the main islands, an estimation based in the total installed capacity is made. From table 3.2 the proportion of the total desalinated water production that corresponds to each island is 45.4% St Croix, and 54.6% to St. Thomas. Of the total operation costs and sales revenues presented, 54.6% account for St. Thomas, which is a fair estimate that can account for the provision to both islands. The source is the unaudited balance sheets of WAPA from 30 Jun 1995 to 30 Jun 1999.

Capital costs For a 14,000 m^3/d plant and according to the range quoted in Section 8.1.5.1.1 the range of costs for a plant will be between $28,000,000 and $14,000,000.

All of the operating expenses, production cost of water distributed, operations and maintenance, customer service, administrative and general expenses, depreciation and amortization, interest expenses, interest income and allowance funds, have been taken from the unedited balance sheets of WAPA from 30 Jun 1995 to 30 Jun 1999.

Depreciation of equipment Based on a lifespan of the plant of 25 years, 1/25 of its value per year has been considered as the depreciation amount. Considering technological change, it is assumed that the replacement plant after year 25 is bought at half the price as the unit in year 1.

Sales To keep the consistency of the analysis the sales revenues are considered to be the constant for St. Thomas throughout the years 1 to 50.

Inflation and interests over capital They have not been considered in the calculations for simplicity.

Detailed calculations are included in APPENDIX A.

Table 9.2

Summary of Costs and Sales WAPA 1999. Distillation.

Description	**Distillation MED (FY 1999) STX+STT**	**Distillation MED (FY 1999) Prop ST Thomas 54,60%**
Maximum capacity per unit worldwide m³/d		36000
Average production per unit on St. Thomas m³/d		5000
Max Capital Cost- U$/installed m^3		2.000,00
Min Capital Cost-U$/installed m^3		1.000,00
Capital Costs for Capacity of 14 MLD(14000 m3/d)		
Max Capital Cost- U$/installed m^3(UNEP max value)		28.000.000,00
Min Capital Cost-U$/installed m^3(UNEP min value)		14.000.000,00
Operating Expenses(Annual)Jun 30 98-Jun 30 99-$	23.812.519,00	13.001.635,37
Production cost of water distributed	9.550.647,00	5.214.653,26
Operations and Maintenance	4.409.058,00	2.407.345,67
Customer Service	1.134.914,00	619.663,04
Administrative and General	3.961.665,00	2.163.069,09
Depreciation and amortization	2.411.538,00	1.316.699,75
Interest expense-income-allowance funds	2.344.697,00	1.280.204,56
Operating Revenues (WATER SALES) $	25.030.291,00	13.666.538,89

9.1.3. Desalination by reverse osmosis benefit/cost analysis

Assumptions

Value of commercial KWh: 1 KWh=0.14 (WAPA 2003)

Personnel average wage $22,222/yr (Male full-time median income 1999 US bureau of the Census totaled $29,309)

Capital costs For a 14,000 m^3/d plant and according to the range quoted in Section 8.1.5.1

Production costs Electric energy represents the primary operating cost, and it ranges from 3 to 6 Kwh/m^3 of potable water produced (UNEP, 1998). For the calculations the worst-case scenario will be assumed in all the cases for fairness of comparison, i.e., 6 Kwh/m^3

Operation and Maintenance To keep the consistency of the analysis the operation and maintenance costs are considered to be constant for St. Thomas throughout the years 1 to 50.

Staffing Level For a 4000 m^3/d plant, 3 persons are required staff (UNEP, 1998). We will take for our calculations 9 persons for a 14,000 m^3/d. Therefore, in the case of distributed RO plants as proposed, the cost analysis will not be different in personnel wages. The only change in this distributed system will be the savings in distribution.

Maintenance Mainly change of membranes (that represent around 1/3 of the value of the equipment) every 3 to 5 years. We take as maintenance full cost change of the membrane every 3 years.

Administration The same as the data from WAPA (1995) = $1,000,000

Depreciation of equipment Based on a lifespan of the plant of 25 years, 1/25 of its value per year. Considering technological change, it is assumed that the replacement plant after year 25 is bought at half the price as the unit in year one.

Sales To keep the consistency of the analysis the sales revenues are considered to be the same as the WAPA FY99 for St. Thomas throughout the years 1 to 50.

Inflation and interests over capital They have not been considered in the calculations for simplicity.

Two different alternatives have been run.

First Alternative: WAPA operates the RO plants.

Second Alternative: A private operator is contracted by WAPA and sells water produced at a fixed value of $3/m^3.

Detailed calculations are included in APPENDIX A.

Table 9.3
Summary of costs and sales. Reverse osmosis..

Description	Reverse Osmosis RO
Maximum capacity per unit worldwide (modular)m³/d	4000
Average production per unit on St. Thomas m³/d	20
Max Capital Cost- U$/installed m^3	1.250,00
Min Capital Cost-U$/installed m^3	800,00
Capital Costs for Capacity of 14 MLD(14000 m3/d)	14000
Max Capital Cost- U$/installed m^3(UNEP max value)	17.500.000,00
Min Capital Cost-U$/installed m^3(UNEP min value)	11.200.000,00
Operating Expenses (Annual)-Jun 30 98-Jun 30 99	9.939.677,42
Production cost of water distributed	3.880.444,42
Operations and Maintenance	1.296.296,30
Customer Service	619.663,04
Administrative and General	2.163.069,09
Depreciation and amortization	700.000,00
Interest expense-income-allowance funds	1.280.204,56
Operating Revenues (WATER SALES)	13.666.538,89

9.1.4. Projects comparison

Table 9.4 presents the summary of the benefit-cost analysis calculations results

Table 9.5
Summary of results of benefit-cost analysis.
For complete calculations see APPENDIX A

Summary of results	DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev / PVCos
Submarine Piping 2 x 10"	0.07	0.142	32,437,545	188,608,436	(156,170,891)	1.208
Submarine Piping 2 x 8"	0.07	0.126	18,295,917	188,608,436	(170,312,519)	1.107
Submarine Piping 2 x 10" Shared	0.07	0.330	51,909,040	188,608,436	(136,699,396)	1.380
Submarine Piping 2 x 8" Shared	0.07	0.289	32,238,440	188,608,436	(156,369,996)	1.206
Desalination by distillation	0.07	#NUM!	(19,571,548)	188,608,436	(208,179,984)	0.906
Reverse Osmosis	0.07	0.270	33,014,739	188,608,436	(155,593,697)	1.212
Private Reverse Osmosis	0.07	#DIV/0!	12,248,307	188,608,436	(176,360,129)	1.069

The alternatives that have been developed are ranked according to the PVBREV/PVCOS ratio, or benefit–cost ratio.

Table 9.5
Ranking by benefit–cost ratio, all projects.

Ranking by PVRev/PVCos	DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev / PVCos
Submarine Piping 2 x 10" Shared	0,07	0,330	51.909.040	188.608.436	(136.699.396)	1,380
Reverse Osmosis	0,07	0,270	33.014.739	188.608.436	(155.593.697)	1,212
Submarine Piping 2 x 10"	0,07	0,142	32.437.545	188.608.436	(156.170.891)	1,208
Submarine Piping 2 x 8" Shared	0,07	0,289	32.238.440	188.608.436	(156.369.996)	1,206
Submarine Piping 2 x 8"	0,07	0,126	18.295.917	188.608.436	(170.312.519)	1,107
Private Reverse Osmosis	0,07	#DIV/0!	12.248.307	188.608.436	(176.360.129)	1,069
Desalination by distillation	0,07	#NUM!	(19.571.548)	188.608.436	(208.179.984)	0,906

For all the alternatives, it is also important to analyze the ranking of the IRR.

Table 9.6
Ranking by internal rate of return, all projects.

Ranking by IRR	DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/ PVCos
Submarine Piping 2 x 10" Shared	0,07	0,330	51.909.040	188.608.436	(136.699.396)	1,380
Submarine Piping 2 x 8" Shared	0,07	0,289	32.238.440	188.608.436	(156.369.996)	1,206
Reverse Osmosis	0,07	0,270	33.014.739	188.608.436	(155.593.697)	1,212
Submarine Piping 2 x 10"	0,07	0,142	32.437.545	188.608.436	(156.170.891)	1,208
Submarine Piping 2 x 8"	0,07	0,126	18.295.917	188.608.436	(170.312.519)	1,107
Desalination by distillation	0,07	#NUM!	(19.571.548)	188.608.436	(208.179.984)	0,906
Private Reverse Osmosis	0,07	#DIV/0!	12.248.307	188.608.436	(176.360.129)	1,069

As all the alternative projects have a cost constraint, the benefit-cost ratio is a good indicator of the choice of project from a purely economic point of view. These projects are not considered as mutually exclusive, because they are part of an augmentation strategy. The proper combination of different alternatives can be suitable for the objectives of water resources planning. That is why the ranking by IRR is not considered definitive in this analysis, although it is a useful reference.

9.2. Environmental impact comparison

The criteria for the environmental impact comparison should be assessed by:

Energy intensity of the process Comparison on energy needed to produce or provide (in the case of the submarine piping) 1000 L of water. It will be expressed in Kwh/m^3. If the source of electricity or steam used in all the processes involved is based on fossil fuels, this comparison will yield an indicator of emission of pollutants to the air.

Water quality Of the processes of desalination, water quality is usually more reliable in the case of distillation, mainly because of the high temperatures of the process that eliminates almost all bacterial activity in water. Reverse osmosis requires more control and monitoring in the resulting water quality.

In the case of submarine piping, the main concern is focused in the possibility of water to act as a vector of epidemics between relatively closed island environments.

Marine eco-system impact Of each of the options, the desalination options will present the pollution due to the discharge of the waste brine that results as effluent of the process of desalination. The waste brine assessment in the case of desalination should be focused on three main parameters to compare:

- Flow rates of the discharge
- Water temperature of the discharge
- Maximum and minimum pH of the effluent.

In the case of the submarine piping, the impact will be assessed by the impact per se of the construction and lay out of the pipe, and then by the impact on the marine environment of further operation of the facilities.

Land use This will depend not only on the size of the required facility, but also on the relative ability of each process to generate toxic wastes. Toxic wastes in turn will pollute the environment. Pollution by toxic wastes will affect the marine environment and groundwater.

All these indicators are of great relative importance, we will determine for the purpose of this work the energy intensity indicator for the three options. Nonetheless, it is required for proper evaluation of each of these alternatives to fulfill the rest of the environmental impacts assessment as well as some others that could be left out of the present shortlist.

9.2.1. Energy intensity of the process

Submarine Piping

In order to pump 14,000 m³/d of water from Puerto Rico to St. Thomas:

- With the dual parallel flexible pipe of 10" system, a total amount of 22,320 KWh is needed.

$$\text{Energy intensity}=\frac{22{,}320\ Kwh/d}{14{,}000\ m^3/d}=1.59 Kwh/m^3$$

- With the dual parallel flexible pipe of 8" system, a total amount of 68,112 KWh is needed.

$$\text{Energy intensity}=\frac{68{,}112\ Kwh/d}{14{,}000\ m^3/d}=4.87 Kwh/m^3$$

Desalination by distillation

According to WAPA the cost to produce 1000 gallons of water is calculated to be in the order of \$5.50 /1000 gal, or \$1.45/ m³.

And the associated cost of electricity was of \$0.061/Kwh (WAPA, 1994)

This implies that: Energy intensity=$23.82 Kwh/m^3$

An important comment to be made on this particular calculation is the fact that the energy intensity calculated, responds to considering the total electricity involved in the process of desalination. This value includes the electricity equivalent needed for the cogeneration plant recovered heat energy.

Desalination by reverse osmosis

Energy efficiency for this process ranges from 3 to 6 Kwh/m³ of potable water produced (UNEP, 1998). An average is taken.

Energy intensity=$4.5 Kwh/m^3$

Table 9.7
Scoring of energy efficiency of selected processes.

Process	Energy intensity Kwh/m³
Submarine Piping 2 x 8"	1.59
Desalination by reverse osmosis	4.50
Submarine Piping 2 x 8"	4.87
Desalination by distillation	23.82

9.3. Equity in the access to water for all people

Regarding the distribution of the public water system, it has been noted that the main problem lies in the centralized distribution of water. The system expansion has not been accomplished as planned in the last two decades. It is a fact that 55% of the permanent population does not have access to the public distribution system. This presents still in 2003, a pending assignment for the water managers and planners. It is also to be highlighted that, lack of access to the public system, does not depend as in many other cases, on the income composition of the population. In other words most of the out of radius zones are inhabited by the fraction of the population with larger income. This adds to the challenge of extending the distribution in a hilly terrain of volcanic soils, the opportunity of the willingness and ability to pay of the potential new customers.

10. Answers towards Integrating Water Resources Management

Returning to the main questions about the key issues on water resources management enunciated in Chapter 4, and after carefully analysis of the actual situation it is possible to discuss the answers to them.

10.1. Environmental consequences of separate operation of water supply and wastewater

Is it desirable to have two different entities operating water supply and water disposal?

By understanding that water is a renewable and reusable resource, a recommended practice is to integrate the management and operation of these two services in order to achieve that wastewater flows can be an effective addition to resource flows of water supply.

During a meeting at DPNR on St. Thomas, the question of why different companies or departments were operating potable water and wastewater was asked. The answer received in the interview was quite representative of the issue. It was "You won't go to a WWTP, then wash your hands and give a glass of that water to your kid." This is a basic answer, but it reflects some culturally accepted feeling about separating freshwater from wastewater.

Although in the case of a watertight economy as the one under consideration, it does not seem rational to operate with different companies water supply and sewage collection. Given the extreme necessity on considering ways of reusing water, it will be highly recommendable to operate and design water supply and wastewater collection and reuse conjunctively. Today two different agencies with no points in common are operating separately these two services, and until now, the government has implemented no significant water reuse policies. Some resorts have been applying the principle of water reuse in the island by recycling treated water for irrigation uses.

This is a direction on which to point in the near future. The California experience in treated wastewater injection as a mean of avoiding saline intrusion and recharging the aquifer should be seriously studied for the island.

10.2. Reliability of public water system based in desalination. Frequency of extreme events.

Is it possible to operate a reliable water system based only in one supply strategy (desalination by distillation) in a place where the occurrence of extreme events is of high frequency?

After the analysis of the water sector situation in the island it is clear that desalination, although having played an important role in the island development in the decade of the sixties and seventies could never give a full response to water needs of the island. At present although a valuable and secure supply for freshwater, and after beginning to charge full price from the water they are selling, WAPA still faces operational problems, and has to think in future alternative technologies that can be more suitable to the St. Thomas needs. Careful consideration should be given to the alternatives that have been developed in this work.

It is possible to apply more cost-effective alternatives as the main supply strategy to the island. It has been proven in this work that importing water from Puerto Rico through submarine pipelines is a feasible alternative. Moreover, in the long term it will allow WAPA to focus in the extension of the system.

On the other hand, private resorts have been successful in incorporating R/O plants with up to day technologies. In addition, they are reporting huge savings over water bought from WAPA.

Two years ago an attempt to privatize part of WAPA as a concession failed. The legislature of the Virgin Islands did not approve the arrangement between WAPA and Southern Waters. Still today all the major services are in government hands and although improvements have been made in the water sector, privatization can be a possibility that ought to be analyzed in the near future. All the facilities operated by resorts and other private owners report better yields than the government owned WAPA.

It is also important to note that the actual institutions have been going through great changes in the last three decades. In 1971 the first elected governor assumed office in the islands, before that the U.S. federal government designed the governor. Institutions are not yet mature, although they have many of the requirements that the continental states have, but lack the proper solid institutional background needed for the task. That is why enforcement of EPA regulations, for instance, is slow and has fewer results than the expected.

10.3. Water costs and prices in this market

How can proper prices on water be managed in a market with these characteristics?

The idea of equitable prices has been undergoing drastic changes in the last decade. Full pricing of water has become a necessity because of the large debt that the government has contracted with the Federal government. Nevertheless, there are some gray areas that need to be defined and clarified. For instance the housing projects managed by VIHA (Virgin Island Housing Authority) as well as other territorial government agencies are still the main clients of WAPA and rarely pay their bills. This sort of cross-subsidies should be corrected, but it seems to be a long road yet to be taken.

10.4. Health consequences, water quality. Rainfall harvesting as main source of water supply.

How can overall water quality be assured when catchments of rainfall is the main water supply for more than 70% of the population?

Water quality for human consumption is still an issue to be solved in the islands. Because 70% of the population relies on water catchments for their daily water consumption, a strict control of water quality should be implemented in households. This task can be done by DPNR and the Department of Public Health. Public campaigns for instructing the population on a regular basis are sporadic and only applied when a breakthrough of waterborne disease appear in the horizon. No up to date studies have been found on statistical datum for waterborne diseases linked with the exposure of the majority of the population to water related health risks.

11. Conclusions: The future

The future of water resources in the Virgin Islands lies in the interconnection for allocating water and the creation of a less distorted and subsidized water market.

The inventory of the available water resources mentioned throughout this work added to an adequate conjunctive use strategy, and a planned augmentation of sources will make water scarcity past history.

Piping and adequate maintenance of the existing infrastructure will result in reducing unaccounted for water, increasing the possibility of managing allocation of the different sources of desalinated water (Water and Power Authority, self-sufficient resorts and industries, and water catchments with strict quality controls).

Projects for piping the whole extension of St. Thomas and St. John, and leave private or third parties deal with in island distribution should be encouraged. Distribution should be given to cooperatives or companies interested in developing and operating the distribution net in that particular sub district or area. Taking into account the actual price of a water residential connection that reaches $1,500 (almost 300% of the average international cost for a developed country), it should be an easy task for a cooperative to extend and operate from the main pipe the distribution.

Piping to the west towards Isla de Culebra (or Vieques), and Puerto Rico, has already been considered, but it had never been put into action because of water rights conflicts and considerations. The only need will be a strong decision on the right way to head. This will make possible the creation of a sustainable regional water market (that will exceed the US Virgin Islands). Undersea piping to the British Virgin Islands and heading east to other islands is also a future possibility of market expansion. A pipe that can connect St. Thomas' north side to Tortola can be installed at not more than 30 m (98 ft) of depth

Almost twenty years ago a project to lay a submarine pipe from Puerto Rico to St. Thomas was proposed, but has never been materialized. Desalination was confirmed as an option in that same period. After twenty years and due to technology change desalination is not the right option as the main supply strategy.

Expansion of the distribution of WAPA's public water; independently of the source of water supply to be chosen is necessary. It should be done for the purpose of equitability. This does not mean to expand the actual central based distribution, but the choice should be made on the base of careful feasibility analysis of all the possibilities, by all the actors.

Voluntary water transfers are a good response from the government's legal action, as a complementary mechanism of water augmentation and demand–management policies. If properly implemented from both the operative and water use regulations it can bring greater economic efficiency in the market. In the last decades and due to the combination of increasing water demands, environmental concerns and exhaustion of the most economic water sources, water transfers represent an efficient economic alternative (Mays, 2002). In an island environment with no irrigation water use the sectors that should be enabled to this type of trade are the local groups of water users, and the water users or operators in neighboring islands (either national or transnational). The experience with water trading has been possible for instance in California because of the high grade of connectivity that the water distribution system has achieved in that state.

Another strong reason for interconnection of available regional resources has to do with the pattern of occurrence of extreme events like hurricanes. The different paths that the eye of the hurricane takes year after year characterize this pattern. It does not always hit twice in the same island. In the event of a given hurricane that fully makes land in any of the interconnected islands, the rest of them that have not suffered the hurricane's full rigor will be readily able to supply water until remediation of damages can be done.

In addition, the interconnection between islands has the advantage of expanding the economy of scales of a reduced island market, which will generate the beneficial economic effect that expansion of a market has (at least until certain point).

The other main problem that should be continuously attended to is the necessity of constant monitoring of water quality standards mainly for rainwater catchments (RWC).

RWC is a fundamental source of water in the islands and should be treated as other water supplies, investing in new technologies for proper conservation of the resource as well as its augmentation.

The rough numbers of total demand and total available supply are useful as a reminder of the limited and insufficient supplies of water, as well as a challenge for innovative water planning and management. A water market, with high grade of distortion created by the government has been set in the islands. Integrating water resources management and planning, that will imply innovating the water market will be the only way of augmentation of water supplies.

The useful life of the desalination trains is past due to its theoretical end of life (assuming a lifespan of 25 years from its installation in 1985). It the right time for all the stakeholders in the USVI water resources sector to analyze its own alternatives. That is the challenge. Trading off environmental impacts and at the same time assuring the water resource quantity and quality at equitable prices for generations to come is achievable.

11.1. Final recommendations

1) Desalination plants by distillation should be gradually phased out as the only source of public water. The options that should be analyzed have been discussed in this thesis. Technologies as submarine piping and Reverse Osmosis desalination in conjunction should be considered as the future options. These alternatives are preferred both from cost analysis and sustainability considerations. Submarine piping from Puerto Rico can be combined with smaller RO plants strategically distributed, to achieve what has been postponed for many years in the islands, an equitable distribution of the available water resources.

2) Funds will be saved from more cost effective alternatives. In turn, these funds should be applied to expand the public system. This can result in a positive cyclic pattern. Incorporating 54% of the population to the system will increase in time

the revenues generated by the water sector. This should make more funds available for the next phase of improvements.

3) A legal set of reforms that will enable water trading should be put into place. These policies combined with a higher level of interconnectivity will enable the gradual development of a regional water market.

4) There is a need of better accounting practices for assessing actual demands and available supplies in order to accomplish informed decision-making. Water scarcity is not only the result of climatic and geographical conditions, but it also depends on adequate management and planning of the present and future resources. A need for more refined analysis or breakdown in information is recommended for water resources managers and planners in the US Virgin Islands.

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APPENDIX A: Benefit-cost analysis detailed calculations.

Submarine Piping (2x10")	Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(41.669.000)	(8.494.316)	(50.163.316)	13.666.539	(36.496.777)
2		(8.494.316)	(8.494.316)	13.666.539	5.172.223
3		(8.494.316)	(8.494.316)	13.666.539	5.172.223
4		(8.494.316)	(8.494.316)	13.666.539	5.172.223
5		(8.494.316)	(8.494.316)	13.666.539	5.172.223
6		(8.494.316)	(8.494.316)	13.666.539	5.172.223
7		(8.494.316)	(8.494.316)	13.666.539	5.172.223
8		(8.494.316)	(8.494.316)	13.666.539	5.172.223
9		(8.494.316)	(8.494.316)	13.666.539	5.172.223
10		(8.494.316)	(8.494.316)	13.666.539	5.172.223
11		(8.494.316)	(8.494.316)	13.666.539	5.172.223
12		(8.494.316)	(8.494.316)	13.666.539	5.172.223
13		(8.494.316)	(8.494.316)	13.666.539	5.172.223
14		(8.494.316)	(8.494.316)	13.666.539	5.172.223
15		(8.494.316)	(8.494.316)	13.666.539	5.172.223
16		(8.494.316)	(8.494.316)	13.666.539	5.172.223
17		(8.494.316)	(8.494.316)	13.666.539	5.172.223
18		(8.494.316)	(8.494.316)	13.666.539	5.172.223
19		(8.494.316)	(8.494.316)	13.666.539	5.172.223
20		(8.494.316)	(8.494.316)	13.666.539	5.172.223
21		(8.494.316)	(8.494.316)	13.666.539	5.172.223
22		(8.494.316)	(8.494.316)	13.666.539	5.172.223
23		(8.494.316)	(8.494.316)	13.666.539	5.172.223
24		(8.494.316)	(8.494.316)	13.666.539	5.172.223
25		(8.494.316)	(8.494.316)	13.666.539	5.172.223
26		(8.494.316)	(8.494.316)	13.666.539	5.172.223
27		(8.494.316)	(8.494.316)	13.666.539	5.172.223
28		(8.494.316)	(8.494.316)	13.666.539	5.172.223
29		(8.494.316)	(8.494.316)	13.666.539	5.172.223
30		(8.494.316)	(8.494.316)	13.666.539	5.172.223
31		(8.494.316)	(8.494.316)	13.666.539	5.172.223
32		(8.494.316)	(8.494.316)	13.666.539	5.172.223
33		(8.494.316)	(8.494.316)	13.666.539	5.172.223
34		(8.494.316)	(8.494.316)	13.666.539	5.172.223
35		(8.494.316)	(8.494.316)	13.666.539	5.172.223
36		(8.494.316)	(8.494.316)	13.666.539	5.172.223
37		(8.494.316)	(8.494.316)	13.666.539	5.172.223
38		(8.494.316)	(8.494.316)	13.666.539	5.172.223
39		(8.494.316)	(8.494.316)	13.666.539	5.172.223
40		(8.494.316)	(8.494.316)	13.666.539	5.172.223
41		(8.494.316)	(8.494.316)	13.666.539	5.172.223
42		(8.494.316)	(8.494.316)	13.666.539	5.172.223
43		(8.494.316)	(8.494.316)	13.666.539	5.172.223
44		(8.494.316)	(8.494.316)	13.666.539	5.172.223
45		(8.494.316)	(8.494.316)	13.666.539	5.172.223
46		(8.494.316)	(8.494.316)	13.666.539	5.172.223
47		(8.494.316)	(8.494.316)	13.666.539	5.172.223
48		(8.494.316)	(8.494.316)	13.666.539	5.172.223
49		(8.494.316)	(8.494.316)	13.666.539	5.172.223
50		(8.494.316)	(8.494.316)	13.666.539	5.172.223

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0,07	0,14	32.437.545	188.608.436	(156.170.891)	1,21

Submarine Piping (2x8")	Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(29.837.000)	(10.320.273)	(40.157.273)	13.666.539	(26.490.734)
2		(10.320.273)	(10.320.273)	13.666.539	3.346.266
3		(10.320.273)	(10.320.273)	13.666.539	3.346.266
4		(10.320.273)	(10.320.273)	13.666.539	3.346.266
5		(10.320.273)	(10.320.273)	13.666.539	3.346.266
6		(10.320.273)	(10.320.273)	13.666.539	3.346.266
7		(10.320.273)	(10.320.273)	13.666.539	3.346.266
8		(10.320.273)	(10.320.273)	13.666.539	3.346.266
9		(10.320.273)	(10.320.273)	13.666.539	3.346.266
10		(10.320.273)	(10.320.273)	13.666.539	3.346.266
11		(10.320.273)	(10.320.273)	13.666.539	3.346.266
12		(10.320.273)	(10.320.273)	13.666.539	3.346.266
13		(10.320.273)	(10.320.273)	13.666.539	3.346.266
14		(10.320.273)	(10.320.273)	13.666.539	3.346.266
15		(10.320.273)	(10.320.273)	13.666.539	3.346.266
16		(10.320.273)	(10.320.273)	13.666.539	3.346.266
17		(10.320.273)	(10.320.273)	13.666.539	3.346.266
18		(10.320.273)	(10.320.273)	13.666.539	3.346.266
19		(10.320.273)	(10.320.273)	13.666.539	3.346.266
20		(10.320.273)	(10.320.273)	13.666.539	3.346.266
21		(10.320.273)	(10.320.273)	13.666.539	3.346.266
22		(10.320.273)	(10.320.273)	13.666.539	3.346.266
23		(10.320.273)	(10.320.273)	13.666.539	3.346.266
24		(10.320.273)	(10.320.273)	13.666.539	3.346.266
25		(10.320.273)	(10.320.273)	13.666.539	3.346.266
26		(10.320.273)	(10.320.273)	13.666.539	3.346.266
27		(10.320.273)	(10.320.273)	13.666.539	3.346.266
28		(10.320.273)	(10.320.273)	13.666.539	3.346.266
29		(10.320.273)	(10.320.273)	13.666.539	3.346.266
30		(10.320.273)	(10.320.273)	13.666.539	3.346.266
31		(10.320.273)	(10.320.273)	13.666.539	3.346.266
32		(10.320.273)	(10.320.273)	13.666.539	3.346.266
33		(10.320.273)	(10.320.273)	13.666.539	3.346.266
34		(10.320.273)	(10.320.273)	13.666.539	3.346.266
35		(10.320.273)	(10.320.273)	13.666.539	3.346.266
36		(10.320.273)	(10.320.273)	13.666.539	3.346.266
37		(10.320.273)	(10.320.273)	13.666.539	3.346.266
38		(10.320.273)	(10.320.273)	13.666.539	3.346.266
39		(10.320.273)	(10.320.273)	13.666.539	3.346.266
40		(10.320.273)	(10.320.273)	13.666.539	3.346.266
41		(10.320.273)	(10.320.273)	13.666.539	3.346.266
42		(10.320.273)	(10.320.273)	13.666.539	3.346.266
43		(10.320.273)	(10.320.273)	13.666.539	3.346.266
44		(10.320.273)	(10.320.273)	13.666.539	3.346.266
45		(10.320.273)	(10.320.273)	13.666.539	3.346.266
46		(10.320.273)	(10.320.273)	13.666.539	3.346.266
47		(10.320.273)	(10.320.273)	13.666.539	3.346.266
48		(10.320.273)	(10.320.273)	13.666.539	3.346.266
49		(10.320.273)	(10.320.273)	13.666.539	3.346.266
50		(10.320.273)	(10.320.273)	13.666.539	3.346.266

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0,07	0,13	18.295.917	188.608.436	(170.312.519)	1,11

Sub- Pipe Shared(2X10")	Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(20.834.500)	(8.494.316)	(29.328.816)	13.666.539	(15.662.277)
2		(8.494.316)	(8.494.316)	13.666.539	5.172.223
3		(8.494.316)	(8.494.316)	13.666.539	5.172.223
4		(8.494.316)	(8.494.316)	13.666.539	5.172.223
5		(8.494.316)	(8.494.316)	13.666.539	5.172.223
6		(8.494.316)	(8.494.316)	13.666.539	5.172.223
7		(8.494.316)	(8.494.316)	13.666.539	5.172.223
8		(8.494.316)	(8.494.316)	13.666.539	5.172.223
9		(8.494.316)	(8.494.316)	13.666.539	5.172.223
10		(8.494.316)	(8.494.316)	13.666.539	5.172.223
11		(8.494.316)	(8.494.316)	13.666.539	5.172.223
12		(8.494.316)	(8.494.316)	13.666.539	5.172.223
13		(8.494.316)	(8.494.316)	13.666.539	5.172.223
14		(8.494.316)	(8.494.316)	13.666.539	5.172.223
15		(8.494.316)	(8.494.316)	13.666.539	5.172.223
16		(8.494.316)	(8.494.316)	13.666.539	5.172.223
17		(8.494.316)	(8.494.316)	13.666.539	5.172.223
18		(8.494.316)	(8.494.316)	13.666.539	5.172.223
19		(8.494.316)	(8.494.316)	13.666.539	5.172.223
20		(8.494.316)	(8.494.316)	13.666.539	5.172.223
21		(8.494.316)	(8.494.316)	13.666.539	5.172.223
22		(8.494.316)	(8.494.316)	13.666.539	5.172.223
23		(8.494.316)	(8.494.316)	13.666.539	5.172.223
24		(8.494.316)	(8.494.316)	13.666.539	5.172.223
25		(8.494.316)	(8.494.316)	13.666.539	5.172.223
26		(8.494.316)	(8.494.316)	13.666.539	5.172.223
27		(8.494.316)	(8.494.316)	13.666.539	5.172.223
28		(8.494.316)	(8.494.316)	13.666.539	5.172.223
29		(8.494.316)	(8.494.316)	13.666.539	5.172.223
30		(8.494.316)	(8.494.316)	13.666.539	5.172.223
31		(8.494.316)	(8.494.316)	13.666.539	5.172.223
32		(8.494.316)	(8.494.316)	13.666.539	5.172.223
33		(8.494.316)	(8.494.316)	13.666.539	5.172.223
34		(8.494.316)	(8.494.316)	13.666.539	5.172.223
35		(8.494.316)	(8.494.316)	13.666.539	5.172.223
36		(8.494.316)	(8.494.316)	13.666.539	5.172.223
37		(8.494.316)	(8.494.316)	13.666.539	5.172.223
38		(8.494.316)	(8.494.316)	13.666.539	5.172.223
39		(8.494.316)	(8.494.316)	13.666.539	5.172.223
40		(8.494.316)	(8.494.316)	13.666.539	5.172.223
41		(8.494.316)	(8.494.316)	13.666.539	5.172.223
42		(8.494.316)	(8.494.316)	13.666.539	5.172.223
43		(8.494.316)	(8.494.316)	13.666.539	5.172.223
44		(8.494.316)	(8.494.316)	13.666.539	5.172.223
45		(8.494.316)	(8.494.316)	13.666.539	5.172.223
46		(8.494.316)	(8.494.316)	13.666.539	5.172.223
47		(8.494.316)	(8.494.316)	13.666.539	5.172.223
48		(8.494.316)	(8.494.316)	13.666.539	5.172.223
49		(8.494.316)	(8.494.316)	13.666.539	5.172.223
50		(8.494.316)	(8.494.316)	13.666.539	5.172.223

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0,07	0,33	51.909.040	188.608.436	(136.699.396)	1,38

Sub Piping Shared (2x8")	Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(14,918,500)	(10,320,273)	(25,238,773)	13,666,539	(11,572,234)
2		(10,320,273)	(10,320,273)	13,666,539	3,346,266
3		(10,320,273)	(10,320,273)	13,666,539	3,346,266
4		(10,320,273)	(10,320,273)	13,666,539	3,346,266
5		(10,320,273)	(10,320,273)	13,666,539	3,346,266
6		(10,320,273)	(10,320,273)	13,666,539	3,346,266
7		(10,320,273)	(10,320,273)	13,666,539	3,346,266
8		(10,320,273)	(10,320,273)	13,666,539	3,346,266
9		(10,320,273)	(10,320,273)	13,666,539	3,346,266
10		(10,320,273)	(10,320,273)	13,666,539	3,346,266
11		(10,320,273)	(10,320,273)	13,666,539	3,346,266
12		(10,320,273)	(10,320,273)	13,666,539	3,346,266
13		(10,320,273)	(10,320,273)	13,666,539	3,346,266
14		(10,320,273)	(10,320,273)	13,666,539	3,346,266
15		(10,320,273)	(10,320,273)	13,666,539	3,346,266
16		(10,320,273)	(10,320,273)	13,666,539	3,346,266
17		(10,320,273)	(10,320,273)	13,666,539	3,346,266
18		(10,320,273)	(10,320,273)	13,666,539	3,346,266
19		(10,320,273)	(10,320,273)	13,666,539	3,346,266
20		(10,320,273)	(10,320,273)	13,666,539	3,346,266
21		(10,320,273)	(10,320,273)	13,666,539	3,346,266
22		(10,320,273)	(10,320,273)	13,666,539	3,346,266
23		(10,320,273)	(10,320,273)	13,666,539	3,346,266
24		(10,320,273)	(10,320,273)	13,666,539	3,346,266
25		(10,320,273)	(10,320,273)	13,666,539	3,346,266
26		(10,320,273)	(10,320,273)	13,666,539	3,346,266
27		(10,320,273)	(10,320,273)	13,666,539	3,346,266
28		(10,320,273)	(10,320,273)	13,666,539	3,346,266
29		(10,320,273)	(10,320,273)	13,666,539	3,346,266
30		(10,320,273)	(10,320,273)	13,666,539	3,346,266
31		(10,320,273)	(10,320,273)	13,666,539	3,346,266
32		(10,320,273)	(10,320,273)	13,666,539	3,346,266
33		(10,320,273)	(10,320,273)	13,666,539	3,346,266
34		(10,320,273)	(10,320,273)	13,666,539	3,346,266
35		(10,320,273)	(10,320,273)	13,666,539	3,346,266
36		(10,320,273)	(10,320,273)	13,666,539	3,346,266
37		(10,320,273)	(10,320,273)	13,666,539	3,346,266
38		(10,320,273)	(10,320,273)	13,666,539	3,346,266
39		(10,320,273)	(10,320,273)	13,666,539	3,346,266
40		(10,320,273)	(10,320,273)	13,666,539	3,346,266
41		(10,320,273)	(10,320,273)	13,666,539	3,346,266
42		(10,320,273)	(10,320,273)	13,666,539	3,346,266
43		(10,320,273)	(10,320,273)	13,666,539	3,346,266
44		(10,320,273)	(10,320,273)	13,666,539	3,346,266
45		(10,320,273)	(10,320,273)	13,666,539	3,346,266
46		(10,320,273)	(10,320,273)	13,666,539	3,346,266
47		(10,320,273)	(10,320,273)	13,666,539	3,346,266
48		(10,320,273)	(10,320,273)	13,666,539	3,346,266
49		(10,320,273)	(10,320,273)	13,666,539	3,346,266
50		(10,320,273)	(10,320,273)	13,666,539	3,346,266

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0.07	0.29	32,238,440	188,608,436	(156,369,996)	1.21

Distillation	Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(28,000,000)	(13,001,635)	(41,001,635)	13,666,539	(27,335,096)
2		(13,001,635)	(13,001,635)	13,666,539	664,904
3		(13,001,635)	(13,001,635)	13,666,539	664,904
4		(13,001,635)	(13,001,635)	13,666,539	664,904
5		(13,001,635)	(13,001,635)	13,666,539	664,904
6		(13,001,635)	(13,001,635)	13,666,539	664,904
7		(13,001,635)	(13,001,635)	13,666,539	664,904
8		(13,001,635)	(13,001,635)	13,666,539	664,904
9		(13,001,635)	(13,001,635)	13,666,539	664,904
10		(13,001,635)	(13,001,635)	13,666,539	664,904
11		(13,001,635)	(13,001,635)	13,666,539	664,904
12		(13,001,635)	(13,001,635)	13,666,539	664,904
13		(13,001,635)	(13,001,635)	13,666,539	664,904
14		(13,001,635)	(13,001,635)	13,666,539	664,904
15		(13,001,635)	(13,001,635)	13,666,539	664,904
16		(13,001,635)	(13,001,635)	13,666,539	664,904
17		(13,001,635)	(13,001,635)	13,666,539	664,904
18		(13,001,635)	(13,001,635)	13,666,539	664,904
19		(13,001,635)	(13,001,635)	13,666,539	664,904
20		(13,001,635)	(13,001,635)	13,666,539	664,904
21		(13,001,635)	(13,001,635)	13,666,539	664,904
22		(13,001,635)	(13,001,635)	13,666,539	664,904
23		(13,001,635)	(13,001,635)	13,666,539	664,904
24		(13,001,635)	(13,001,635)	13,666,539	664,904
25	(14,000,000)	(13,001,635)	(27,001,635)	13,666,539	(13,335,096)
26		(13,001,635)	(13,001,635)	13,666,539	664,904
27		(13,001,635)	(13,001,635)	13,666,539	664,904
28		(13,001,635)	(13,001,635)	13,666,539	664,904
29		(13,001,635)	(13,001,635)	13,666,539	664,904
30		(13,001,635)	(13,001,635)	13,666,539	664,904
31		(13,001,635)	(13,001,635)	13,666,539	664,904
32		(13,001,635)	(13,001,635)	13,666,539	664,904
33		(13,001,635)	(13,001,635)	13,666,539	664,904
34		(13,001,635)	(13,001,635)	13,666,539	664,904
35		(13,001,635)	(13,001,635)	13,666,539	664,904
36		(13,001,635)	(13,001,635)	13,666,539	664,904
37		(13,001,635)	(13,001,635)	13,666,539	664,904
38		(13,001,635)	(13,001,635)	13,666,539	664,904
39		(13,001,635)	(13,001,635)	13,666,539	664,904
40		(13,001,635)	(13,001,635)	13,666,539	664,904
41		(13,001,635)	(13,001,635)	13,666,539	664,904
42		(13,001,635)	(13,001,635)	13,666,539	664,904
43		(13,001,635)	(13,001,635)	13,666,539	664,904
44		(13,001,635)	(13,001,635)	13,666,539	664,904
45		(13,001,635)	(13,001,635)	13,666,539	664,904
46		(13,001,635)	(13,001,635)	13,666,539	664,904
47		(13,001,635)	(13,001,635)	13,666,539	664,904
48		(13,001,635)	(13,001,635)	13,666,539	664,904
49		(13,001,635)	(13,001,635)	13,666,539	664,904
50		(13,001,635)	(13,001,635)	13,666,539	664,904

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0.07	#NUM!	(19,571,548)	188,608,436	(208,179,984)	0.91

Reverse Osmosis		Cost	O&M	Total Cost	Sales Revenues	Net C F
YEAR	1	(17.500.000)	(9.939.677)	(27.439.677)	13.666.539	(13.773.139)
	2		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	3		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	4		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	5		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	6		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	7		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	8		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	9		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	10		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	11		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	12		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	13		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	14		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	15		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	16		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	17		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	18		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	19		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	20		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	21		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	22		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	23		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	24		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	25	(11.200.000)	(9.939.677)	(21.139.677)	13.666.539	(7.473.139)
	26		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	27		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	28		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	29		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	30		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	31		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	32		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	33		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	34		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	35		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	36		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	37		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	38		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	39		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	40		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	41		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	42		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	43		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	44		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	45		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	46		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	47		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	48		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	49		(9.939.677)	(9.939.677)	13.666.539	3.726.861
	50		(9.939.677)	(9.939.677)	13.666.539	3.726.861

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0,07	0,27	33.014.739	188.608.436	(155.593.697)	1,21

Private RO @ U$/m3=	3	O&M	Total Cost	Sales Revenues	Net C F
YEAR 1	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
2	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
3	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
4	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
5	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
6	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
7	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
8	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
9	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
10	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
11	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
12	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
13	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
14	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
15	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
16	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
17	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
18	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
19	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
20	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
21	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
22	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
23	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
24	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
25	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
26	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
27	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
28	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
29	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
30	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
31	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
32	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
33	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
34	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
35	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
36	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
37	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
38	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
39	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
40	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
41	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
42	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
43	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
44	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
45	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
46	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
47	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
48	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
49	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510
50	(8.700.000)	(4.079.028)	(12.779.028)	13.666.539	887.510

DISC RATE	IRR	NPV	PVREV	PVCOS	PVRev/PVCos
0,07	#DIV/0!	12.248.307	188.608.436	(176.360.129)	1,07