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Country Case Study on Climate Change Impacts and Adaptation Assessment in Antigua and Barbuda

Water Resources Management

Mission Report

Norwegian Institute for Water Research

REPORT

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Abstract

This Report is a summary of findings from a mission to Antigua & Barbuda August 12 - 16, 1997. The quality and quantity of fresh water resources in Antigua and Barbuda are particularly vulnerable to climate change. The study addressed the following interconnected climate change issues: (i) impacts on the national hydrological cycle and water resources availability; (ii) impacts on water demand and water supply economics; and (iii) necessary adaptation measures to build the country's preparedness to meet future situations due to climate change. In conclusion, it is likely that climate change will have a set of impacts on the water sector in Antigua and Barbuda, although the exact magnitude of these impacts still remain unclear. The data and modeling tool required for the assessment of these relationships will need to be strengthened. The most appropriate adaptation measure to mitigating possible impacts of climate change would be to launch a Water Resources Management Action Program in Antigua and Barbuda. A part of such initiative would be to strengthen water resources monitoring and information systems, as well as the legal and institutional framework for integrated water resources management. The report presents an outline description of such action program.

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Preface

The project "Country Case Studies on Climate Change Impacts and Adaptation Assessment" is a sub-project under the United Nations Environment Programme (UNEP) Atmosphere Program. With Funding from the Global Environment Facility (GEF), UNEP has organised a country case study program to test and apply the methods established by the Intergovernmental Panel on Climate Change (IPCC). The Center for International Climate and Environmental Research - Oslo (CICERO), has been contracted by UNEP to co-ordinate and provide the international technical assistance to this project. The country case study program is currently working with four countries: Antigua & Barbuda, Cameroon, Pakistan, and Estonia. The assessment is focused on sectors identified as vulnerable to climate change, such as agriculture, forestry, hydrology, coastal zones, human health and settlements, and ecosystems.

NIVA has been contracted by CICERO to assist the country study team of Antigua and Barbuda in addressing the climate impact on the water resources sector of the country. The mission was received with great hospitality by all whom it met, and wishes to express its appreciation and gratitude to the Government of Antigua and Barbuda and others who made this short mission interesting and enjoyable. Special thanks to Mr. Daven Joseph, National Co-ordinator - Ministry of Trade and Planning, and Mr. Jerry Fernandez, Irrigation Engineer/Co-ordinator - Water Sector Team Soils & Water Conservation Division, Ministry of Agriculture, in providing invaluable guidance for the mission and for their continuos support throughout the visit to Antigua and Barbuda. A draft mission report, which was submitted August 25, 1997, has serves as an input to the preparation of the final Water Resources Sector Report by the country study team.

Oslo, January 29, 1998

Torbjørn Damhaug

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Summary

This Report is a summary of findings from a mission to Antigua & Barbuda August 12 - 16, 1997. The quality and quantity of fresh water resources in Antigua and Barbuda are particularly vulnerable to climate change. The study addressed the following interconnected climate change issues: (i) impacts on the national hydrological cycle and water resources availability; (ii) impacts on water demand and water supply economics; and (iii) necessary adaptation measures to build the country's preparedness to meet future situations due to climate change. In conclusion, it is likely that climate change will have a set of impacts on the water sector in Antigua and Barbuda, although the exact magnitude of these impacts still remain unclear. The data and modeling tool required for the assessment of these relationships will need to be strengthened. The most appropriate adaptation measure to mitigating possible impacts of climate change would be to launch a Water Resources Management Action Program in Antigua and Barbuda. A part of such initiative would be to strengthen water resources monitoring and information systems, as well as the legal and institutional framework for integrated water resources management. The report presents an outline description of such action program.

1. DEFINING THE PROBLEM

1.1 General

Climate change will probably lead to an intensification of the global hydrological cycle and is expected to have major impacts on water resources. A change in the volume and distribution of water will affect both ground and surface water supply for domestic and industrial uses, irrigation and instream ecosystems. Overall freshwater availability in Antigua and Barbuda is in the order of 220 m3 per person per year which falls far below 1,000 m3 per person per year - a common benchmark for water scarcity. Hence, the quantity and quality of water supplies in Antigua and Barbuda are particularly vulnerable to any reduction in available freshwater resources, and provision of safe and sufficient water supply already represents an important challenge of the nation.

Climate change impacts on water resources, future water demands and socio-economic development is a complex process, and this study represents an initial approach to quantify some of the key factors an give some preliminary recommendations related to the water resources sector. It is meant to assist policy and decision makers focus on the issues of climate change and management of water resources in a medium and long-term perspective. In order to assess the climate change impacts on the water sector it is suggested to address the following broad and interconnected components: (i) impacts on the national hydrological cycle and water resource availability; (ii) impacts on water demand and water supply economics; and (iii) adaptation measures to build the country’s preparedness to meet future scenarios, such as launching of an integrated water resources management strategy.

1.2 Goals of the Assessment

The primary goals of this project is to propose methods of addressing climate change impact on the water resources sector of Antigua & Barbuda, and to propose measures which can be adopted to minimize the negative effect and take advantage of possible positive effects. The particular goals are:

- ◊ to collect and examine background material in hydrology, basin characteristics, runoff, and current and future water use;
- ◊ to develop a methodology to establish a baseline and future projections related to water demand, water resources availability and variability;
- ◊ to identify possible impacts of climate change on the water resources sector and the socio-economic effects;
- ◊ to undertake case scenario studies and make projections to identify possible impacts;
- ◊ to identify appropriate adaptation policies and strategies and propose projects to enhance Antigua and Barbuda’s preparedness to cope effectively with recurrent climate variability and possible long term consequences of climate change.

1.3 Scope of the Study

The study covers the entire water sector of Antigua and Barbuda. It comprises a first step of a comprehensive view of climate change on water resources and related economic activities for the country a whole. For the assessment of the correlation between precipitation, recharge and runoff patterns a watershed approach has been suggested. The water supply and management assessment considers the three major freshwater resources utilised for water supply: (i) surface water; (ii) groundwater; and (iii) desalinated water. The national water distribution system is supplied by these three sources which form the major supply to vital economic sectors (hotels, government, domestic, agriculture etc.) of the economy. In addition, rainwater harvesting at household level is an important source of drinking water for the majority of the population.

2. THE WATER RESOURCES OF ANTIGUA AND BARBUDA

2.1 Watersheds

Antigua has been divided into 86 watersheds according to natural drainage boundaries. However, in 1985 the "Natural Resource Assessment Project" of the Organization of American States (OAS) aggregated these watersheds into 13 for land use, land capability and water resource planning. Six of the thirteen water-sheds have been identified as major catchments based on socio-economic and agro-ecological conditions. These major watersheds (Map 1, Annex 4) are listed in the table below.

Table 1 Major Watersheds in Antigua

Watershed	Area	Existing Store		Groundwater
	Watershed	Agriculture	Municipal	Yield
	hectares	m3	m3	mill m3/yr.
Creekside	4,000	200,400	278,000	390,000
Potworks	3,160	30,600	4,010,000	220,000
Christian Valley	1,780	9,200	166,000	610,000
Fitchers Creek	1,040	334,500		
Parham	1,472	33,400		
Bethesda	120	540,000		
Total	11,572	1,148,100	4,454,000	1,220,000

These major watersheds contain approximately:

- ⇒ 70% of Antigua's population.
- ⇒ 80% of ground water supplies.
- ⇒ 90% of surface water supplies.
- ⇒ 90% of crop production.
- ⇒ 43% of the island's land area.
- ⇒ 60% of total livestock population.
- ⇒ 50% of forest land.
- ⇒ centers of economic activity (tourism, fishing, etc.)

Available records for Barbuda show that the average rainfall of the island is averaging approximately 1000 mm. Although Barbuda is arid, most of the island is covered with evergreen woodland. Even if there are no perennial surface streams, there are some seasonal lakes in the inland depressions in the south of the island. The main source of water supply is groundwater, however the water in the wells is increasingly saline, and improvement of Barbuda’s water supply system is urgently needed.

2.2 Surface Water

Antigua has some 10 medium to small reservoirs and about 550 ponds and earth dams. The total combined capacity of all reservoirs, ponds and mini-dams is approximately 6 mill m3 (6000 acre-feet/1.6 billion imperial gallons).

Table 2. Agriculture Reservoir Location and Capacity in Antigua

Reservoir	Location	Storage (m3)
Bethesda	Bethesda	537,000
Red Hill	Red Hill	46,000
Gunthorpes #4	Gunthorpes	26,000
Gunthorpes #7	Gunthorpes	67,000
Olivers Dams	Olivers	59,000
ASF Dams	Sugar Factory	116,000
Langfords	Sugar Factory	110,000
Gaynors	Collins	32,000
Bendals	Bendals	23,000
Total		1,016,000

Table 3. Municipal Reservoirs of Antigua

Reservoir	Drainage Area (ha)	Spillway Elevation (m)	Storage Volume (m3)
Potworks	2,430	20.42	4,142,000
Collins	172	11.89	342,000
Wallings	44	150.88	51,680
Fig Tree	72	112.78	2,280
Dunnings	146	30.38	136,040
Brecknocks #1	56	73.15	20,520
Brecknocks #2	48	39.93	76,380
Hamilton	175	46.94	104,120
Body Ponds Fisher Finns	779	27.43	101,460
Total	3,922		4,976,480

Within major watersheds, there are important catchments which yield water to major reservoirs, which include:

Blubber Valley Catchment: the Blubber Valley Catchment supplies water to the Dunnings Reservoir. This stored water is then pumped eastward to the Bendals Water Treatment Plant.

Fig Tree Catchment: this catchment supplies water to the Fig Tree Dam. Water is pumped from this dam to the Wallings Reservoir where it is treated and gravity fed to a number of lower elevations in the water system.

Bethesda Catchment: the Bethesda Catchment supplies water to the Bethesda Reservoir (constructed in 1968). This water is normally used as an Agricultural supply, however, during some drought periods this water is pumped to the Delapps Water Treatment and added to the APUA supply network.

Potworks Catchment: the Potworks Catchment supplies to major Reservoirs (Potworks Reservoir and the Collins Reservoir). The Potworks Catchment is the largest of the APUA's National Water supply. Water from the Potworks Reservoir (constructed in 1975) is pumped to the Delapps Water Treatment Plant before pumping to the National Water system. The Collins Reservoir (constructed in 1966) is used primarily as recharge for some 4 wells located in the area.

Due to the low quality of the surface water from the reservoirs (high turbidity and bacteriological contamination) the water is being fully treated in mechanical-chemical treatment plants before disinfection. This is one of the reasons for the relatively high price of surface water supply.

2.3 Groundwater

The active ground water in Antigua consists of approximately 50 active wells with major well fields located in the Bendals Valley, Bolans and Collins areas. Wells have been drilled around Antigua but detailed information on the water bearing aquifers have not been recorded until recently. The major well-fields includes:

Bendals: these wells are located in the Bendals Valley. These wells supply water to the Bendals Valley area through an 8in. pipeline. There are some 13 operational wells in the Bendals area.

The Valley: these fields are located in the valley of the Southwestern part of the island between Jennings and Fryes Mill. There are about 20 wells which are developed in the unconsolidated alluvial deposits of Blubber, Christian, Roses, and Orange Valleys.

Cades Bay and Claremont: there are 5 active wells in this area which supply approximately 30,000 igpd from alluvial deposits. Water is pumped from the wells through a 150mm (6 in.) water mains which supplies the villages of Old Road, Urlings, Johnson's Point and Crabb Hill. The water in this area is treated with chlorine.

Follies: the Follies well-fields consist of 5 active wells located between the villages of John Hughes and Sweetes. The wells in this area are rested periodically and desalting water supplied. These wells produce about 152 m3/day (40,000 igpd).

Bristol Springs/Collins: These well-fields are located in the Eastern part of the island just East of the Collins Reservoir. The parent material in this area is limestone rock. There are 7 wells in this area which supply water to the Collins pump station where the water is chlorinated and distributed to Willikies, Newfield, St. Phillips, Mill Reef and Bethesda. The water abstracted from these fields is approximately 170 m3/day (150,000 igpd).

Groundwater is in principle hygienically safe, but some of the old wells contain saline water and have been abandoned.

2.4 Desalinated Water

There are two desalination systems situated at Crabbs Peninsular. One of the Plants is Government owned and through the process of flash distillation produces 10640 m3 (2.8 Million Gallons per Day (MGD). The heat which is generated by this process is used to power two generating plants that supplies a total of approximately 9.1 Mega-Watts (MW) of electricity to the National Electrical Grid. The other plant, which is privately owned, uses reverse osmosis to supply approximately 3040 m3 (800,000 gallons) of water per day to the national water supply system. This water, however, is somewhat brackish and requires further treatment (addition of phosphates) to reduce corrosion of pipelines. In terms of water quality desalinated water normally contain some residual salts and it has to be treated chemically to reduce its corrosion impacts on the distribution network and other water supply installations.

2.5 Rainwater Harvesting

Harvesting of rainwater by the households contributes an important source of safe drinking water provided the collection and storage system is kept in an hygienically good condition. By law all new houses are supposed to be equipped with rainwater collection and storage systems, and even if this law is not being duly enforced, most of the people build these systems in their own interest. For this assessment it is assumed that the average size of the storage is 200 m3 (50,000 gal) and the number of households is approximately 20,000.

2.6 Water Sector Issues

Some specific water resources issues of Antigua and Barbuda are as follows:

Water resources scarcity: When it comes to available freshwater resources per capita Antigua and Barbuda falls below the benchmark for water scarcity commonly used to describe the overall water resources situation in a country

High seasonal and inter-annual rainfall variability: Antigua and Barbuda are tropical islands with highly variable inter-annual rainfall variations (Figure 1) and most of the rainfall is received with severe intensity during the rainy season (July - December).

High exposure of water sheds to stress and pollution: the major water-sheds are exposed to a number of productive systems (crop, livestock, human settlement) that can cause the water capacity to be stressed and/or polluted. For example, the Creekside water-shed is impacted by the activities of the inhabitants of the villages of St. Lukes, Ebenezer, Cookes, Golden Grove, John Hughes and Buckleys.

Inadequate reservoir design and catchment management: Many of the water storage structures are not holding water effectively due to their design (embankment, spillway, etc.) as well as the management of the structure and its specific catchment area. Some of these watershed management problems include:

* employing bad farming techniques, such as slash and burn practices, planting up and down excessive sloping areas, and indiscriminate cutting of trees for charcoal,
* uncontrolled clearing of hillsides for housing.

High risk and vulnerability to flood and drought: some characteristics that make the country's watersheds vulnerable to changes in climate include:

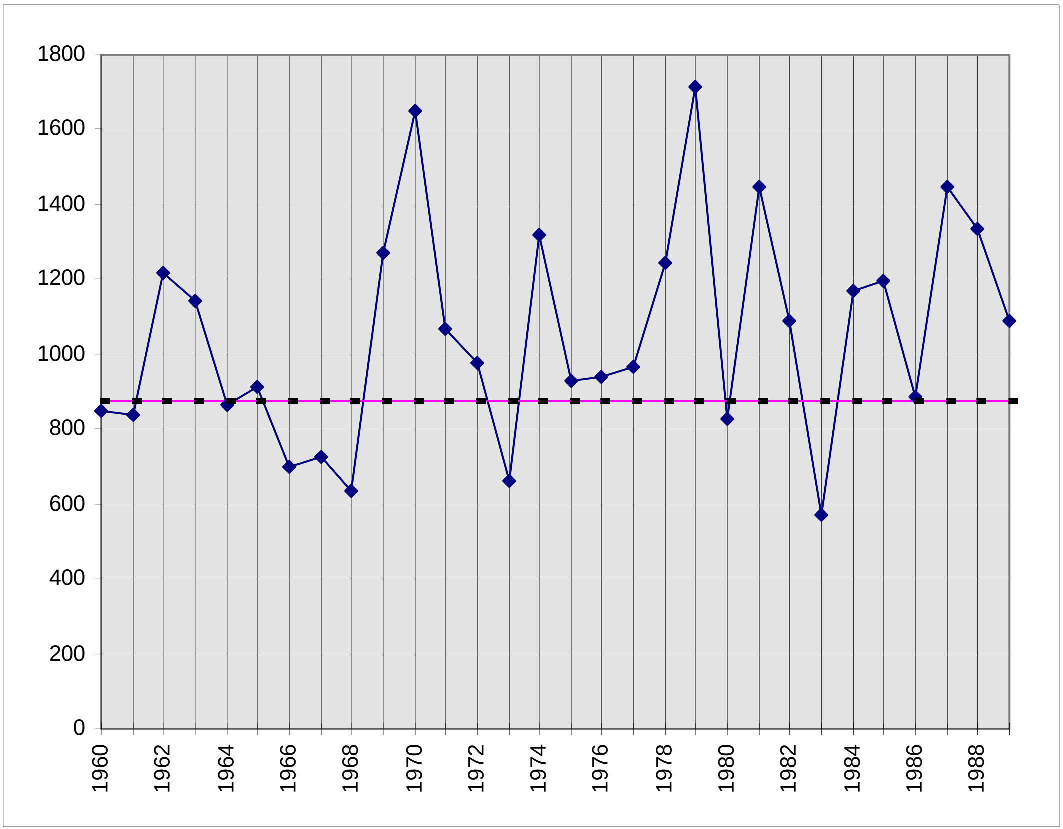
* A relatively low water storage capacity relative to the average streamflow in the basins each year. The Creekside Catchment has approximately 12% ratio of storage to annual water-shed flow while the Potworks Catchment has around a 90% ratio. This scenario would suggest that the Creekside Watershed is more vulnerable to flooding and drought.

* Regions that depend on groundwater for fresh-water needs like the St. Phillips Area and in particular the island of Barbuda. If climate change should decrease surface water availability it would also increase further demand for groundwater, thereby causing a mining of groundwater. This could also imply that desalinated water may prove necessary and cost of water production would increase accordingly.

Important abatement measures to reduce the risk and consequences of floods and drought is to maintain effective regulation capacity of stormwater runoff.

Sharing of water between sectors: at present, several major storages including Potworks are being used for both irrigation and municipal supply. However, during the drier months irrigation is restricted to smaller perimeters due to the shortfall in ground water yield, when most surface water is diverted to municipal supply. Mechanisms for allocation of water among municipal and economic sectors is an important water resource management issue

Legal and Institutional Framework - Water Resources Management: Water resources management in Antigua & Barbuda is vested in the Public Utility Act with Antigua Public Utilities Authority (APUA) as the implementing authority. To date there is no national water resources management policy or strategy, which should be in place to cope with the stressed water situation and the possible impacts of climate change.



Station: TAPA Location 17° 06’; 61° 47’W

Figure 1. Yearly Rainfall Distribution and Average Rainfall for the Period 1960 to 1989

2.7 The Socio-economic contribution of the water sector in Antigua and Barbuda.

Antigua and Barbuda has a small economy open to private sector development. The GNP per capita in this middle income economy was US Dollars 6390 in 1993. Tourism is the largest contributor to the country’s economy, and the fast expansion of this sector is supported by large private and public investments, trade and a number of other related services. The growth performance of the 1980s was accompanied by steady social development reflecting the strong commitment of the Government. Increased public investments in the social sectors were instrumental in improving access to health services, safe water supply and sanitation to almost 100 percent of the population. Indicators of life expectancy, infant mortality, malnutrition, and fertility of Antigua and Barbuda compares well with other middle income countries.

Although the revenues from the water supply sector as such has a less significant share of the Gross Domestic Product (about 3%), the national water distribution system forms a major input to vital economic sectors (tourism, government, domestic, agriculture) as well as it is imperative for public health and people's welfare.

The fast expansion of tourism and construction activities, has led to more intensive land use and increased pollution. The latter has started to threaten beaches, and the agriculture development has changed the watersheds by eroding the forest cover aggravating the effects of erosion and siltation. Improved water resources management will be particularly important because of the fragility of the watersheds, and the significant effects of neglect on this small territory. The challenge for the future will be to integrate water resources and environmental concerns in investment programs and policy frameworks to ensure sustainability for future growth, and to build the institutional capacities to implement priority programs and to monitor compliance.

2.8 Current Plans for Development of Water Resources in Antigua & Barbuda

APUA has plans to further develop the water supply systems of the islands to meet the growing demands. These plans include increasing the supply capacity by construction of new works and reservoirs and rehabilitation of existing ones. A few examples of current plans for development of the water sector in Antigua and Barbuda are as follows:

More desalination capacity: the Government of Antigua & Barbuda has plans to install a desalination plant in Barbuda. This will augment the existing well water supply which proves to be saline during dry conditions. Also private investors are planning new desalination plants.

Exploration of deep aquifers: the APUA in collaboration with the Government will commission an International Company to conduct a hydro-geological survey of Antigua with a view towards developing deep wells. In such instances wells will be dug into bedrock in excess of 180m. to search for pockets of water.

Automatic water transmission control: the Water Division is also in the process of automating the pumping stations as well as the water levels in holding tanks. This will allow the national water transmission and distribution network to function more efficiently and provide a more reliable supply to the consumers.

Reduction of unaccounted for water: APUA has initiated a comprehensive program to reduce the high portion of unaccounted for water (40%). The action plan includes leakage and wastage control, but also by reducing the number of illegal connections etc.

In addition to the above short and medium term activities, the authorities of Antigua and Barbuda should consider to develop and implement a long term integrated water resources management strategy. The Country Case Study on Climate Change Impacts provides an excellent opportunity to promote further preparations in this direction, which will be further elaborated upon in this report.

3. METHODOLOGY AND APPROACH

3.1 Rainfall - Runoff Correlation

A number of methods could be applied for the assessment of the consequences of climate change for the water resources. The specific methods of assessment will necessarily have to take into account the actual situation and address priority issues identified by the authorities of Antigua and Barbuda. The selection of appropriate methodology to describe the baseline situation and possible water resource scenarios has taken into consideration the inadequate knowledge about the hydrological characteristics and limited availability of data for quantitative assessment of the impacts.

The hydrological characteristics of the past and current situation is the basis of the water resources climate impact assessment. There are no perennial streams in Antigua and Barbuda and the streams go dry when much time elapses between rains. The rainfall distribution is typical of the more intense storms that occur over short periods of time. The resulting runoff is highly dependent on the kind of soil and the type of vegetation growing in the watersheds, agriculture development in addition to its topography and shape. Evapotranspiration is believed to be a major cause of runoff losses in the catchments.

Due to lack of streamflow records and a precise analytical method of determining the amount of runoff in an unmonitored watershed, the study team considered alternative approaches to describe watershed recharge and runoff patterns. An approximation would be to calculate the water balance over the storage reservoirs over certain periods of time in selected reference sheds. The method suggests calculation of monthly streamflows on the basis of rainfall data, reservoir records and pertinent water production figures, and make rainfall - runoff correlation plots. For this exercise, reservoir operation records have been provided by APUA, and corresponding rainfall statistics have been obtained from the Meteorological Department. Figure 2 illustrates the main features of this water balance model.

The suggested approach can not be expected to have a high order of accuracy due to the scarcity of data. Simulation techniques based on hydrological records including the infiltration characteristics of the soils, measurements of soil moisture, evaporation data, and other important factors influencing the basin recharge and runoff conditions would provide a more reliable answer. One of the shortcomings of this water balance model is that it is based on average monthly data, and does not take into account daily or hourly precipitation events, (intensity-duration-interval) which would affects evapotranpiration and the response of the watershed to rainfall inputs, even if the average monthly rainfall is in the same order of magnitude.

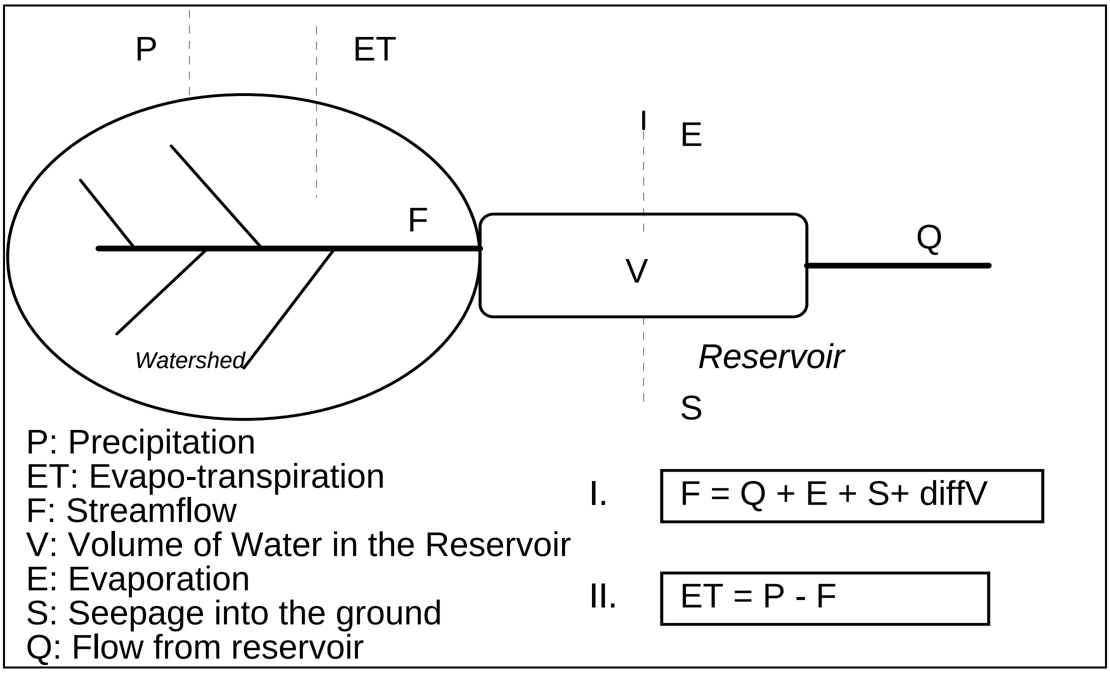


Figure 2. Model for Approximation of Rainfall - Runoff Correlation

The next step will be to estimate the effect of climate change on water resources, which will depend on the ability to relate change in actual evapotranspiration to the predicted changes in precipitation and potential evapo-transpiration. Such analysis can only be based on some agreed assumptions on the impacts of the anticipated temperature increase on the overall evapotranspiration in the watersheds.

3.2 Water Demand Projections

The estimates of existing water demands by sector and water resource is by and large based on data from APUA complemented with estimates of additional household rain harvesting and private dams for irrigated agriculture. The future domestic water demand are assumed to increase in proportion to the population growth. It is assumed that that domestic per capita water consumption remains constant over the next 20-25 years, although it should normally increase with improved standard of living. This assumption is, however, takes into account that the potential per capita increase will be compensated by the expected positive effects of water saving measures and awareness campaigns. When it comes to the projections of future demands for agriculture and tourism it is assumed that these will increase in proportion to anticipated economic growth for these sectors, using the medium economic growth scenario for each of the sectors as a basis.

3.3 Selection of the Study Areas

The Water Resources Sector Study basically covers the whole of Antigua and Barbuda. Since the country is located in a single hydroclimatic zone, a single basin approach can be used. The study team decided to concentrate on two watersheds as reference areas for the hydrological analysis, the Potworks and Creekside watersheds. The Potworks watershed, being the most important one provides more than 90% of the island's surface water supply. The Creekside Watershed is selected because it is the second largest watershed and also due to its low reservoir capacity vs. runoff ration. Data and hydrological characteristics and the results of the assessment of these two watersheds serve as a basis for the analysis of other watersheds in Antigua and Barbuda.

The Potworks Watershed is located in the southern part of the central plain region. This watershed, which supplies the Potworks and Collins Reservoirs, includes 2600 hectares (6,500 acres) drainage area which are sparsely covered with vegetation. Inhabited areas occupy only 5% of the watershed with the remainder being pasture and agricultural land. Relatively large scale agriculture is being carried out on the land adjacent to the Potworks Reservoir which does cause some concern relative to silting and organic and bacteriological contamination. The topography of the watershed is that of low lying land, and the entire watershed is less than 830 meters (250 feet) above the sea level. The two reservoirs within the watershed has a combined storage capacity of 4.5 million m3 (1,180 million imperial gallons). The Potworks Reservoir, which was constructed in 1968, is by far the most significant surface water reservoir in the APUA system representing over 83% of the total surface storage capacity. It receives runoff from a drainage area of 430 hectares (1,071 acres). Its maximum surface area is about 192 hectares (475 acres) has extensive shallow zones with high evaporation rates.

The Creekside Watershed is with its 780 hectare (1947 acres) is the second largest surface water source in the APUA water supply system. *(The analysis of the Creekside Watershed has not been included in this draft report due to time limitations, but will be considered as a part of the final report.).*

3.4 Time Frame

The time frame for the assessment of climate change impacts on the water resource sector is by and large the same as for other sectors. The main difference is that the water demand projections can only be done with some degree of certainty by 10 year intervals up the year 2020 due to lack of socio-economic projections beyond that year. Assessments of the situation from 2020 to 2050 would therefore have to build on qualified extrapolations in consultation with the other Sector Country Case study teams.

3.5 The Applied Temperature Change Scenario

It is important to establish a common base for all Country Case Study Components concerning projected temperature changes. Mean temperature predictions between 1995 and 2075 has been received from the Meteorological Department, suggesting an overall increase of 1.25 ^{o}C. The proposed mean temperature change shown in Table 4 could be used as the anticipated temperature change over the assessment period.

Table 4. Assumed Temperature Increase between 1995 and 2075

Year	Mean Temperature ^{o}C	Temperature Change ^{o}C
1995	29.5	0
2001	30.08	0.58
2011	30.17	0.67
2021	30.26	0.76
2025	30.30	0.80
2050	30.53	1.03
2075	30.75	1.25

3.6 Other Data Needs

It is important that the selected approach and methods require data which can be easily obtained. Emphasis has been placed on making the techniques simple and allow users to assess climate change impacts on water resources. The data required consist of hydro-meteorological data, water use information and socio-economic statistics. In the case of Antigua & Barbuda emphasis will be given to appropriate and reliable data so as to generate meaningful results, taking into consideration the special features of the country. Most of the data about hydro-meteorological conditions, reservoir yields and water production data needed was obtained from the Meteorological Department, APUA, and Ministry of Agriculture. The socio-economic data for the water sector study was provided by the Department of Statistics in a table named "Projected Gross Domestic Product by Economic Activity". Moreover it is assumed that the existing water tariff structure and unit production costs are applicable in the future.

4. RESULTS OF THE ANALYSIS AND ASSESSMENT OF IMPACTS

It should be noted that the specific numerical results of the analysis are not meant to be interpreted as representing likely future conditions. The focus should rather be on the general insights gained regarding the underlying determinants of water resource issues.

4.1 The Baseline: current status of water resources in Antigua and Barbuda

Table 5 gives a summary of the current water resources and water supply situation in Antigua and Barbuda.

Table 5. Current Water Resources and Water Demand Situation

KEY DATA		
Population	65000	
Area Antigua	277 km2	
Area Barbuda	161 km2	
Precipitation Antigua and Babuda	1000 mm	
WATER RESOURCES	acre-feet	mill m3
Existing storage capacity surface water	6000	6.2
Potential storage capacity surface water	7090	7.3
Total storage capacity/yield surface water	13090	13.5
	acre-feet/yr	mill m3/yr
Theor. Surface Water Yield (10% of precip. in watersheds)	7350	7.6
Groundwater yield	1260	1.3
Desalination capacity	5130	5.3
Total renewable water resources capacity	13,740	14.1
Per capita renewable water resources		217.1
WATER SUPPLY BY SOURCE	mill gal./mo.	mill m3/yr
Groundwater (APUA)	14	0.6
Surface Water (APUA)	19	0.9
Rainwater Harvest (private) (estimated)	3	0.1
Surface Water (private dams) (estimated)	2	0.1
Desalinated Water (APUA)	62	2.8
Total Water Production average 1993-96	**100**	**4.6**
WATER CONSUMPTION BY SECTOR	mill gal./mo.	mill m3/yr
Domestic Water Supplied by APUA	30	1.4
Rainwater Harvesting (private)	3	0.1
Commercial & Hotels (APUA)	17.5	0.8
Government (APUA)	3	0.1
Agriculture (APUA)	1.5	0.1
Agriculture (private dams)	2	0.1
APUA	0.25	0.0
Unaccounted for Water physical+commercial (APUA)	42.75	1.9
Total Water Supply, Average 1994&96	**100**	**4.6**

4.2 Prediction of future scenario

The numerical basis for the water resources and water use projections in Figure 3 and 4 is presented in Annex 1.

4.2.1 Water Resources Projections

A preliminary assumption for the water resource development in the future are the following two scenarios:

* Scenario 1: No development of additional surface and groundwater sources and supply capacity in the future and that the increase in water demand will be covered by desalinated water.

* Scenario 2: Doubling of the surface and groundwater production towards the year 2020, and cover the gap with desalinated water.

The assumptions for these two scenarios have to be adjusted in accordance with plans for more desalination capacity and anticipated surface and groundwater development. The water resource situation is already dominated by supply of desalinated water, and unless substantial investment will be made in new reservoir and treatment capacity for surface water and groundwater resources these two water resources would be small compared to desalination in the future, as indicated in **Figure 3**. If the development should follow Scenario 2 in **Figure 4**, surface and groundwater would account for more than 50% of the total supply.

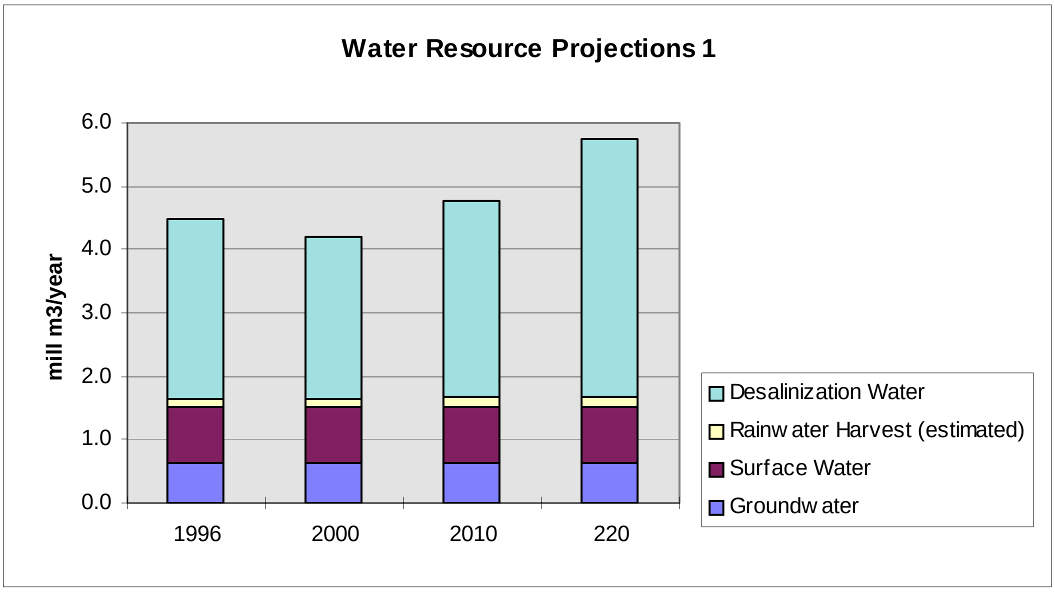


Figure 3. Water Resources Projections in the Case of Constant Groundwater and Surface Water Supply

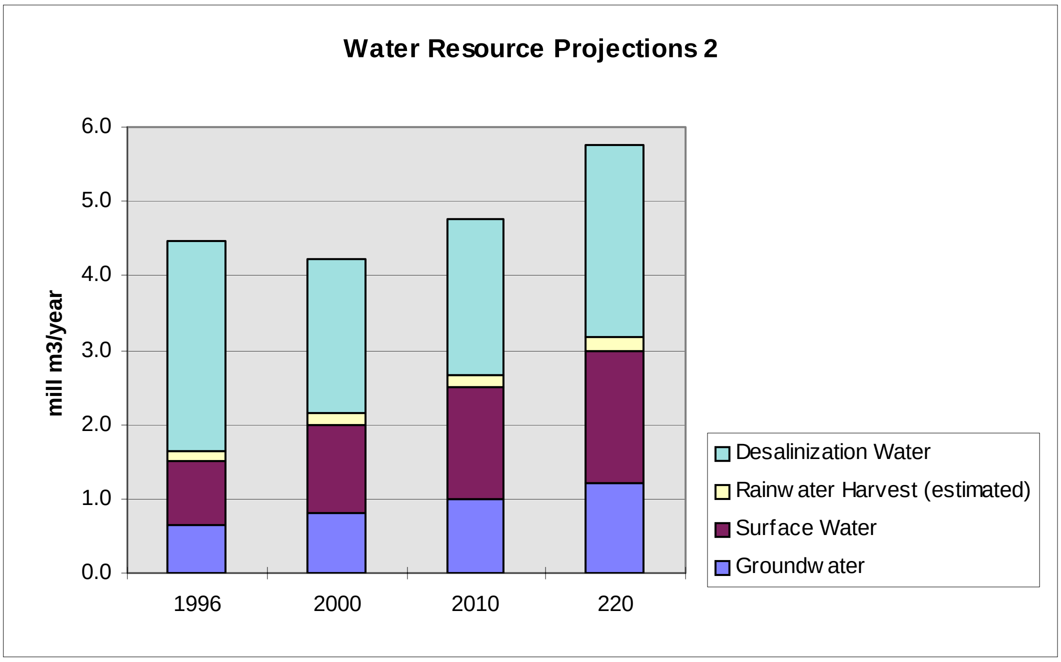


Figure 4. Water Resource Projections in the Case of Doubling the Surface and Groundwater Production Towards the Year 2020

4.2.2 Water Use by Sector

Water use by sector (**Figure 5**) shows the expected impacts of the ongoing program for reduction of unaccounted for water. It also illustrates that the highest increase is related to the tourist sector development.

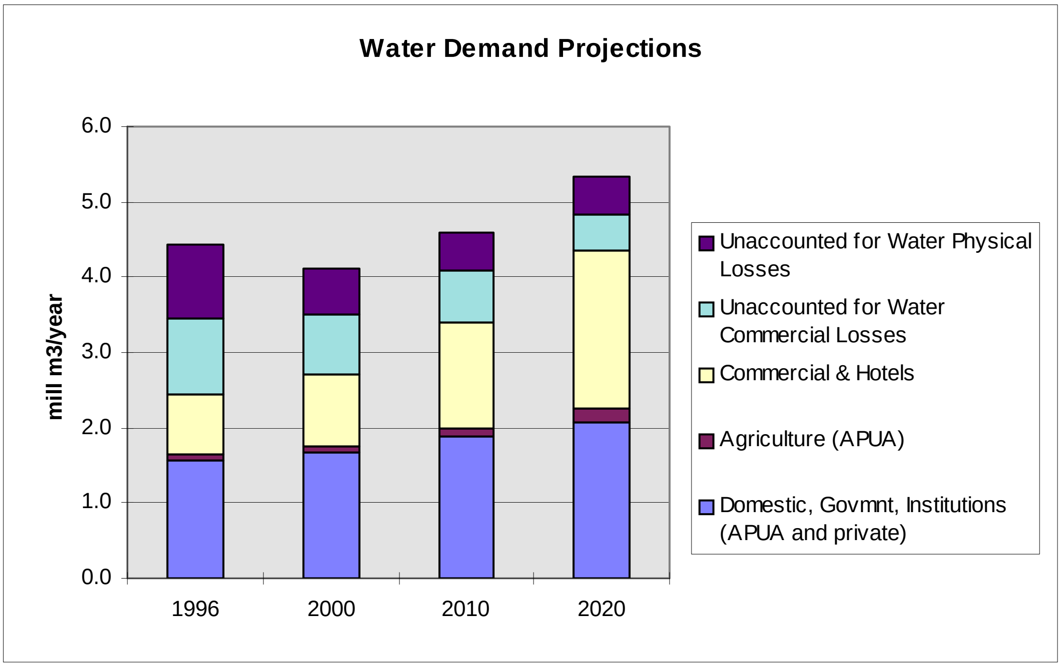


Figure 5. Water Demand Projections

4.3 Rainfall - Streamflow and Reservoir Correlation Analysis.

The results presented in this section are based on rainfall data, reservoir volume and water abstraction from the Potworks dam during the three years 1994, 95 and 96. The complete database and calculations are shown in the spreadsheet in Annex 3. The average rainfall in the three reference years was as follows:

Year	Annual Rainfall (mm)	Average Monthly Rainfall (mm)
1994	774.5	65
1995	1277.2	106
1996	915.2	76

4.3.1 Correlation between Filling of Reservoirs and Rainfall

The timeline presentation of rainfall and water volume in the Potworks dam (**Figure 6**) shows some interesting patterns concerning the influence of precipitation on filling of reservoirs. These observations illustrate that the filling of the reservoir seems to depend not only on the amount of rainfall during the peak months, but also to the rainfall distribution over the peak month. For example, the peak rains in September 1994 appear to have only minor impact on the replenishment of water in the reservoir, whereas the peak rains in August-September 1995 filled the reservoir completely (4,142,000 m3). According to **Figure 7**, the September 94 rainfall pattern had four smaller peaks distributed over the maximum month, whereas, in August 95 more than 50% of the monthly rainfall came in one day.

Although this observation is based on a very limited period of time, it indicates the importance of daily rainfall distribution and intensity on the filling of reservoirs. This indicator should therefore be considered together with annual rainfall when assessing drought and water scarcity from rainfall data. The importance of rainfall intensity on reservoir filling was also underlined by APUA. The above phenomenon will also have bearings on the assessment of the impacts of climate change on the water supply situation, as extreme rainfall patterns seems to have a positive effect on reservoir filling compared to the more evenly distributed rainfall patterns.

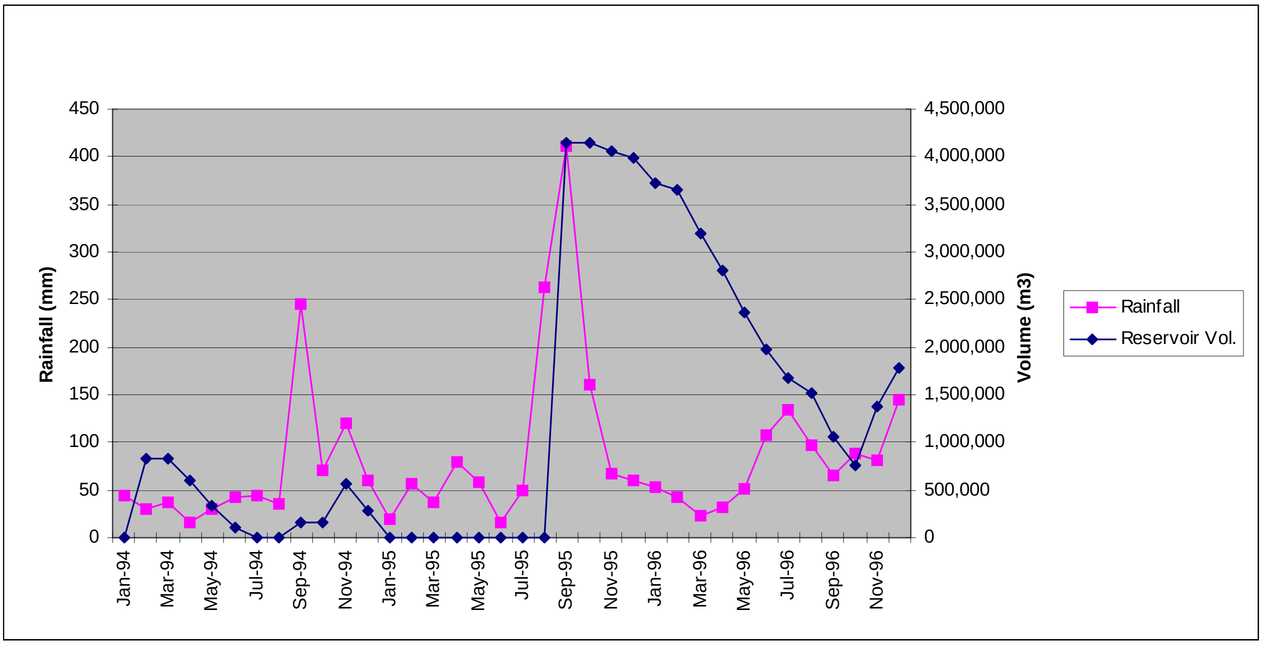


Figure 6. Rainfall and Reservoir Volume Potworks Watershed

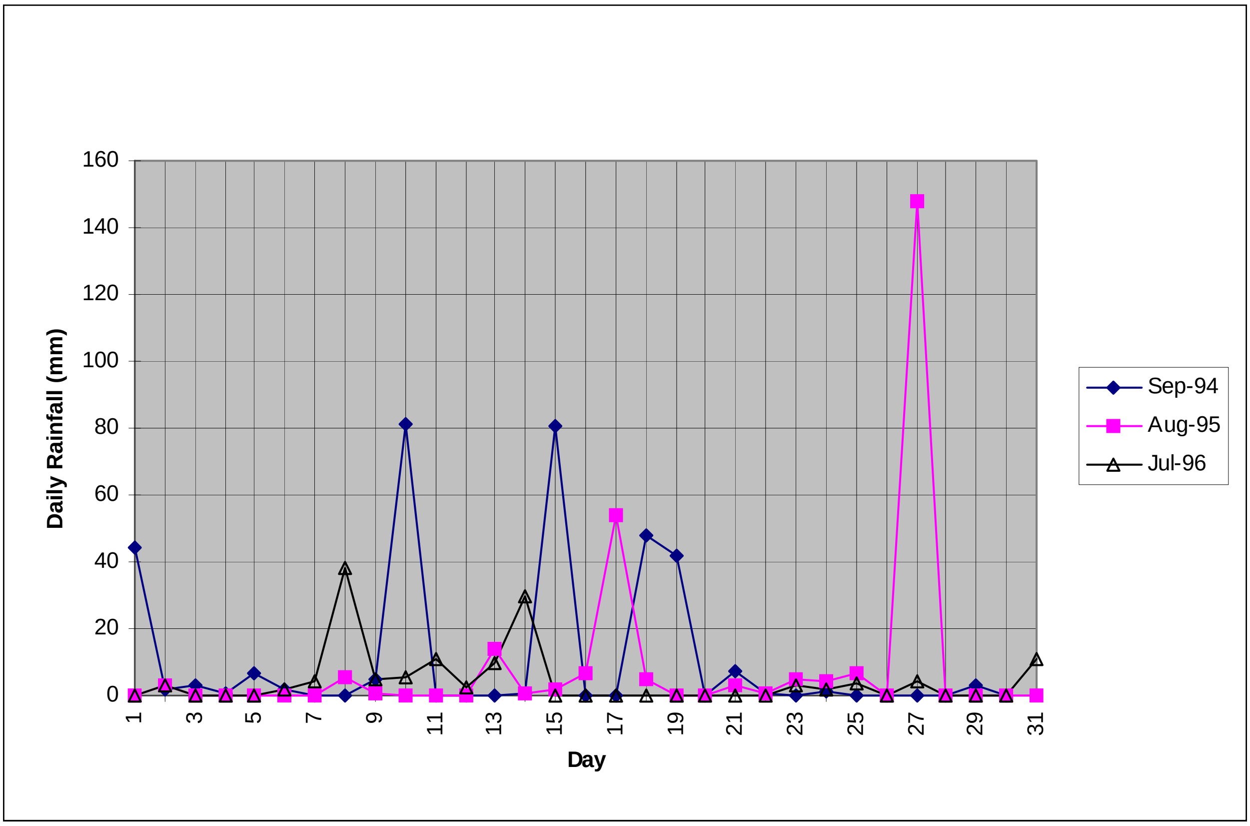


Figure 7. Daily Rainfall During Three Peak Months

4.3.2 Reservoir characteristics

One interesting factor is the total evaporation, seepage and other losses from the reservoirs. Looking at **Figure 6**, the most suitable period for such assessment should be the period of December 1995 through May 1996, because (i) the dam was almost full at the beginning of the period, and (ii) it was moderate rainfall during the period so the streamflow into the reservoir could be neglected. By using a simple mass balance the losses from the dam could be estimated as follows:

Table 6. Water Balance over Potworks Reservoir (December 1995 - May 1996)

Month	Rainfall	Reservoir Vol.	Reservoir Area	Rainfall on Dam	Evaporation and Seepage		Outflow Water Supply
	mm/mo.	m3	ha	m3/mo.	mm	m3/mo.	m3/mo.
Nov-95	66.2	4,066,000	188	124,456	155	291,400	135,052
Dec-95	60.3	3,990,000	184	110,952	155	285,200	99,127
Jan-96	52.2	3,724,000	180	93,960	155	279,000	63,954
Feb-96	42.2	3,648,000	176	74,272	155	272,800	78,394
Mar-96	22.1	3,192,000	172	38,012	155	266,600	125,704
Apr-96	31.3	2,812,000	164	51,332	155	254,200	105,640
May-96	50.7	2,356,000	152	77,064	155	235,600	83,220
Tot (m3)		1,710,000		445,592		1,593,400	556,039

The evaporation and seepage (mm per month) from the dam has been calculated to fit the following balance:

(Reservoir Volume difference + Rainfall on Dam) = (Evaporation and Seepage + Outflow Water Supply)

The estimated losses (evaporation and seepage) is **155 mm per month** (5 mm per day). This is an important parameter in planning and operation of water reservoirs. In fact, the losses from the Potworks reservoir was about three times the outflow for water supply during the 6 month period (**Figure 8**). In general it has been observed that only about 10% of the rainfall in a catchment area will be utilized for water supply.

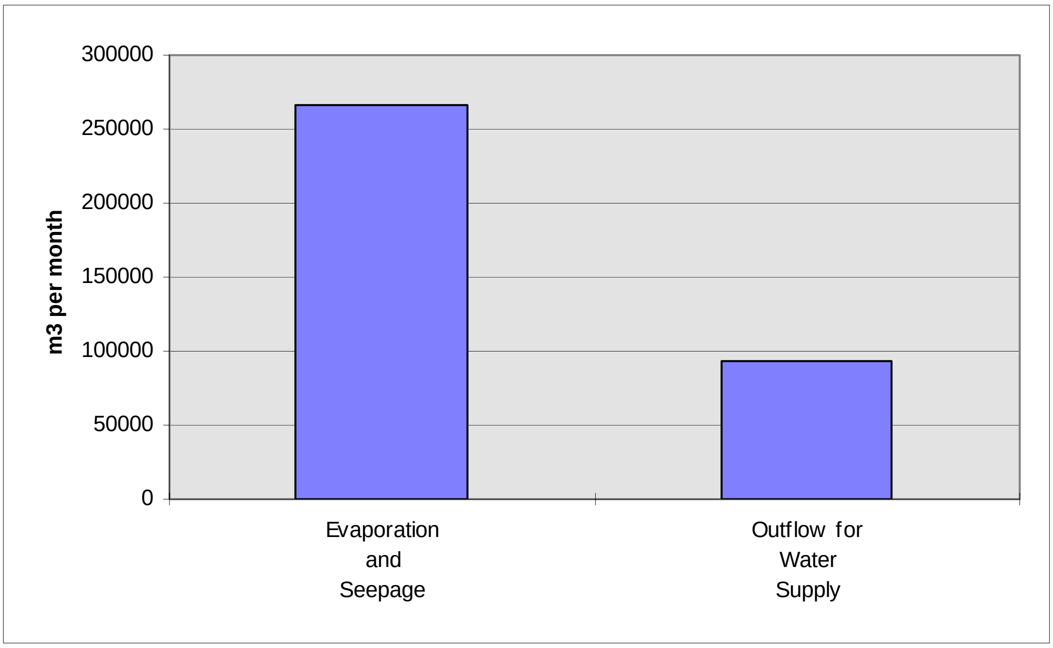


Figure 8. Reservoir Losses (Evaporation and Seepage) versus Outflow for Water Supply at Potworks Reservoir

4.3.3 Streamflow versus Rainfall

The evaporation and seepage figures estimated in section 4.3.2 for the Potworks Reservoir has been us in the model to approximate the correlation between rainfall and streamflow (Annex 3). Due to the use of monthly lumped figures for precipitation as well as dam volume the attempted correlation between streamflow and rainfall turned out to be quite scattered as shown in **Figure 9**. All negative streamflow values have been set as 0 in this plot. In order to picture the monthly streamflow - rainfall variations it was decided also to present the results as a timeline (**Figure 10**). It is recommended to establish hydrometric stations in some of the strategically important water courses in order to improve the water resources assessment through more reliable streamflow data for reservoir and water supply management.

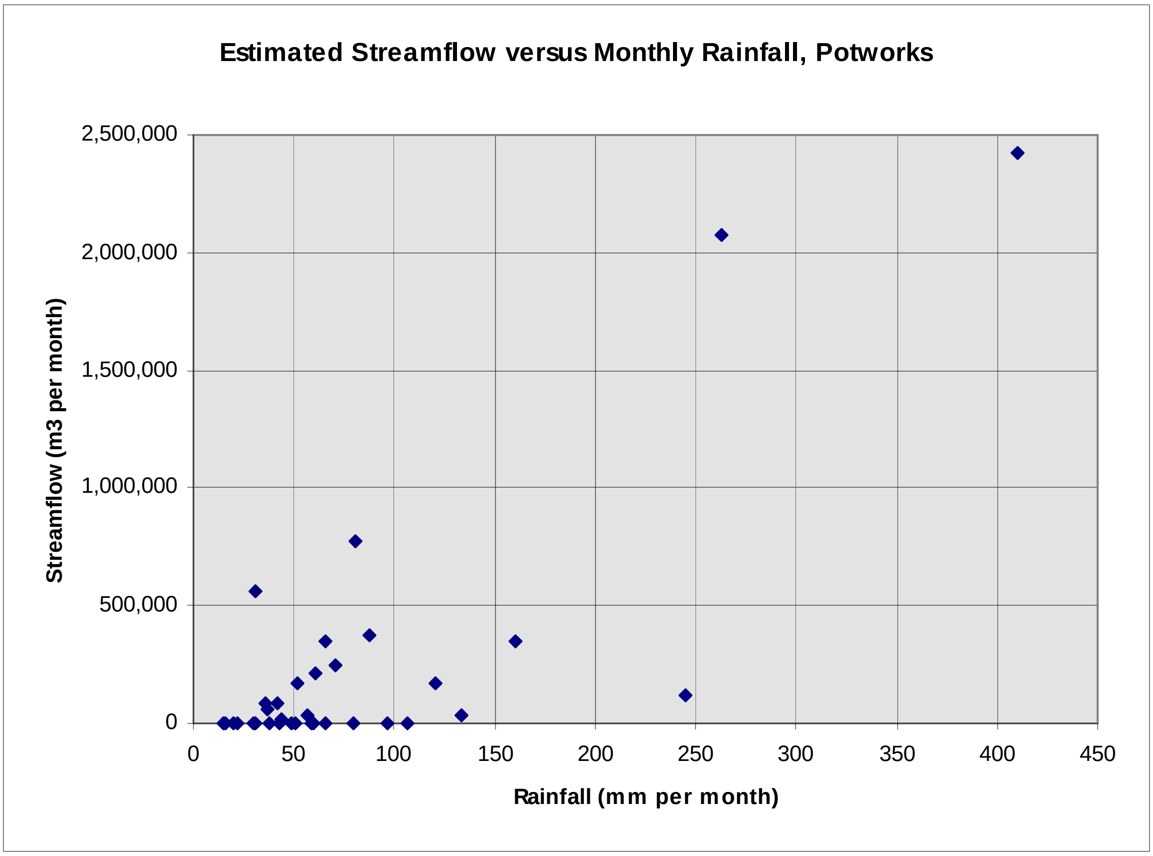


Figure 9. Estimated Monthly Streamflows versus Rainfall, Potworks Watershed

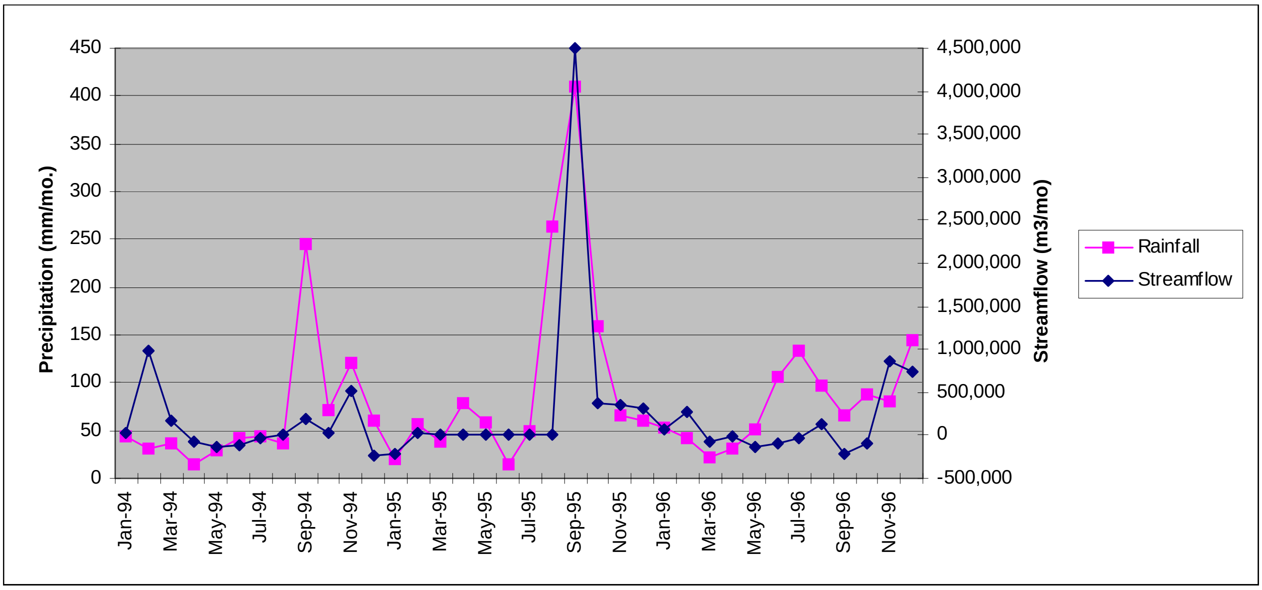


Figure 10. Result of the Streamflow versus Rainfall Approximation, Potworks Watershed

4.4 Possible Climate Change Impacts

4.4.1 General

Although the specific local effects of climate change remain uncertain, changes in the total amount of precipitation and in its frequency/intensity will directly affect the magnitude and timing of runoff and the intensity of floods, droughts and hurricanes. As has been demonstrated in this report, the current climate variability is already having substantial impacts on the inter-annual water resource situation in Antigua and Barbuda even before the effects of climate change are in place.

4.4.2 Impacts of Climate Change on Surface Water Resources

The freshwater resources of Antigua and Barbuda is already under severe strain from population growth and expanding economic activity. Climate change will lead to an intensification of the hydrological cycle and can have major impacts on the national water resources. Higher temperatures will lead to a more vigorous hydrological cycle which may lead to more severe droughts and/or floods. Increase the average temperature of the surface, and the evapotranspiration cycle is also expected to speed up leaving the soils drier during critical parts of the growing season, and reduce the runoff to the water reservoirs. The latter would have consequences for the supplies of freshwater to the communities.

The quality and quantity of water supplies is already an important issue in Antigua and Barbuda, making this country particularly vulnerable to any additional reduction in water availability. Availability of natural freshwater resources including the desalination capacity is currently about 220 m^3 per person per year which falls below the common benchmark for water scarcity of about 1000 m^3 per person per year. A change in the volume and distribution of water will affect both ground water and surface water supply for domestic uses, hotels, cruise liners, commercial, irrigation, instream ecosystems, water based recreation and other important freshwater requirements.

4.4.3 Impacts on the Filling of the Reservoirs

The reservoirs are the main hydraulic structures in flood control and storing of water for supply over longer periods. It appears that the total reservoir storage capacity is only equivalent to about one year’s water demand, and is therefore dependent on full annual replenishment to avoid shortages. Relatively small changes in temperature and precipitation, together with progressive effects on evapotranspiration and soil moisture, can result in relatively large reductions in runoff due to the combined effects of increased evapotranspiration and decreased precipitation. However, more intense rainfall would tend to increase runoff and risk of flash flooding, which would be caused not only by the change in rainfall but also on catchment physical and biological characteristics. Attempts have been made to evaluate the connections between precipitation and surface runoff in the intermittent streams of Antigua and Barbuda. Preliminary observations suggest that high intensity rainfall situations are more favorable than more evenly distributed rainfall over the peak months when it comes to filling the reservoirs. Experience from recent years shows that this system is highly vulnerable, even to marginal changes in rainfall amounts and patterns. In order to analyze the overall effects of these mechanisms, the data base and analytical tools need to be further developed.

4.4.4 Impacts on the losses from the reservoirs

The reservoir losses (evaporation and seepage) is three times as high as the outlet for supply in the Potworks reservoir. The losses have been estimated to 155 mm per month (5 mm per day), and an increase in temperature would have negative consequences for the storage capacity in terms of higher losses than today.

4.4.5 Impacts on Water Supply Costs, Water Tariffs and Employment

Water is already an expensive commodity in Antigua and Barbuda compared to most other countries. According to APUA, typical production costs in US$/m3 for the three main water sources are:

Groundwater	Surface Water	Desalinated Water
2.5 US$/m3	3.0 US$/m3	4.7 US$/m3

Lack of developed freshwater resources will have to be compensated by building more surface and groundwater supply capacity or stepping up the production of desalinated water. Both actions will lead to increased water costs. The difference between water production costs and water revenues (Annex 1 & 2) shows that piped water is already a subsidized commodity. A question is whether this situation will prevail, or if the consumers have to pay the real cost in the future. It is assumed that the existing differentiated tariff structure will be maintained, which means that certain consumer groups have to pay a higher price. The impacts on the water production costs for the two described water resource scenarios (section 4.2.1) are illustrated in the two tables below. It should be noted that the analysis is based on the current unit costs, and the investment component has not been included here. The alternative of using desalinated water to fill the future water resource gap (Scenario) would increase the 2020 overall production costs by US 0.50 per m3, which would raise the annual production costs from 20.50 to 23.36 mill US.

Scenario 1: Prediction of Water Production Cost in the Case of Constant Surface and Groundwater Supply

	1996	2000	2010	2020
Groundwater	1.60	1.60	1.60	1.60
Surface Water	2.60	2.60	2.60	2.60
Desalinization Water	13.29	12.05	14.54	19.17
Total Production Costs (mill US per year)	**17.48**	**16.24**	**18.73**	**23.36**
Average Production Costs US$ per m3	3.86	3.86	3.93	4.05

Scenario 2: Prediction of Water Production Cost by Doubling of the Surface and Groundwater Supply Component Towards the Year 2020

	1996	2000	2010	2020
Groundwater	1.60	2.00	2.50	3.00
Surface Water	2.60	3.60	4.50	5.40
Desalinated Water	13.29	9.72	9.86	12.14
Total Production Costs (mill USS per year))	**17.48**	**15.32**	**16.86**	**20.54**
Average Production Costs US$ per m3	3.86	3.64	3.54	3.56

The employment within the water sector will probably be affected by both scenarios, as there will be extensive construction activity and a possibly higher demand for skilled operators for the new plants.

4.4.6 impacts on Water Dependent Sectors

The water related sectors (chapter 2.6) is already used to consider water as a precious commodity, and a possible water tariff increase due to higher production costs is so far believed not to significantly affect these sectors. This issue has to be examined more in detail.

5. ASSESSMENT OF ADAPTATION MEASURES

5.1 Adaptation to Changes in the Hydrological Cycle

Options for coping with the possible impacts of changed climate and increased uncertainty about future supply and demand for freshwater include more efficient management of existing supplies and infrastructure, institutional arrangements to limit future demands/promote conservation, improved monitoring and forecasting systems for floods/droughts, rehabilitation of watershed, especially relevant for Antigua and Barbuda, and construction of new reservoir capacity to capture and store excess flows produced by altered precipitation, runoff patterns, and storms.

5.2 Technological Options

5.2.1 Desalination

Due to the limited possibilities of increasing the storage capacity of surface water Antigua and Barbuda is dependent on supplementary production of freshwater from desalinization of seawater or saline groundwater. The desalinization process is rather expensive, and the high water cost will prohibit use of this water for irrigation without subsidizing the supply. The selection of desalination technology is also an important issue. The flash destination techniques gives much lower residual flows, and it has the advantage of energy recovery. The membrane filtration technology gives a small freshwater flow compared to the total raw water consumption. This must be kept in mind in connection with desalination of saline groundwater since the groundwater would be subject to over-exploitation compared to the amount of freshwater produced. This could lead to a fast deterioration of adjacent groundwater resources through saltwater intrusion.

5.2.2 Import of Water

A supplementary solution would be to import water from outside the territory provided it is competitive to desalination. New technology of towing water in large 100,000 m3 plastic bags is now being developed as an alternative to the more expensive transport in barges or tankers.

5.2.3 Water Saving Devises and Reduction of Unaccounted for Water

Modern household utilities and water saving techniques have to be considered carefully as water demand management measures.

5.2.4 Rainwater Harvesting

Harvesting of rainwater is a high potential option for supplementary water supply in Antigua and Barbuda. This method does not require expensive treatment, and the is much more efficiently collected than water from the streams. Policies, laws and regulations need to be revised and enforced in order to develop this concept in a systematic way. This could be part of the water resources management initiative.

5.2.5 More Reservoir Capacity.

The feasibility of construction more dam capacity to meet future requirements for flood control and water supply should be investigated.

5.3 Economic, and Social Adaptation

Economic and social adaptation should be an integrated element in a new water resources management strategy.

5.4 A New Strategy for Water Resources Management

A Water Resources Management Action Plan - Preliminary Project Proposal

Freshwater resources of Antigua and Barbuda are already limited and increasingly scarce and polluted due to population growth, socio-economic development, agriculture, industrialization and tourism. The inadequacy of water resources and the intensifying competition for clean water now call for a move towards an integrated water resources management initiative which would be one of the most important actions to meet the water sector challenges caused by current climate variations as well as the possible impacts of climate change in the future. In response to the above need the national study team has proposed a Water Resources Management Action Program, which sets out to develop and implement strategies for national water resources management, and at the same time building awareness and capacity across society. It is proposed that the overall objective of the Water Resources Action Program will be to strengthen national water legislation and policies and to develop strategies for how Antigua and Barbuda is going to manage its water resources in an economic, social, and environmentally sustainable way in the future. Specific objectives related to this Action Plan would be:

◊ to mobilize and build capacity within the public and private sector for cross-sectoral water resources management;
◊ to analyze necessary legal and regulatory framework;
◊ to build awareness across society of the challenges and opportunities in the management of water resources;
◊ to ensure participation of civil society as stakeholders in water resources management;
◊ to develop appropriate water resources monitoring systems and information services;
◊ to review and analyze key issues constraining effective water resources management, bringing international expertise to bear, where necessary;

The Action Plan is proposed to have three broad phases, as follows:

Strategy Development: Identifying key issues constraining effective water resources management, undertaking analysis of these issues, identifying possible solutions and recommending options for implementation;

Consultation: designing and implementing a national program for public consultation and awareness raising in the water resources management;

Implementation: implementing integrated water resources management and planning program, adopting the policies and strategies developed in the first stage of the Action Plan and endorsed by the Government of Antigua and Barbuda.

Funding to launch the above process should be sought from relevant international climate change and water resources programs. A first step towards a Water Resources Management Action Program would be to establish the Terms of Reference for an preparatory study to develop the common directions for the proposed process.

6. CONCLUSION

It is likely that climate change will have a set of impacts on the water sector in Antigua and Barbuda, although the exact magnitude of these impacts still remain unclear. The data and modeling tool needed to assess of these relationships will need to be strengthened, and the most appropriate adaptation measure to mitigating possible impacts of climate change would be to launch a Water Resources Management Action Program in Antigua and Barbuda. A part of such initiative would be to strengthen water resources monitoring and information systems, as well as the legal and institutional framework for integrated water resources management. The report presents an outline description of this program.

Appendix A. Predictions 1996 - 2020 of Water Resources, Water Demand, Production Costs

Scenario 1

BASIC ASSUMPTIONS FOR FUTURE PROJECTIONS

	1996	2000	2010	2020
Population (Medium Scenario)	68100	72300	81000	89500
Domestic Water m3/capita*day (as per econ. growth)	0.063	0.063	0.063	0.063
Agriculture (relative econ growth, Medium Scenario)	1	1.19	1.76	2.62
Hotels & Commercial (Medium Scenario)	1	1.19	1.76	2.62

WATER DEMAND PROJECTIONS
mill m3/yr

	1996	2000	2010	2020
Domestic, Govmnt, Institutions (APUA and private)	1.6	1.7	1.9	2.1
Agriculture (APUA)	0.1	0.1	0.1	0.2
Agriculture (private dams)	0.1	0.1	0.2	0.4
Commercial & Hotels	0.8	0.9	1.4	2.1
Unaccounted for Water Commercial Losses	1.0	0.8	0.7	0.5
Unaccounted for Water Physical Losses	1.0	0.6	0.5	0.5
Total Water Demand	**4.5**	**4.2**	**4.8**	**5.8**

WATER RESOURCES
mill m3/yr

	1996	2000	2010	220
Groundwater	0.6	0.6	0.6	0.6
Surface Water	0.9	0.9	0.9	0.9
Rainwater Harvest (estimated)	0.1	0.1	0.2	0.2
Agriculture (private dams)	0.1	0.1	0.2	0.4
Desalinization Water	2.8	2.6	3.1	4.1
Total Water Resources	**4.5**	**4.2**	**4.8**	**5.8**

WATER PRODUCTION COSTS
mill. US$/yr

	1996	2000	2010	2020
Groundwater (2.5 US$/m3)	1.60	1.60	1.60	1.60
Surface Water (3.0 US$/m3)	2.60	2.60	2.60	2.60
Rainwater Harvest N/A				
Agriculture (private dams) N/A				
Desalinization Water (4.7 US$/m3)	13.29	12.05	14.54	19.17
Total Production Costs	**17.48**	**16.24**	**18.73**	**23.36**
Average Production Costs US$ per m3	3.86	3.86	3.93	4.05

WATER REVENUES
mill. US$/yr

Domestic, Government & Inst. (2.0 US$/m3)	3.15	3.35	3.75	4.14
Agriculture (2.4 US$/m3)	0.16	0.20	0.29	0.43
Commercial & Hotels (4.9 US$/m3)	3.91	4.65	6.88	10.24
Unaccounted for Water	0.00	0.00	0.00	0.00
Sales of electricity from desalinization plant (5USc/kWh)	0.46	0.41	0.50	0.66
Total Water Revenues	**7.23**	**8.20**	**10.92**	**14.82**
WATER REVENUES - PRODUCTION COST	**-10.26**	**-8.05**	**-7.81**	**-8.54**

Appendix B. Predictions 1996 - 2020 of Water Resources, Water Demand, Production Costs

Scenario 2

BASIC ASSUMPTIONS FOR FUTURE PROJECTIONS

	1996	2000	2010	2020
Population (Medium Scenario)	68100	72300	81000	89500
Domestic Water m3/capita*day (as per econ. growth)	0.063	0.063	0.063	0.063
Agriculture (relative econ growth, Medium Scenario)	1	1.19	1.76	2.62
Hotels & Commercial (Medium Scenario)	1	1.19	1.76	2.62

WATER DEMAND PROJECTIONS
mill m3/yr

	1996	2000	2010	2020
Domestic, Govmnt, Institutions (APUA and private)	1.6	1.7	1.9	2.1
Agriculture (APUA)	0.1	0.1	0.1	0.2
Agriculture (private dams)	0.1	0.1	0.2	0.4
Commercial & Hotels	0.8	0.9	1.4	2.1
Unaccounted for Water Commercial Losses	1.0	0.8	0.7	0.5
Unaccounted for Water Physical Losses	1.0	0.6	0.5	0.5
Total Water Demand	**4.5**	**4.2**	**4.8**	**5.8**

WATER RESOURCES
mill m3/yr

	1996	2000	2010	220
Groundwater	0.6	0.8	1.0	1.2
Surface Water	0.9	1.2	1.5	1.8
Rainwater Harvest (estimated)	0.1	0.1	0.2	0.2
Agriculture (private dams)	0.1	0.1	0.2	0.4
Desalinization Water	2.8	2.1	2.1	2.6
Total Water Resources	**4.5**	**4.2**	**4.8**	**5.8**

WATER PRODUCTION COSTS
mill. US$/yr

	1996	2000	2010	2020
Groundwater (2.5 US$/m3)	1.60	2.00	2.50	3.00
Surface Water (3.0 US$/m3)	2.60	3.60	4.50	5.40
Rainwater Harvest N/A				
Agriculture (private dams) N/A				
Desalinization Water (4.7 US$/m3)	13.29	9.72	9.86	12.14
Total Production Costs	**17.48**	**15.32**	**16.86**	**20.54**
Average Production Costs US$ per m3	3.86	3.64	3.54	3.56

WATER REVENUES
mill. US$/yr

Domestic, Government & Inst. (2.0 US$/m3)	3.15	3.35	3.75	4.14
Agriculture (2.4 US$/m3)	0.16	0.20	0.29	0.43
Commercial & Hotels (4.9 US$/m3)	3.91	4.65	6.88	10.24
Unaccounted for Water	0.00	0.00	0.00	0.00
Sales of electricity from desalinization plant (5USc/kWh)	0.46	0.33	0.34	0.42
Total Water Revenues	**7.23**	**8.20**	**10.92**	**14.82**
WATER REVENUES - PRODUCTION COST	**-10.26**	**-7.12**	**-5.94**	**-5.72**

Appendix C. Precipitation, Runoff, and Reservoir Operation Spreadsheet for Potworks Watershed

Period	Drainage Area		Reservoir		Reservoir		Reservoir		Reservoir		Reservoir		Stream-	Drainage Area	
	Rainfall (P)		Volume (V)		Area (A)		Evaporation (E)		Seepage (S)		Outflow (Q)		flow (F)	Evapotranspiration (E)	
mo.-yr	mm/mo.	m3/mo.	MG	m3	acres	ha	mm/mo	m3/mo.	mm/mo.	m3/mo.	MG/mo	m3/mo.	m3/mo.	m3/mo.	mm/mo.
jan-94	43.7	1,061,211	0	0	0	0	130	0	25	0	6.4	24,191	24,191	1,037,020	43
feb-94	30.6	743,090	220	836,000	190	76	130	98,800	25	19,000	6.4	24,320	560,120	182,970	8
mar-94	37	898,508	220	836,000	190	76	130	98,800	25	19,000	15.2	57,692	61,492	837,016	34
apr-94	15.1	366,688	160	608,000	150	60	130	78,000	25	15,000	17.5	66,500	-87,500	454,188	19
mai-94	30	728,520	90	342,000	110	44	130	57,200	25	11,000	18.7	71,136	-107,664	836,184	34
jun-94	42.4	1,029,642	30	114,000	40	16	130	20,800	25	4,000	25.3	96,216	-49,984	1,079,626	44
jul-94	44.3	1,075,781	0	0	0	0	130	0	25	0	20.2	76,760	19,760	1,056,021	43
aug-94	35.7	866,939	0	0	0	0	130	0	25	0	3.0	11,552	87,552	779,387	32
sep-94	244.8	5,944,723	40	152,000	60	24	130	31,200	25	6,000	1.8	6,764	119,964	5,824,759	240
okt-94	70.6	1,714,450	40	152,000	60	24	130	31,200	25	6,000	0.0	0	246,200	1,468,250	60
nov-94	120.2	2,918,937	150	570,000	130	52	130	67,600	25	13,000	7.1	26,995	174,095	2,744,842	113
des-94	60.1	1,459,468	75	285,000	65	26	130	33,800	25	6,500	1.3	4,788	-239,912	1,699,380	70
jan-95	20.1	488,108	0	0	0	0	130	0	25	0	16.3	61,788	-80,712	568,820	23
feb-95	56.7	1,376,903	0	0	0	0	130	0	25	0	8.6	32,832	32,832	1,344,071	55
mar-95	37.6	913,078	0	0	0	0	130	0	25	0	0.0	0	0	913,078	38
apr-95	79.2	1,923,293	0	0	0	0	130	0	25	0	0.0	0	0	1,923,293	79
mai-95	59	1,432,756	0	0	0	0	130	0	25	0	0.0	0	0	1,432,756	59
jun-95	15.5	376,402	0	0	0	0	130	0	25	0	0.0	0	0	376,402	16
jul-95	49.1	1,192,344	0	0	0	0	130	0	25	0	0.0	0	0	1,192,344	49
aug-95	263.2	6,391,549	0	0	0	0	130	0	25	0	0.0	0	2,071,000	4,320,549	178
sep-95	410.3	9,963,725	1090	4,142,000	480	192	130	249,600	25	48,000	13.6	51,748	2,420,348	7,543,377	311
okt-95	160	3,885,440	1090	4,142,000	480	192	130	249,600	25	48,000	22.7	86,298	345,898	3,539,542	146
nov-95	66.2	1,607,601	1070	4,066,000	470	188	130	244,400	25	47,000	35.5	135,052	350,452	1,257,149	52
des-95	60.3	1,464,325	1050	3,990,000	460	184	130	239,200	25	46,000	26.1	99,127	213,327	1,250,998	52
jan-96	52.2	1,267,625	980	3,724,000	450	180	130	234,000	25	45,000	16.8	63,954	171,954	1,095,671	45
feb-96	42.2	1,024,785	960	3,648,000	440	176	130	228,800	25	44,000	20.6	78,394	85,194	939,591	39
mar-96	22.1	536,676	840	3,192,000	430	172	130	223,600	25	43,000	33.1	125,704	-25,696	562,372	23
apr-96	31.3	760,089	740	2,812,000	410	164	130	213,200	25	41,000	27.8	105,640	-58,160	818,249	34
mai-96	50.7	1,231,199	620	2,356,000	380	152	130	197,600	25	38,000	21.9	83,220	-99,180	1,330,379	55

jun-96	107	2,598,388	520	1,976,000	350	140	130	182,000	25	35,000	19.1	72,656	-52,344	2,650,732	109
jul-96	133.8	3,249,199	440	1,672,000	300	120	130	156,000	25	30,000	20.3	77,102	35,102	3,214,097	132
aug-96	96.7	2,348,263	400	1,520,000	290	116	130	150,800	25	29,000	29.0	110,200	-14,000	2,362,263	97
sep-96	66.1	1,605,172	280	1,064,000	230	92	130	119,600	25	23,000	28.0	106,423	-130,977	1,736,150	71
okt-96	87.4	2,122,422	200	760,000	180	72	130	93,600	25	18,000	28.3	107,350	370,950	1,751,472	72
nov-96	80.7	1,959,719	360	1,368,000	260	104	130	135,200	25	26,000	25.6	97,185	771,385	1,188,334	49
des-96	145	3,521,180	470	1,786,000	330	132	130	171,600	25	33,000	31.7	120,536	743,136	2,778,044	114

Appendix D. People Met

Name	Position	Institution/Phone/Fax
Mr. Daven Joseph	National Coordinator	Ministry of Trade and Planning Tel.: 1 268 462 5935 Fax. 1 268 462 9338
Mr. Jerry Fernandez	Irrigation Engineer, Coordinator, Water Sector Team	Soils & Water Conservation Division Ministry of Agriculture Tel.: 1 268 462 1213 Fax.: 1 268 462 6104
Mr. Patrick Jeremiah	Director	Meteorological Services
Mr. Ivan Rodrigues	O&M Engineer	Antigua Public Utilities Authority (APUA)
Ms. Veronica Yearwood	Hydrologist	APUA Tel: 480 7000/480 7063 Fax.: 462 2751
Mr. Alvin Christian	Irrigation Farmer outside St.John’s	