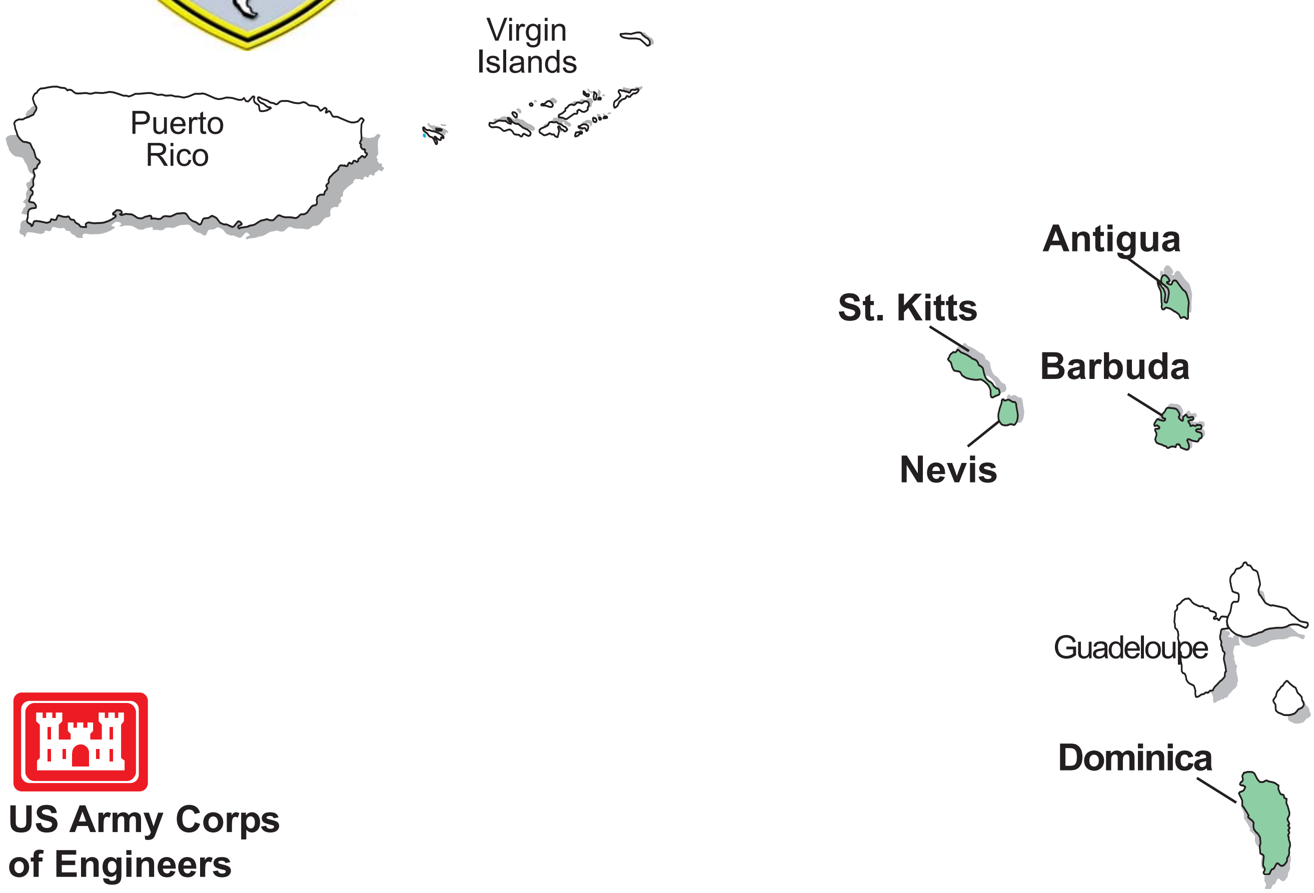
WATER RESOURCES ASSESSMENT OF DOMINICA, ANTIGUA, BARBUDA, ST. KITTS AND NEVIS

UNITED STATES SOUTHERN COMMAND



US Army Corps of Engineers
Mobile District &
Topographic Engineering Center

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Executive Summary

These island nations are among the smallest countries in the world. St. Kitts and Nevis is the smallest nation in the western hemisphere, and ranks among the 10 smallest countries in the world. Tourism and agriculture constitute the basis of the economies on these islands. Water plays a significant role in the sustainability and success of each.

The hydrologic characteristics of each island vary. Dominica has abundant rainfall and surface water resources, and a tremendous elevation range. Ground water exploration is not needed. Antigua has less annual rainfall, and is heavily dependent upon desalination for water supply. Barbuda relies on ground water, which is in a semi-fragile state due to a high water table and climate change forecasts. Hotels and resorts on Barbuba have their own desalination plants. St. Kitts and Nevis rely on surface and ground water. A lack of water storage on these islands exacerbates seasonal shortages. Domestic rooftop catchment systems contribute significantly to domestic water supplies, particularly in Barbuda and Nevis.

Much of the water supply is untreated, except for chlorination. Excessive turbidity, particularly in Dominica, and inadequate filtration, is causing problems. High unaccounted for losses due to illegal connections and old distribution systems, are common to these islands, and to Latin America and the Caribbean as a whole.

Sewage treatment is non-existent, except for some private entities. This lack of treatment coupled with improper disposal, affects water quality, as the untreated effluent is discharged in watersheds, rivers, and in outfalls in the coastal areas. The islands are heavily dependent on septic tanks, soakaways, and pit latrines. This has a high potential for increasing ground water and surface water contamination, as construction may be faulty and maintenance most likely inadequate with little enforcement of either.

The population of these islands is concentrated in the coastal areas. As a result, the population and the economy of the islands are very vulnerable to natural disasters, particularly hurricanes, and the flooding associated with it. Moderate to heavy hurricanes could not only devastate the economy, but also the water supply.

Desalination of seawater is very important for water supply, to increase the tourist-based economy for many of the islands. Desalination provides the majority of the water supply for Antigua, and resorts in Barbuda. It is also an option for future use for the other islands. For instance, in Dominica, the water exports (from surface water sources) come under increasing scrutiny due to quality problems.

Many agencies have responsibility for the water resources and supplies of each country. National water laws and a national water sector for each country would help improve the situation, particularly for the future. Enhanced coordination between the individual agencies working to provide water and sanitation could be a benefit. Innovative technology to improve the sanitation would help reduce the amount of chemical and biological wastes contaminating the watersheds, surface water, ground water and coastal areas due to untreated effluent discharge.

Preface

The U.S. Southern Command Engineer's Office commissioned the U.S. Army Corps of Engineers District in Mobile, Alabama, and the U.S. Army Corps of Engineers Topographic Engineering Center in Alexandria, Virginia, to conduct a water resources assessment of Dominica, Antigua and Barbuda, and St. Kitts and Nevis. This assessment has two objectives: (1) to provide U.S. military planners with accurate information for planning various joint military training exercises and humanitarian civic assistance engineer exercises; and (2) to provide an analysis of the existing water resources and identify some opportunities available to the governments of Dominica, Antigua and Barbuda, and St. Kitts and Nevis to maximize the use of these resources.

A team, listed below, consisting of water resources specialists from the U.S. Army Corps of Engineers, Mobile District and the U.S. Army Topographic Engineering Center, conducted the water resources investigations in 2002, 2003, and 2004, and subsequently prepared the report. Visits were made to Dominica, Antigua, and St. Kitts in September 2002 by John Baehr and Alan Fong, to meet with the numerous agencies, organizations, companies, academia and individuals in Appendix A having responsibility for and knowledge of the water resources of the countries. The resulting assessment that follows is also available on website: http://www.sam.usace.army.mil/en/wra/wra.html.

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List of Acronyms, Abbreviations, and Symbols

APUA	Antigua Public Utilities Authority
CARICOM	Caribbean Community
CDERA	Caribbean Disaster Emergency Response Agency
CEPIS	Centro Pan-Americano de Engenharia Sanitaria e Ciencias do Ambiente
CICP	Consortium for International Crop Protection
CIMH	Caribbean Institute for Meteorology and Hydrology
^{o}	degrees
$	dollars
D.C.	District of Columbia
deg	degrees
DOWASCO	Dominica Water and Sewerage Company
E	Eastern
ENERSERVE	Veolia Water Company
=	equals
etc.	etcetera
ft	feet
gal	gallons
GDP	Gross Domestic Product
GNS	GEOnet Names Server
gpcd	gallons per capita per day
gpm	gallons per minute
>	greater than
≥	greater than or equal to
HEC	Hydrologic Engineering Center
Igpd	Imperial gallons per day
km^2	square kilometers
<	less than
≤	less than or equal to
m	meters
m^3	cubic meter
MALFH	Ministry of Agriculture, Laws, Fisheries and Housing (Antigua)
mgd	million gallons per day
mi	miles
mi^2	square miles
min	minutes
mm	millimeters
MOH	Ministry of Health (Dominica)
N	Northern
NODS	National Office of Disaster Services (Antigua)
OAS	Organization of American States
OECS	Organization of the Eastern Caribbean States
PAHO	Pan American Health Organization

%	percent
pH	hydrogen-ion concentration
PHD	Public Health Department (St. Kitts and Nevis)
S	Southern
St.	Saint
3D	three dimensional
TDS	total dissolved solids
UNICEF	United Nations Children's Fund
U.S.	United States
USAID	United States Agency for International Development
W	Western
WD	Water Department (St. Kitts and Nevis)
WHO	World Health Organization

List of Place Names

The List of Place Names is a list of names and geographic coordinates that are mentioned in the text of this document. The country name is included in parentheses directly following the place name. Place names included in the surface water and ground water tables (tables C-1 and C-2) are not reflected in this list. Coordinates in the tables are included in parentheses directly following the place names. Coordinates are generally obtained from the GEOnet Names Server (GNS). GNS provides access to the National Geospatial-Intelligence Agency's (NGA) and the U.S. Board on Geographic Names' (US BGN) database of foreign geographic feature names.

Place Name	Geographic Coordinates
Anse Du Me (Dominica)	1536N06123W
Ayers Creek (Antigua)	1704N06142W
Bagatelle Estate (Dominica)	1514N06117W
Barbuda Basin (XI) (Barbuda)	1736N06147W
Basseterre (St. Kitts)	1717N06243W
Basseterre Valley Basin (St. Kitts)	1717N06243W
Batali River (Dominica)	1527N06127W
Bath Estate (Dominica)	1517N06123W
Beauplan River (Dominica)	1535N06124W
Belfast River (Dominica)	1522N06125W
Belle Fille River (Dominica)	1525N06116W
Bellevue Chopin (Dominica)	1516N06121W
Bells (Dominica)	1525N06121W
Bendals (Antigua)	1704N06150W
Bense (Dominica)	1535N06122W
Bethesda Reservoir (Antigua)	1703N06145W
Boggy Peak (Antigua)	1703N06151W
Bioche (Dominica)	1530N06128W
Boeri Lake (Dominica)	1521N06120W
Boetica (Dominica)	1518N06116W
Boiling Lake (Dominica)	1518N06118W
Bornes (Dominica)	1535N06125W
Brick Kiln (Nevis)	1711N06233W
Buckleys (St. Kitts)	1718N06244W
Butlers (Nevis)	1709N06233W
Cabrits (Dominica)	1535N06129W
Calibishie (Dominica)	1535N06121W
Campbell (Dominica)	1522N06122W
Camps (Nevis)	1711N06234W
Camp Basin (St. Kitts)	1717N06244W
Canal River (Dominica)	1532N06118W
Capucin (Dominica)	1538N06128W
Carholm (Dominica)	1525N06124W
Carib Reserve (Dominica)	1529N06116W

List of Place Names, Continued

Place Name	Geographic Coordinates
Carlisle (Antigua)	1708N06148W
Castle Bruce (Dominica)	1526N06116W
Castle Bruce Basin (V) (Dominica)	1521N06118W
Cayon (Nevis)	1721N06244W
Cayon Basin (St. Kitts)	1721N06244W
Cayon River (St. Kitts)	1721N06243W
Charlestown (Nevis)	1708N06237W
Charlestown Basin (XV) (Nevis)	1709N06236W
Check Hall River (Dominica)	1520N06124W
Claire River (Dominica)	1518N06122W
Clarke’s River (Dominica)	1522N06117W
Clifton (Dominica)	1535N06128W
Cochrane (Dominica)	1520N06122W
Codrington (Barbuda)	1737N06149W
Codrington Lagoon (Barbuda)	1739N06151W
Colihaut (Dominica)	1529N06129W
Collins Reservoir (Antigua)	1704N06144W
Con Phipps Estate (St. Kitts)	1720N06249W
Cooks Creek Watershed (Antigua)	1705N06150W
Cottage (Dominica)	1537N06128W
Cotton Ground (Nevis)	1710N06237W
Coulibistri (Dominica)	1527N06128W
Delices (Dominica)	1517N06116W
Des Por area (Dominica)	1521N06122W
Diamond Reef (Antigua)	1712N06153W
Dos D’ Ane (Dominica)	1535N06125W
Douce River (Dominica)	1536N06121W
Dublanc (Dominica)	1531N06128W
Dublanc River (Dominica)	1531N06128W
Dubuc (Dominica)	1515N06119W
East Basin (X) (Antigua)	1704N06145W
English Harbour Town (Antigua)	1701N06145W
Fitches Creek (Antigua)	1707N06147W
Fond Saint Jean (Dominica)	1515N06117W
Fountain Basin (XVI) (Nevis)	1709N06234W
Fountain Ghut (Nevis)	1712N06233W
Fountain Ghut (Nevis)	1706N06233W
Franklands (St. Kitts)	1719N06247W
Fresh Water Lake (Dominica)	1521N06119W
Galion (Dominica)	1513N06122W
Geneva River (Dominica)	1514N06119W

List of Place Names, Continued

List of Place Names, Continued

Place Name	Geographic Coordinates
Morning Star (Nevis)	1707N06235W
Morpo (Dominica)	1525N01600W
Mount Liamuiga (St. Kitts)	1722N06248W
Mount Lily (Nevis)	1712N06236W
Nevis Peak (Nevis)	1709N06235W
Newcastle (Nevis)	1712N06235W
Newcastle Airport (Nevis)	1712N06235W
North Basin (VII) (Antigua)	1708N06149W
Northeast Basin (XII) (St. Kitts)	1721N06246W
Northwest Basin (II) (Dominica)	1530N06127W
Northwest Basin (St. Kitts)	1723N06250W
Old Road (Nevis)	1719N06247W
Olivees Mountain (St. Kitts)	1719N06245W
Oualie Bay (Nevis)	1711N06233W
Pagua River (Dominica)	1531N06117W
Paix Bouche (Dominica)	1536N06125W
Palaster Reef (Barbuda)	1732N06145W
Parson’s Ghut (St. Kitts)	1724N06248W
Peineville (Dominica)	1538N06125W
Petite Savane (Dominica)	1515N06117W
Petite Soufriere (Dominica)	1523N06116W
Pillips (St. Kitts)	1721N06245W
Picard River (Dominica)	1533N06128W
Pichelin (Dominica)	1516N06120W
Pointe Michel (Dominica)	1515N06123W
Pointe Mulatre (Dominica)	1517N06115W
Portsmouth (Dominica)	1534N06128W
Potters Ville (Dominica)	1518N06124W
Potworks Reservoir (Antigua)	1704N06145W
Profit Estate (St. Kitts)	1724N06248W
Ravine Sibouli (Dominica)	1515N06123W
River Ouayaneri (Dominica)	1520N06115W
Riviere Cyriques (Dominica)	1521N06116W
Roseau (Dominica)	1518N06124W
Roseau Basin (IV) (Dominica)	1520N06123W
Roseau River (Dominica)	1518N06124W
Saddle Hill (Nevis)	1707N06234W
Sadlers (Nevis)	1724N06247W
Saint John’s (Antigua)	1707N06151W
Saint Joseph (Dominica)	1524N06126W
Saint Marie River (Dominica)	1530N06117W

List of Place Names, Continued

Place Name	Geographic Coordinates
Saint Sauveur (Dominica)	1524N06116W
Salisbury (Dominica)	1526N06127W
Sandy Point Bay (St. Kitts)	1720N06251W
Sandy Point Town (St. Kitts)	1721N06250W
Scotts Head Village (Dominica)	1512N06123W
Sir Gillies (St. Kitts)	1722N06251W
Snug Corner Estate (Dominica)	1516N06122W
Soufriere (Dominica)	1514N06122W
South Basin (IX) (Antigua)	1701N06148W
Southeast Basin (XIV) (St. Kitts)	1716N06239W
Southwest Basin (XIII) (St. Kitts)	1721N06248W
Springfield Estate (Dominica)	1520N06122W
Stone Fort Basin (St. Kitts)	1719N06247W
St. Peter’s (St. Kitts)	1718N06243W
Stowe (Dominica)	1515N06118W
Sulphur Ghut (Nevis)	1707N06237W
Tabernacle (St. Kitts)	1723N06246W
Tanetane (Dominica)	1536N06128W
Tete Morne (Dominica)	1514N06121W
Thibaud (Dominica)	1536N06124W
Ti Tou Gorge (Dominica)	1519N06121W
Toucari (Dominica)	1537N06128W
Toulaman River (Dominica)	1533N06118W
Trafalgar (Dominica)	1519N06121W
Trafalgar Falls (Dominica)	1519N06121W
Valley of Desolation (Dominica)	1518N06118W
Vare Cornwall Bird International Airport (Antigua)	1708N06147W
Verchilds Mountain (St. Kitts)	1721N06247W
Vieille Case (Dominica)	1537N06124W
Warner (Dominica)	1523N06124W
Watt Mountain (Dominica)	1519N06118W
Wesley (Dominica)	1534N06119W
West Basin (VIII) (Antigua)	1704N06151W
Westbury (Nevis)	1710N06236W
West Farm (St. Kitts)	1718N06245W
Windy Hill (Nevis)	1712N06238W
Wingfield Level (St. Kitts)	1720N06247W
Wingfields River (St. Kitts)	1719N06248W
Woodford Hill (Dominica)	1534N06120W
Wotten Waven (Dominica)	1518N06120W
Zion (Nevis)	1708N06233W

Geographic coordinates for place names and primary features are in degrees and minutes of latitude and longitude. Latitude extends from 0 degrees at the Equator to 90 degrees north or south at the poles. Longitude extends from 0 degrees at the meridian established at Greenwich, England, to 180 degrees east or west established in the Pacific Ocean near the International Date Line. Geographic coordinates list latitude first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or Western (W) Hemisphere. For example:

Anse Du Me (Dominica) ………………. 1536N06123W

Geographic coordinates for Anse Du Me (Dominica) that are given as 1536N06123W equal 15°36' N 61°23' W and can be written as a latitude of 15 degrees and 36 minutes north and a longitude of 61 degrees and 23 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

I. Introduction

Water, possibly the world's most indispensable resource, nourishes and sustains all living things. At least 400 million people in the world live in regions with severe water shortages. By the year 2050, this number is expected to be 4 billion people. At least 5 million people die every year from water-related illnesses. The projected shortage of potable water could result in the most devastating natural disaster in recorded history, unless something is done to stop it.[1]

A direct relationship exists between the abundance of water, population density, and quality of life. As the world's population grows, pressure on limited water resources grows. Unless water resources are properly managed, scarcity can be a roadblock to economic and social progress. A plentiful supply of water is one of the most important factors in the development of modern societies. The two major issues in the development of water resources are quantity and quality. Availability of water for cleansing is directly related to the control and elimination of disease. The convenience of water improves the quality of life.[2] In developing countries, water use drops from 40 liters per day per person when water is supplied to the residence, to 15 liters per day per person if the source is 200 meters (656 feet) away. If the water source is more than 1,000 meters (3,281 feet) away, water use drops to less than 7 liters per day per person.[3] As well as being in abundant supply, the available water must have specific quality characteristics, such as the low concentration of total dissolved solids (TDS). The TDS concentration of water affects the domestic, industrial, commercial, and agricultural uses of water. The natural nontoxic constituents of water are not a major deterrent to domestic use until the TDS concentration exceeds 1,000 milligrams per liter. As TDS values increase over 1,000 milligrams per liter, the usefulness of water for commercial, industrial, and agricultural uses decreases. In addition to TDS concentrations, other quality factors affect water. These factors include the amount of disease-causing organisms, the presence of manufactured chemical compounds and trace metals, and certain types of natural ions that can be harmful at higher concentrations.

When potable water is scarce or not available, the population will likely turn to contaminated water sources out of desperation. Contaminated water can cause debilitating diseases and death.

Clean water prevents:

- Cholera
- Diarrhea
- Amoebic and parasitic dysentery
- Typhoid and other gastro-intestinal diseases

Clean water means:

- Health for families
- Sanitary households
- Lower mortality rates in children under 5 years of age
- Fewer productive work hours spent hauling water great distances and dealing with sickness

The purpose of this assessment is to document the general overall water resources situation in Dominica, Antigua and Barbuda, and Saint (St.) Kitts and Nevis. This work involves describing the existing major water resources in the country, identifying special water resources needs and opportunities, documenting ongoing and planned water resources development activities, and suggesting practicable approaches to short- and long-term water resources development. This assessment resulted from an in-country information-gathering trip and from information obtained in the United States on the part of several water resources professionals.

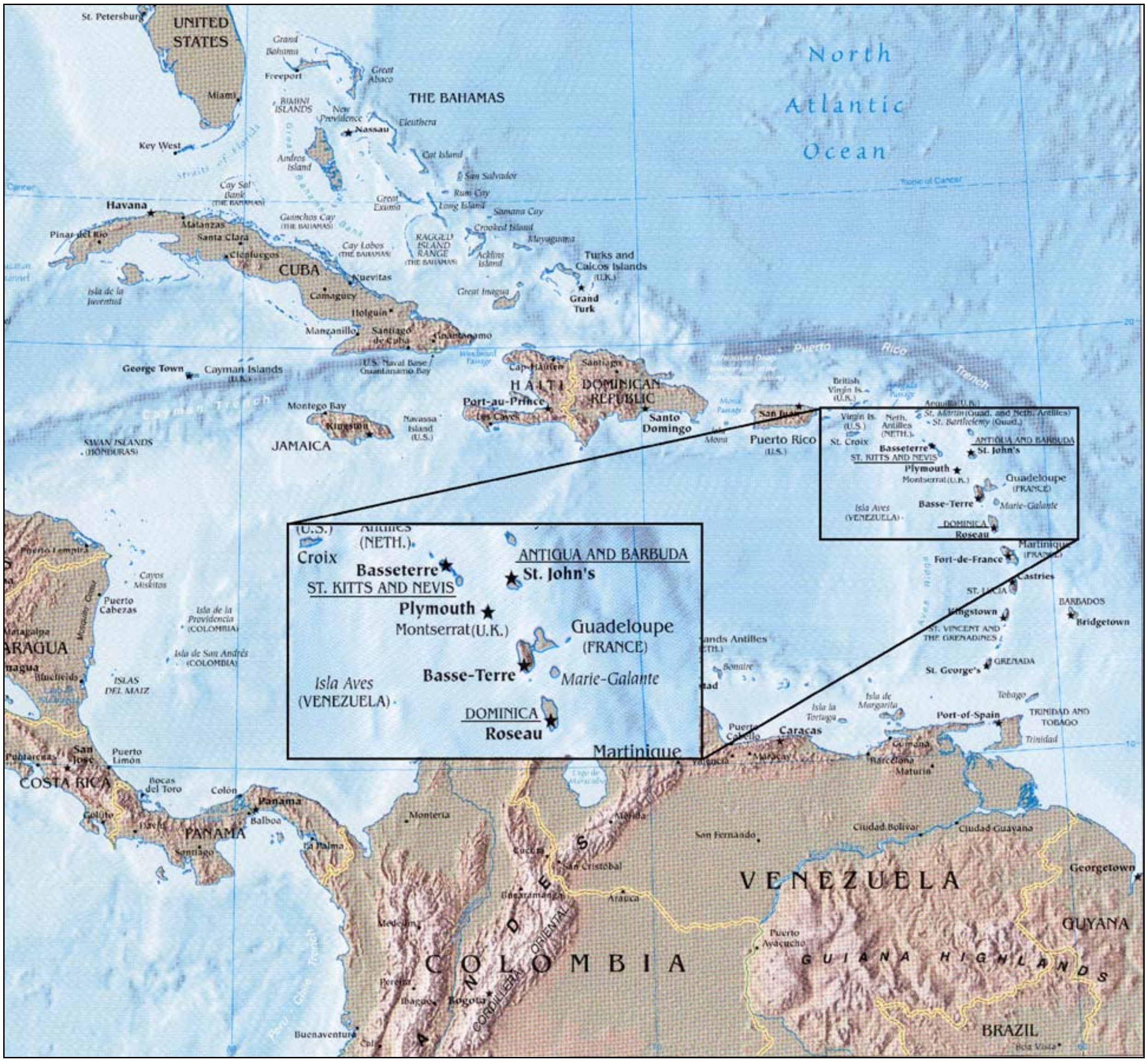


Figure 1. Vicinity Map

The organization of this Water Resources Assessment consists of Chapters I through VII with associated tables and figures followed by appendices. The following information summarizes the contents of each chapter and appendix:

- Chapter I presents an introduction to the purpose and scope of this assessment.
- Chapter II presents a country profile and discusses the geography, population and social impacts, economy, flooding, flood control and landslides, and legislative framework.
- Chapter III presents current uses of water resources including water supply and sanitation for domestic, industrial and commercial, and agricultural uses; hydropower; hydrological monitoring; waterway transportation; and recreation.

- Chapter IV presents information on the existing water resources including surface water resources, ground water resources, and water quality.

- Chapter V presents water resources maps and tables and summarizes the water resources information for each island.

- Chapter VI provides recommendations for water resources management and policy, watershed protection and management, troop exercise opportunities, and water quality and supply improvement.

- Chapter VII provides a summary of the water resources issues discussed in this report.

- Tables 1 through 16 and figures 1 through 14 are provided within the document following the text reference.

- Appendices A through C provide supporting information for the report:

  Appendix A – Officials Consulted
  Appendix B – Glossary
  Appendix C – Surface Water and Ground Water Resources Tables and Figures

This information can be used to support current and potential future investments in managing the countries' water resources and to assist military planners during troop engineering exercises. The surface water and ground water maps (figures C-1 and C-2), complemented by the tables in Appendix C, should be useful to planners as overviews of available water resources on a country scale. The surface water map divides the countries into surface water regions, based on water quantities available and water quality. The ground water map divides the countries into regions with similar ground water characteristics.

In addition to assisting the military planner, this assessment can aid the host nations by highlighting critical need areas, which in turn serves to support potential water resources development, preservation, and enhancement funding programs.

Responsibility for overseeing the water resources of Dominica, Antigua and Barbuda, and St. Kitts and Nevis is shared by several government agencies and institutions. The U.S. Army Corps of Engineers assessment team met and consulted with the organizations most influential in deciding priorities and setting goals for managing water resources. See Appendix A. Most of these agencies conduct their missions with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources. The glossary provided in Appendix B contains definitions for terms used in this assessment.

II. Country Profile

A. Geography

The geography of Dominica, Antigua and Barbuda, and St. Kitts and Nevis is presented in the following subsections. These countries are among the smallest in the world, with St. Kitts and Nevis being the smallest country in the western hemisphere.[4] Antigua and Barbuda, and St. Kitts and Nevis are referred to as 'micro-states' due to their small size, being less than 450 square kilometers (km^2)(174 square miles [mi^2]).[5]

Dominica

The island of Dominica is one of the Windward Islands in the eastern Caribbean Sea and lies approximately halfway between the islands of Guadeloupe and Martinique.[6] See figure 1. With a land area of 750 km^2 (290 mi^2), Dominica is the third largest island in the eastern Caribbean. In land area comparison, it is slightly more than four times the size of Washington, D.C.[7] Dominica is divided into 10 parishes. See figure 2, and table 1 in the "Population Section."

The topography is characterized by very rugged mountains of volcanic origin. A series of high peaks with connecting ridges runs north to south with several peaks rising above 1,220 meters (m) (4,000 feet [ft]). The highest point, Morne Diablotins at 1,447 m (4,747 ft), is located in the north-central portion of the island. Morne Trois Pitons, Morne Micotrin, Morne Anglais, and Morne Plat Pays are mountain peaks extending to the south of the island.[8]

The island of Dominica is part of a volcanic island arc formed by the Windward Islands. Lava flows, ash, and pyroclastic deposits ranging in age from Miocene to Recent are the principal bedrock material with some limestone interfingered with the volcanic layers.[9] Mixed volcanics include basalt, dykes, dacite, andesite, ignimbrite, ash, tuff, and pumice.

Antigua and Barbuda

Antigua and Barbuda are part of the Leeward Islands located in the eastern Caribbean Sea. Antigua has a land area of 280 km^2, while Barbuda has 160 km^2. The combined total area of both islands is 440 km^2.[10] Total land area comparison is about 2.5 times the size of Washington, D.C.[11] Antigua is divided into 6 parishes. See figure 3.

The topography of Antigua is generally low-lying with volcanic areas in the south and west. Boggy Peak is the highest point, rising to 470 m (1,542 ft).[12] The northeast area is composed of limestone with elevations up to 120 m (400 ft) above sea level. The low-lying central area consists of alluvium with elevations less than 15 m (50 ft) above sea level.[13]

The island of Barbuda, composed of limestone, is relatively flat with a maximum elevation of 63 m (208 ft) above sea level.[14] Codrington Lagoon is a large lagoon located on the west side of the island, with important recreational and economic value.[15,16]

St. Kitts and Nevis

The islands of St. Kitts and Nevis are located in the northern part of the Leeward Islands in the eastern Caribbean Sea.[17] St. Kitts is the larger of the two islands with 176 km^2 (68 mi^2) in area, and Nevis is 93 km^2 (36 mi^2). The combined total area of both islands is 269 km^2. Total land area comparison is about 1.5 times the size of Washington, D.C.[18] See figure 4. St. Kitts is divided into 9 parishes. Nevis is divided into 5 parishes. See the "Population Section" and table 3.

The two mountainous islands are separated by a channel approximately 3 kilometers (2 miles [mi]) in width.[19] St. Kitts is roughly oval in shape with a long neck of land extending to the southeast. The physical geography of St. Kitts is divided into ranges trending northwest to southeast across the island. The highest point in the northwest range is Mount Liamuiga with an elevation of 1,156 m (3,792 ft). The central range consists of several irregular peaks with Verchilds Mountain rising to a height of 975 m (3,200 ft). The central and southwest ranges are separated by a broad gently sloping saddle known as Phillips and Wingfield Levels approximately 457 m (1,500 ft) high. The southeast range consists of several irregular peaks and is dominated by Olivees Mountain at a height of 900 m (2,953 ft).

Figure 2. Dominica Country Map

Figure 3. Antigua and Barbuda Country Map

Figure 4. St. Kitts and Nevis Country Map

The island of Nevis lies to the southeast and is circular in shape. Nevis Peak is located in the center of the island, reaching an elevation of 985 m (3,232 ft). Windy Hill is located to the northwest at an elevation of 309 m (1,013 ft), and Saddle Hill at an elevation of 381 m (1,250 ft) is to the southeast of Nevis Peak forming a northwest/southeast trending spine across the island.[20]

B. Population and Social Impacts

The population and social impacts for Dominica, Antigua and Barbuda, and St. Kitts and Nevis are presented in the following subsections. The highest population concentrations are on the coasts.

Dominica

The total population in Dominica in 2001 was 71,727, with a density of about 250 persons per mi^2.[21] See table 1. According to the national census of 1991, about 74 percent of the population lived in rural areas and the remaining lived in urban areas.[22] The total population change in Dominica is 0.1 percent since the 1991 census, and –3.5 percent since the 1981 census.[23] The drop in population has been attributed to emigration.[24] The population is basically young with 40 percent under the age of 15 years.[25]

Dominica is divided into 10 regions or parishes. In 2001, the parish of St. George, where the capital city of Roseau is located, had the highest population density of 931 persons per mi^2. St. Peter Parish had the lowest population density with 120 persons per mi^2.[26]

According to the 1991 Population and Housing Census Report, 77.5 percent of the households had direct access to piped water supply from the national system operated and maintained by the Dominica Water and Sewerage Company. The water supply is routinely treated to maintain bacteriological quality.[27]

Table 1. Population Distribution for Dominica, 2001

Parish	Population	Approximate Area (mi^2)
St. George	20,538	21.7
(Roseau)	(15,167)	--
(Rest of St. George)	(5,371)	--
St. John	5,932	22.8
St. Peter	1,522	12.6
St. Joseph	5,961	46.8
St. Paul	8,522	25.2
St. Luke	1,581	3.0
St. Mark	1,895	4.0
St. Patrick	8,489	33.8
St. David	6,792	50.8
St. Andrew	10,495	68.8
Total	**71,727**	**289.5**

Source: Central Statistical Office, Ministry of Finance and Planning, *Population and Housing Census – 2001, Preliminary Results, August 2001*.
(mi^2 = square miles)

Antigua and Barbuda

The total population of Antigua and Barbuda according to the National Census of 1991 was 63,800.[28] Antigua is divided into 6 parishes. Barbuda is a dependency. The population density (for both islands) is about 412 persons per mi^2. Barbuda has a very low population density of about 24 persons per mi^2. The population is distributed over the rural areas with the highest population concentrations on the coast.[29] In 1991, about 66 percent of the population lived in urban areas and the remaining lived in rural areas.[31] In 2000, the annual rate of growth was estimated at 0.8 percent.[32] See table 2 for population distribution for 1999.

Table 2. Population Distribution for Antigua and Barbuda, 1999

Island	Population	Approximate Area (mi^2)
Antigua	68,500	108
Barbuda	1,500	62
Total	**70,000**	**170**

Source: CEPIS, "Assessment of Drinking Water and Sanitation 2000 in the Americas, Internet, http://www.cepis.ops-oms.org/enwww/eva2000/Antigua/informe/inf-02.htm, Accessed 21 April 2003.
mi^2 = square miles

St. Kitts and Nevis

The total population of St. Kitts and Nevis according to the National Census of 1991 was 40,618.[33] See table 3. According to the 1991 census, about 66 percent of the population lived in rural areas and the remainder lived in urban areas.[34] For 2003, the total population for both islands is estimated at 38,763, and the annual growth rate was estimated at –0.2 percent in 2000.[35] The drop in population is attributed to intra-regional migration. Similar to other Caribbean Islands, St. Kitts and Nevis have a relatively young population with 30.8 percent under the age of 15.[36]

St. Kitts and Nevis are divided into 14 parishes. See table 3. In St. Kitts, the parish of St. George, where the capital city of Basseterre is located, has the greatest population with 12,605 persons. Trinity parish has the lowest population with 1,250 persons. In Nevis, the parish of St. John has the greatest population with 2,191 persons, while St. Paul has the lowest with 1,411 persons.[37]

Table 3. Population Distribution for St. Kitts and Nevis, 1991

Parish	Population
St. Kitts	
St. George	12,605
(Basseterre)	(11,295)
(Rest of St. George)	(1,310)
St. Anne	3,077
St. John	2,936
St. Thomas	2,257
Christ Church	1,664
Trinity	1,250
St. Peter	2,656
St. Paul	2,130
St. Mary	3,249
Total for St. Kitts	**31,824**
Nevis	
St. Paul	1,411
St. George	2,086
St. Thomas	1,613
St. James	1,493
St. John	2,191
Total for Nevis	**8,794**
Total for St. Kitts and Nevis	**40,618**

Source: Statistics Division Planning Unit, Ministry of Finance, Development and Planning, *St. Kitts and Nevis Annual Digest of Statistics,* 2000, data based on 1991 census.

C. Economy

Dominica, Antigua and Barbuda, and St. Kitts and Nevis are members of the Organization of the Eastern Caribbean States (OECS). These countries share a common central bank and a common currency, and the operation of the currency is overseen by the Eastern Caribbean Central Bank.[38]

Agriculture and natural resource extraction constitute the basis of the economies for the Caribbean islands with growth in the tourism and service sectors.[39] Economic details for Dominica, Antigua and Barbuda, and St. Kitts and Nevis are presented in the following subsections.

Dominica

The economy of Dominica is open and agriculturally based with some diversification toward tourism, communications, and financial services.[40] Agriculture contributes 19 percent to the Gross Domestic Product (GDP), 30 percent to employment, 37.5 percent to exports, and provides about 60 percent of the food needs of the population.[41]

Bananas are the main commercial crop and export.[42] Strong attempts have been made to diversify the agriculture efforts to include citrus fruits, coconuts, coffee, cocoa, exotic vegetables, and rice. Other efforts include pilot projects in aquaculture, expansion of the acreage for cultivating ornamental flowers, and distillation of essential oils.[43]

The performance of banana production and exportation has steadily deteriorated since the early 1990s and has adversely affected developments in other sectors. The decelerated economic growth below one percent per year has led to a persistently high unemployment rate (upwards of 20 percent) and more widespread poverty (30 percent).[44]

The OECS has helped Dominica maintain monetary discipline and price stability. Vulnerability to external shocks and frequent natural disasters (particularly hurricanes) had a major negative impact on Dominica's economic performance during the 1990s.[45]

Tourism provides a significant contribution to the Dominican economy.[46] Tourism has been identified as the most viable option for stimulating the economy and increasing job opportunities.[47]

Antigua and Barbuda

The economy of the dual island nation of Antigua and Barbuda is based primarily on tourism. Tourism has been the main force behind the economy since the 1960s when it replaced sugar production. Antigua has the largest tourism industry of all the Leeward and Windward Islands.[48] Tourism accounts for 65 percent of the GDP. The tourism sector was devastated by Hurricane Luis in September 1995 and Hurricane Georges in September 1998. Despite these natural disasters, the economy is steadily increasing.[49] Additional economic contributors include government services, wholesale and retail trade, construction, communications, real estate and housing.[50]

The agricultural production is directed at the domestic market which is constrained by the limited water supply and labor shortages resulting from the higher wages in the tourism and construction industries.[51] The contribution of agriculture to the GDP has decreased from 40 percent to 12 percent in the last 30 years. During 1990 and 1991, crop production increased to around 20 percent. Most of the produce was consumed in Antigua, with the exportation of crops including pineapples and melons increasing dramatically.[52] Other agricultural production includes livestock, fish, cotton, corn, and improved fruit and vegetable production including aubergines (eggplant), cucumbers, limes, pumpkins, and mangoes.[53]

Codrington Lagoon in Barbuda is very important for the large spiny lobster aquaculture. The lobster fishery makes up 40 percent of Barbuda's GDP.[54]

Water and sanitation services are of the utmost importance to continued growth and development in a country with tourism as the main contributor to the GDP. Antigua and Barbuda rely on the quality of the natural environment as a source of revenue.[55]

St. Kitts and Nevis

Until the 1970s, sugar was the economic mainstay in St. Kitts and Nevis. Due to declining profits in the sugar industry, the government began a program to diversify the agriculture sector and stimulate other sectors of the economy. Investment incentives were initiated for businesses to encourage domestic and foreign private investment.

Tourism has shown the greatest economic growth, and in 1987, it surpassed sugar as the major foreign exchange earner.[56] Government services, wholesale and retail trade, construction, and communications have also contributed significantly to the GDP.[57]

Sugar is still the main agricultural export. It is produced on 30 large estates taken into ownership by the state in 1975 and 1976.[58] Other agricultural products include rice, yams, vegetables, bananas, and fish.[59]

According to the 1999 Pan American Health Organization (PAHO) Basic Country Health Profiles, unemployment in St. Kitts and Nevis is among the lowest in the Caribbean. The unemployment rate was 4.3 percent, according to a survey by the Organization of American States (OAS) and the government in 1994. The service industry, which is dominated by tourism, was the largest employer at 36.5 percent.[60]

The economy experienced strong growth in the 1990s until 1998, when growth decreased due to effects from hurricanes.[61] Real growth averaged 4.4 percent during the 1992 to 1995 time period. A major challenge for the government is economic revitalization and stimulating economic growth.[62]

D. Flooding, Flood Control, and Landslides

Flooding can be defined as a general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland waters or from the usual and rapid runoff of surface waters from rainfall.[63] Inland flooding is primarily from rainwater runoff. For example in Dominica, flooding has occurred after failure of natural dams that were created from landslides. Coastal flooding on any of the island countries may occur during storm surges. Also, the concern exists that coastal flooding may increase if sea levels rise in response to climatic changes.

Dominica, Antigua and Barbuda, and St. Kitts and Nevis are members of the Caribbean Disaster Emergency Response Agency (CDERA). CDERA was established in September 1991 by the Agreement of the Conference of Heads of Government of the Caribbean Community (CARICOM) to be responsible for disaster management. Each member is required to maintain a National Disaster Organization or a national relief organization capable of assisting other members in case of a hurricane, flood, landslide, earthquake, volcano, tsunami, technological and man-made disasters. In February 2002, CDERA began the "Enhancing Flood Disaster Preparedness in the Caribbean" project. The project has four specific objectives:

1. To enhance national preparedness efforts for flood hazards through an enhanced public education program for schools.
2. To enhance the managerial and operational capability of the region in addressing flood hazards.
3. To improve disaster management capability in the region by ensuring that relevant national and regional organizations have the capability to access, use and disseminate disaster management information to specific target audiences via the most effective media and for specific hazards, particularly flood hazards.
4. To promote community disaster planning at the regional and national level for the enhancement of national disaster management programs.[64]

Dominica

CDERA and the Caribbean Council of Science and Technology are completing flood hazard mapping and development of flood alert systems for Dominica. The map and alert system should improve planning and emergency response for communities along the Roseau Basin.[65]

Landslides occur in Dominica as a result of the topography, geology, soil, deforestation, numerous rivers, and human activity. The steep slopes are one of the principal conditions favoring landslide development. The principal trigger for landslides is rainfall, with hurricanes as one source of intense rainfall. Prolonged rainfall during the rainy season often produces landslides. Earthquake activity can also trigger landslides. Agricultural practices (and other human activities) such as 'slash and burn' on steep slopes is a primary factor in causing landslides.[66]

From information and data obtained from an investigation by the Corps of Engineers in 2001, a landslide occurred in November 1997 which breached the Layou River and a tributary, the Matthieu River. The dam is about five miles from the mouth of the river where the Layou River is joined by the tributary, Matthieu River. The Layou River dam breached after three days, but the Matthieu River blockage remained. In July 2002, the blockage measured 75 meters (246 feet) in height and 40 meters (131 feet) in width at the narrowest point and 200 meters (656 feet) long along the reservoir. The dammed reservoir was 30 meters deep and 200 meters at its widest point. From 1998 to 2001, the level increased 10 meters (33 feet). The walls of the eroded soil continue to lose soil and it appears another landslide may occur. There is great concern that heavy rainfall, particularly flash flooding may breach this dam, causing tremendous destruction and loss of life downstream. To remediate, three viable plans exist:

1. Drain the reservoir water in a controlled setting, then remove the 'dam';
2. Create a dam up the Matthieu River to control the water flow to the reservoir;
3. Use an early warning system and develop a floodplain evacuation plan.

The Corps of Engineers recommends the third option. This plan provides adequate warning to the downstream population. The cost estimate of option 3 is US$50,000 to $100,000.[67,68,69]

Shortly after the natural dam formed, two breaches occurred, resulting in two flood events.The amount of water that flooded the valley below the breach for each event was estimated at 300 and 350 million gallons of water, respectively. Both events required the evacuation of several hundred people in the Layou community. Significant crop loss, road damage, and sediment deposition occurred along the river. [70]

Antigua and Barbuda

The National Office of Disaster Services (NODS) is the agency that assumes responsibility for providing assistance due to flood disasters. NODS is the national agency that reports to CDERA.

The main cause of flooding in Antigua and Barbuda is extreme rainfall associated with hurricanes. The main properties of the islands that increase flooding are the following:

- Soils that have generally low permeability or/and shallow depths.
- Dense drainage networks (mainly Antigua) that permit rapid flow within the channel banks and rapid concentration of runoff onto the floodplains.
- Expanding urbanization, which replaces pervious areas with impervious surfaces such as roofs and roadways.
- Widespread grazing by goats and cattle (mainly on Antigua) that compacts soils and removes vegetative cover, leaving the soil surface exposed to the full impact of the rainfall and vulnerable to soil erosion.[71]

The Antigua Flood Hazard Map and the Barbuda Flood Hazard Map are shown as figures 5 and 6, respectively. Map explanatory notes for the flood hazard maps are provided in text boxes 1 and 2. These maps show the areas that may experience very low to very high flooding. A very high flood zone exists in the west central part of Antigua in the floodplain of Cooks Creek Watershed. This area is of particular concern since the Cooks Creek watershed is a densely populated area with basic housing. Three high flood hazard zone areas are located in the west central, central, and north central parts of Antigua. A moderate flood hazard zone is located in the northern section of Antigua. Several of the roads that connect St. John's and the Vare Cornwall Bird International Airport are located within the moderate flood hazard zone. The remainder of the island has a very low flood hazard potential.[72]

Barbuda has one area located within a high hazard flood zone. Codrington, the major city on the island, is located within this zone. Two moderate hazard flood zones exist in the southern part of the island. Two low hazard flood zones are located in the northern portion of the island. Since Barbuda has no rivers, roads appear to function as drains. Several of these roads intersect north of Codrington. This area reported some of the worst damage from Hurricane Lenny.[73]

In 1999 Hurricane Lenny produced severe flooding. As much as 635 millimeters (mm) (25 inches) of rain fell on Antigua and Barbuda during the hurricane. In Barbuda, water wells were contaminated when floodwater entered the wells. In the southern part of Antigua, wells may be submerged during flooding. The main problem to the wells from the flooding results from the loss of power and contamination. Short-circuiting of the equipment is common.[74]

St. Kitts and Nevis

The main cause of flooding in St. Kitts and Nevis is extreme rainfall associated with hurricanes and violent thunderstorms. Violent thunderstorms have caused the most severe flooding. These thunderstorms are a result of the high relief of the watersheds. The four main properties of the islands that increase flooding are the following:

1. Soils are highly erodible. The soil is washed away by runoff and deposited in the ghauts/ghuts. Road crossings at bridges and culverts often become blocked, which increases flooding.

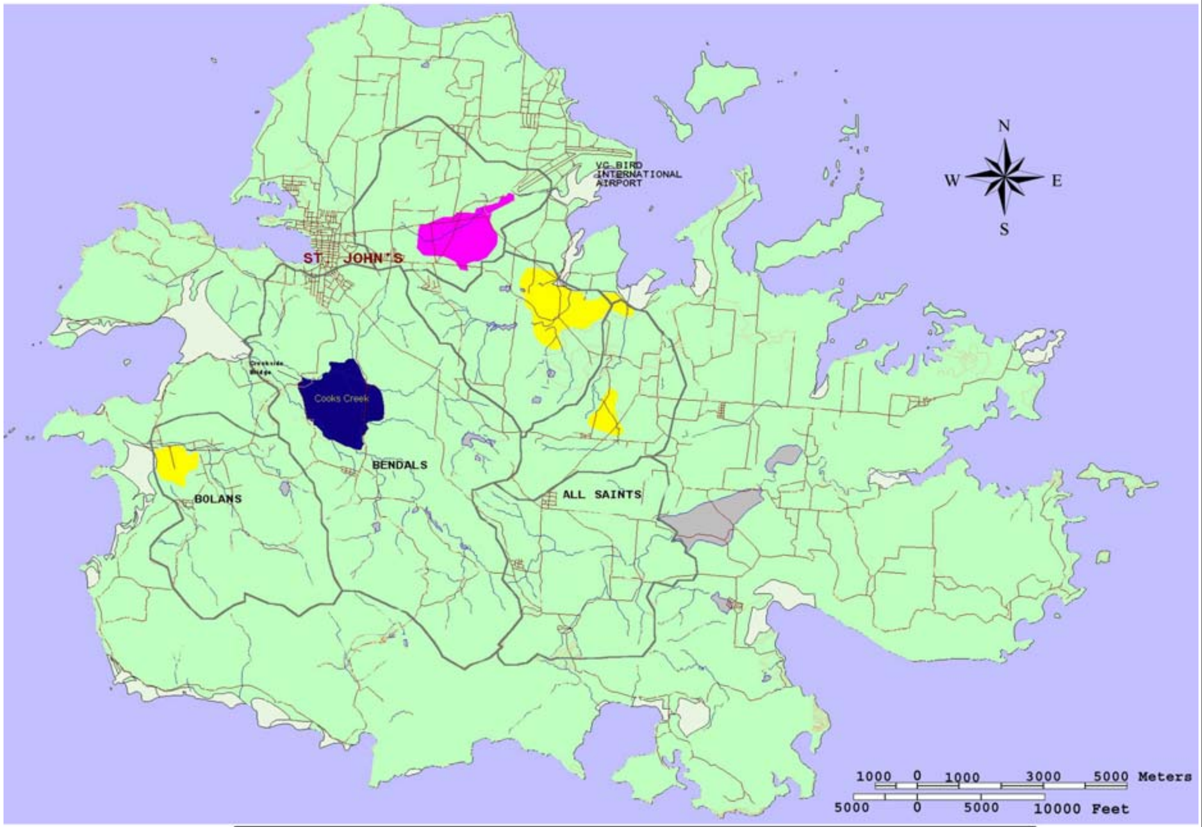
2. The watersheds are very steep which cause rapid flow of water.

3. The foothills (especially in St. Kitts) are being urbanized.

4. Livestock grazing on Nevis compacts soils and reduces infiltration rates.[75]

The St. Kitts Flood Hazard Map and the Nevis Flood Hazard Map show the areas that may experience very low to very high flooding; see figures 7 and 8, respectively. Map explanatory notes are provided in text boxes 3 and 4. Several areas near Basseterre have the highest potential for flooding. This area is within the major commercial center. On Nevis, the Newcastle Airport is located within a high flood hazard zone.

ANTIGUA FLOOD HAZARD MAP



Dated: May 2001

LEGEND, MAIN FEATURES

Roads	Watershed boundary
Ponds	Very high flood hazard zone
Mangrove	High flood hazard zone
Creeks and drains	Moderate flood hazard zone
Project Website: http://www.oas.org/pgdm	Very low flood hazard zone

Grid: British West Indies
Projection: Transverse Mercator
Latitude of Origin: Equator
Longitude of Origin: 62 deg 00 min West of Greenwich
Scale factor on central meridian: 0.9995
False co-ordinates of Origin: 400,000 metres East, nil North
Unit of measurement: metre

Detailed Surveys within Cooks Creek floodplain along Bendals Government Quarry Road to the east and the Creekside Bridge to the west were conducted by Anwar Deonanan and Associated, 3rd Street Barataria, Trinidad West Indies, using Total Station and data collectors.

Controls points obtained from the Land and Surveys Department, Antigua Government, were used for placing the survey data on the National Grid.

Adapted from Antigua Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/anfldmap.htm

Figure 5. Antigua Flood Hazard Map

ANTIGUA FLOOD HAZARD MAP EXPLANATORY NOTES (Figure 5 Notes)

Adapted from Antigua Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/anfldmap.htm

Flood Hazard Qualification

For the maximum 24 hour cumulative rainfall from Hurricane Lenny (equivalent to the 100 year storm***), the mean water depth within hazard zones will be as follows:

Very high = exceeds 600 millimeters (mm) (about 2 ft).
High = between 300 mm and 600 mm (1 ft to 2 ft).
Moderate = between 150 mm and 300 mm (0.5 ft to 1 ft).
Low = between 75 mm and 150 mm (3 inches to 6 inches).
Very low = less then 75 mm (3 inches).

This depth is a measure of the volume (from rainfall) running onto the zone from surrounding lands, after abstracting rainfall amounts due to infiltration and from natural land drainage. Since this is a mean value, there may be places within the zone that are not inundated, and other places (e.g., close to the drains and in depressions) where the water depth exceeds the mean value.

1. Potential flood prone zones were defined as ones with small slopes (about 0.2% to 0.5%). These would most likely be drained by streams and rivers with similar slopes. The drainage with such limited slopes are likely to be inadequate for draining floodplains. Areas of the potential flood zones and the catchments draining into them were determined using ArcView Version 3.1 and 3D Analyst Version 1.0.
2. Rainfall frequency was determined from a limited database, consisting of six years of continuous daily rainfall records from one rain gage sited at the Lester Bird Airport. Water depths from the 100 year return period storms are not expected to be substantially different from the Hurricane Lenny records and so these were used for determining the flood hazard zones. When additional records become available, the 100 year return period should be determined compared with the Hurricane Lenny value and the map accordingly updated.
3. Runoff hydrographs for Hurricane Lenny (assumed equivalent to the 100 year storm) were developed using the HEC-1 procedure developed by the U.S. Army Corps of Engineers (1990). The hydrographs were based on the following:

   a) the Type III temporal distribution curve of the 24 hour rainfall produced by the National Resource Conservation Service, (formerly the Soils Conservation Service) United States.

   b) a fully saturated watershed with water already on the ground from previous rainfall 24 hours earlier.

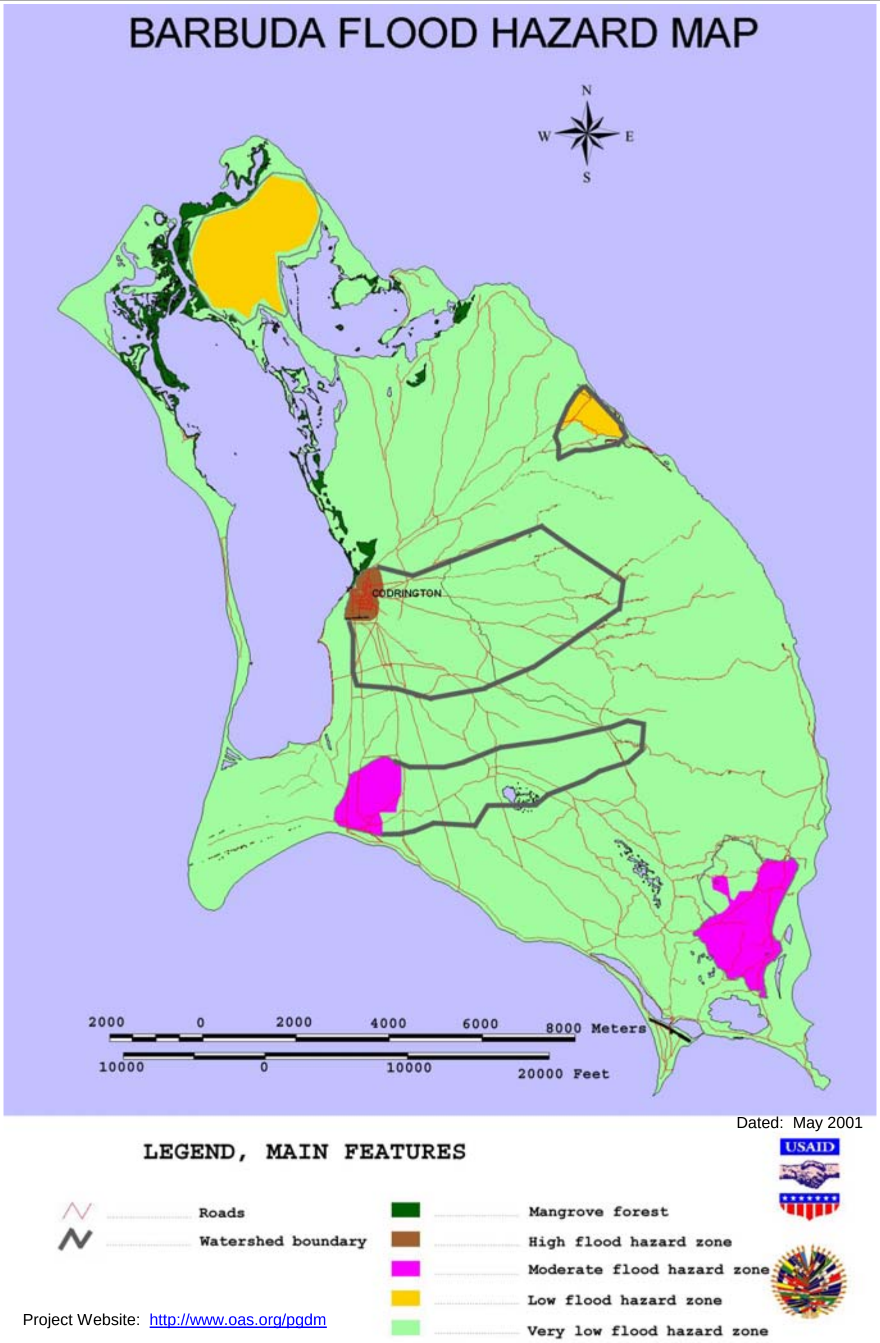
*** A 100 year flood return period storm has a 1/100 chance of occurring in any year. Storms with high return periods, though seldom occurring, have high rainfall amounts; small return period storms, which occur frequently, have small rainfall amounts.

Use of the Map

The map was produced using (i) a small (6 year) rainfall database; (ii) coarse topographical contour intervals; and (iii) limited information on observed water levels during a single high flow event, Hurricane Lenny (November, 1999). Detailed information such as flood levels and water level variation during storm events cannot confidently inferred unless these constraints are removed.

1. The map is therefore to be regarded as preliminary; and the delineated flood areas represent only the approximate extent of flooding at the indicated hazard level.
2. The map provides information on areas of focus during large rainfall events, particularly within the Cook Creek Watershed where a substantial portion of the population lives. The map also shows roadway sections likely to be under water during these events; this is not exhaustive information, as other localized flooding may occur on other roadway sections.
3. The map is useful for broad predictions about the areas likely to be inundated on forecasting of particular extreme rainfall events following several days of inclement weather during the wet season.
4. The map can also be used for broad assessment of the flood hazard associated with development of infrastructure, including roads (and their elevations) and housing, within the island of Antigua.
5. It can be used as a guide for determining areas for further detailed flood studies.
6. The map DOES NOT provide any assessment of the hazard due to FLASH FLOODING.

Text Box 1. Antigua Flood Hazard Map Explanatory Notes



Projection: Transverse Mercator
Spheroid Clarke 1866
Unit of measurement: metre
Meridian of Origin 63° 00' West Greenwich
Latitude of Origin Equator
Scale factor at Origin 0.9996
False co-ordinates of Origin 500,000 metres in Easting

Adapted from Barbuda Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/bbfldmap.htm

Figure 6. Barbuda Flood Hazard Map

BARBUDA FLOOD HAZARD MAP EXPLANATORY NOTES (Figure 6 Notes)

Adapted from Barbuda Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/bbfldmap.htm

Flood Hazard Qualification

For the maximum 24 hour cumulative rainfall from Hurricane Lenny (equivalent to the 100 year storm***), the mean water depth within hazard zones will be as follows:

Very high = exceeds 600 mm (about 2 ft).
High = between 300 mm and 600 mm (1 ft to 2 ft).
Moderate = between 150 mm and 300 mm (0.5 ft to 1 ft).
Low = between 75 mm and 150 mm (3 inches to 6 inches).
Very low = less then 75 mm (3 inches).

This depth is a measure of the volume (from rainfall) running onto the zone from surrounding lands, after abstracting rainfall amounts due to infiltration and from natural land drainage. Since this is a mean value, there may be places within the zone that are not inundated, and other places (e.g., close to the drains and in depressions) where the water depth exceeds the mean value.

1. The flood prone zones were defined as ones with small slopes (about 0.5% to 0.2%). Areas of the flood zones and the catchments draining into them were determined using ArcView Version 3.1 and 3D Analyst Version 1.0.
2. Rainfall frequency was determined from a limited database, consisting of eight years of continuous daily rainfall records from one rain gage sited in Codrington. Water depths from the 100 year return period storms are not expected to be substantially different from the Hurricane Lenny records and so these were used for determining the flood hazard zones. When records become available, the 100 year return period should be determined and the map accordingly updated.
3. Runoff hydrographs for Hurricane Lenny (assumed equivalent to the 100 year storm) were developed using the HEC-1 procedure developed by the U.S. Army Corps of Engineers (1990). The hydrographs were based on the following:
   (a) the Type III temporal distribution curve of the 24 hour rainfall produced by the National Resource Conservation Service, (formerly the Soils Conservation Service) United States.
   (b) a fully saturated watershed with water already on the ground from previous rainfall 24 hours earlier.
4. The mean water depths on the flood plains were based on the volume of the runoff hydrographs and an estimate of the drainage efficiency of the flood zones. Drainage rates were estimated from field surveys and information contained in topographical maps. Drainage was considered restricted if the drains and streams at their outlets were (or there was a high probability that they could have been) blocked or limited by vegetation (mangroves) high seawater levels, or/and debris from within human settlements.

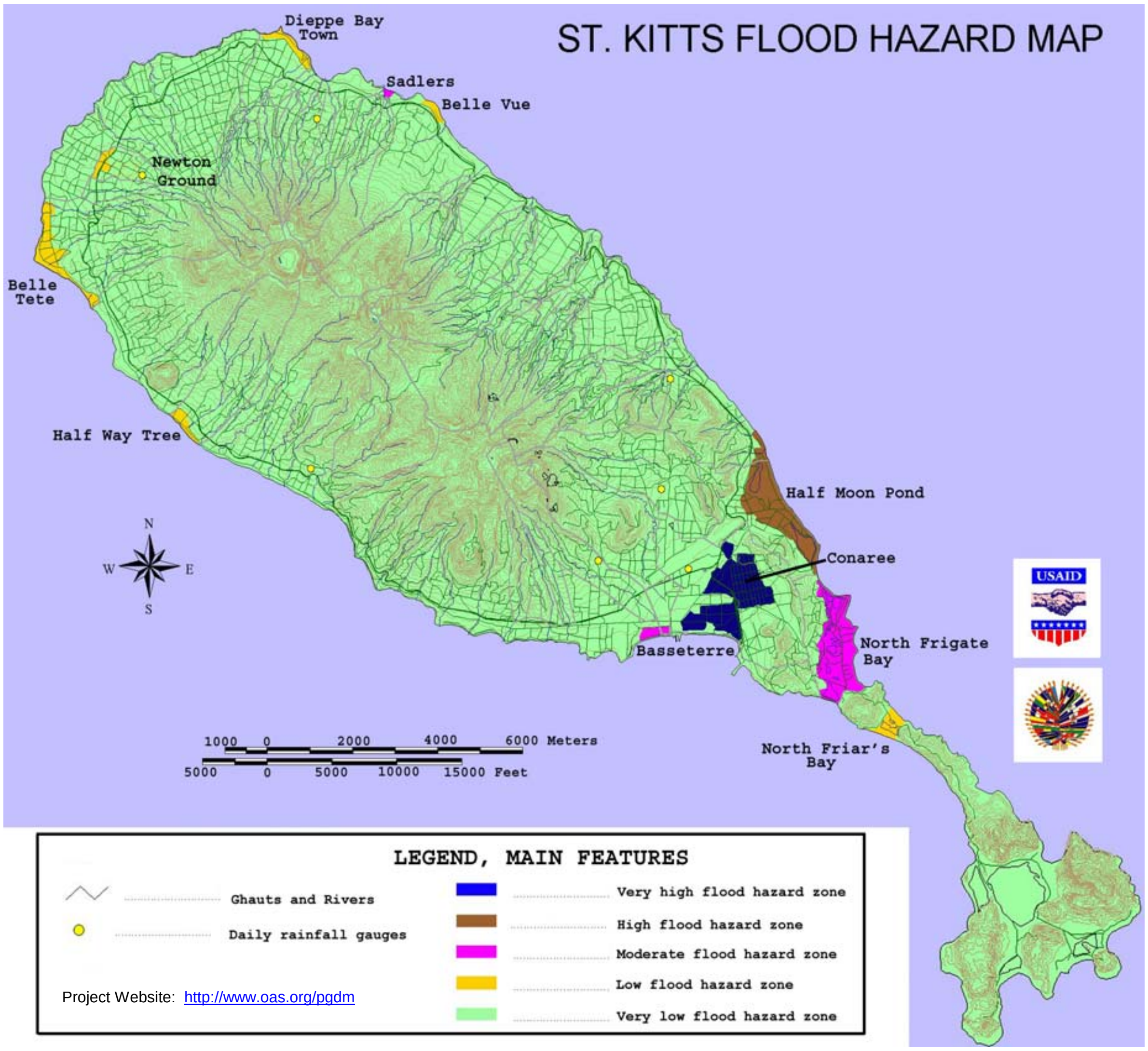
*** A 100 year flood return period storm has a 1/100 chance of occurring in any year. Storms with high return periods, though seldom occurring, have high rainfall amounts; small return period storms, which occur frequently, have small rainfall amounts.

Use of the Map

The map was produced using (i) a small (8 year) rainfall database; (ii) coarse topographical contour intervals; and (iii) field interviews on the observed water levels during a single high flow event, Hurricane Lenny (November 1999).

1. Owing to these limitations, the map is to be regarded as preliminary and the delineated flood zones represent only the approximate extent of flooding at the indicated hazard level.
2. The map is useful for broad predictions about the areas likely to be inundated.
3. The map can also be used for broad assessment of the flood risk associated with development of infrastructure, including roads and housing near and within Codrington.
4. It can be used as a guide for determining areas for further detailed flood studies.

Text Box 2. Barbuda Flood Hazard Map Explanatory Notes



Dated: May 2001

Grid: British West Indies
Projection: Transverse Mercator
Latitude of Origin: Equator
Longitude of Origin: 62 deg 00 min West of Greenwich
Scale factor on central meridian: 0.9995
False co-ordinates of Origin: 400,000 metres East, nil North
Unit of measurement: metre

Detailed surveys along Wash Ghaut and its surroundings were conducted by Dwight C. Francis Saddle Village St. Kitts.

Detailed surveys along College Street Ghaut and its surroundings were conducted by Anwar Deonanan and Associated, 3rd Street, Barataria, Trinidad, West Indies.

Control points obtained from the Land and Surveys Department, St. Kitts/Nevis Government were used for placing the survey data on the National Grid.

Adapted from St. Kitts Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/skfldmap.htm

Figure 7. St. Kitts Flood Hazard Map

<u>ST. KITTS FLOOD HAZARD MAP EXPLANATORY NOTES</u> (Figure 7 Notes)

Adapted from St. Kitts Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/skfldmap.htm

Flood Hazard Qualification

For the maximum 24 hour cumulative rainfall with a 100 year return period***, the mean water depth within hazard zones will be as follows:

Very high = exceeds 600 mm (about 2 ft).

High = between 300 mm and 600 mm (1 ft to 2 ft).

Moderate = between 150 mm and 300 mm (0.5 ft to 1 ft).

Low = between 75 mm and 150 mm (3 inches to 6 inches).

Very low = less then 75 mm (3 inches).

This depth is a measure of the volume (from rainfall) running onto the zone from surrounding lands, after abstracting rainfall amounts due to infiltration and from natural land drainage. Since this is a mean value, there may be places within the zone that are not inundated, and other places (e.g., close to the drains and in depressions) where the water depth exceeds the mean value.

1. The flood prone zones were defined as ones with very small slopes (about 0.5% to 0.2%). Areas of the flood zones and the catchments draining into them were determined using ArcView Version 3.1 and 3D Analyst Version 1.0.
2. Rainfall frequency was determined from a adequate database, consisting of twenty three years of continuous daily rainfall records from seven rain gage sited in sited throughout the island.
3. Runoff hydrographs for Hurricane Lenny (assumed equivalent to the 100 year storm) were developed using the HEC-1 procedure developed by the U.S. Army Corps of Engineers (1990). The hydrographs were based on the following:
   (a) the Type III temporal distribution curve of the 24 hour rainfall produced by the National Resource Conservation Service, (formerly the Soils Conservation Service) United States.
   (b) a fully saturated watershed with water already on the ground from previous rainfall 24 hours earlier.
4. The topography was determined from a 1 in 50,000 contour map, and therefore could not include specific details of infrastructure such as road elevation, embankments, bridges and culvert openings, spillway details and reservoir sections, which are required for good estimates of drainage from the flood hazard zones.
5. Drainage rates were estimated from field surveys and information contained in topographical maps. Drainage was considered restricted if the drains and streams at their outlets were (or there was a high probability that they could have been) blocked or limited by vegetation (mangroves) high seawater levels, or/and debris from within human settlements.

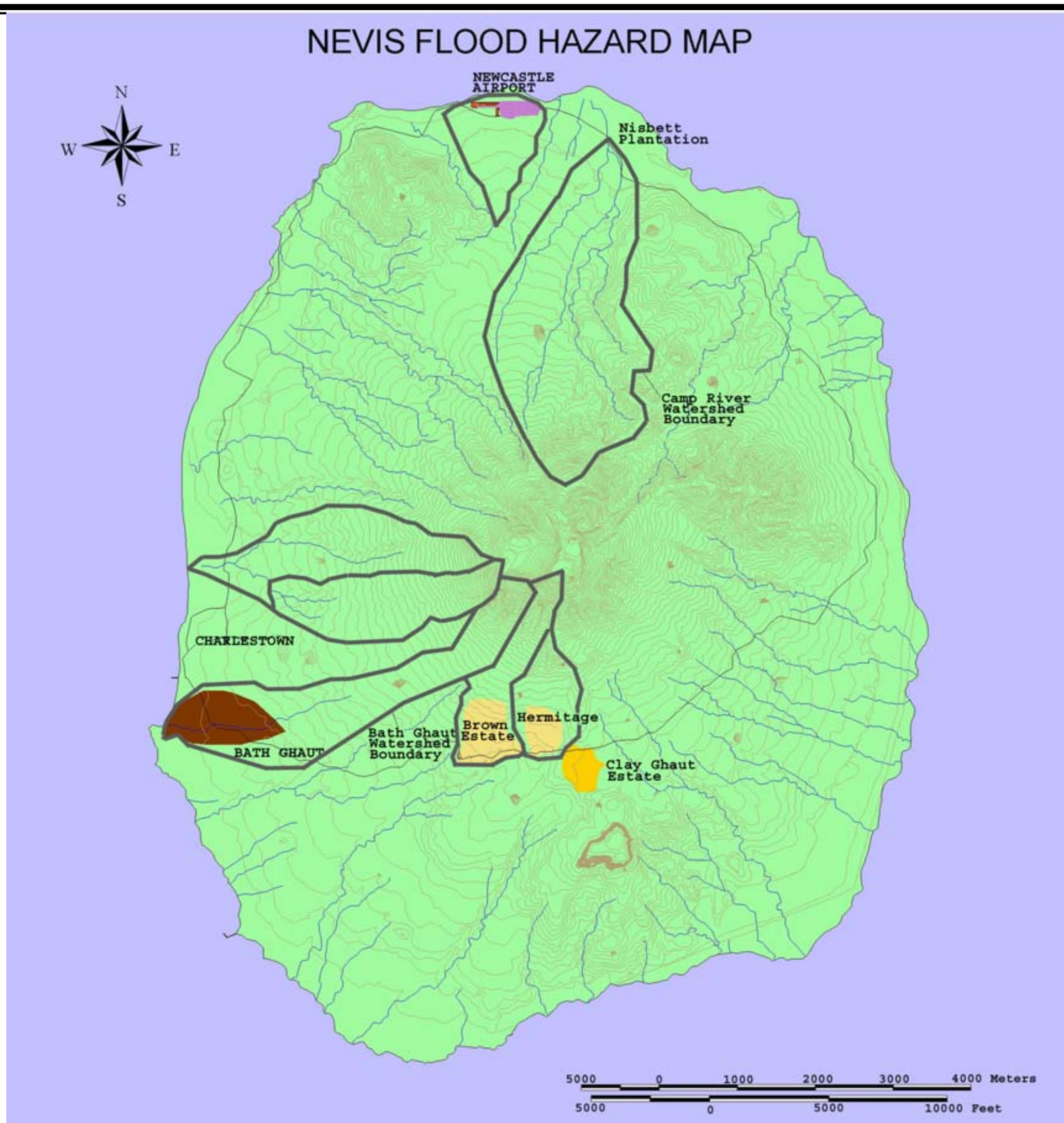
*** A 100 year flood return period storm has a 1/100 chance of occurring in any year. Storms with high return periods, though seldom occurring, have high rainfall amounts; small return period storms, which occur frequently, have small rainfall amounts.

Use of the Map

The information for island wide flooding was developed using an adequate rainfall database containing seven gages located around the island, and therefore the derived daily extreme rainfall is likely to be good approximately, but owing to limitations in high resolution elevation data, the resulting map can only be considered preliminary. Nevertheless, it can be used for the following.

1. Ranking of areas on the island according to flood hazards.
2. Development of land use zoning plans.
3. Determination of areas for which detailed flood studies should be undertaken (or further development).
4. The map MUST NOT be used for estimating water levels for various storm return periods.
5. The map DOES NOT provide any information about localized flooding due to flash flooding.
6. The map DOES NOT make any declaration of erosion hazard due to flash flowing water currents.

Text Box 3. St. Kitts Flood Hazard Map Explanatory Notes



Dated: May 2001

LEGEND, MAIN FEATURES

Watershed boundary

High flood hazard zone
Moderate flood hazard zone (Temporary. See Notes)
Low flood hazard zone
Low flood hazard zone (Temporary. See Notes)

Project Website: http://www.oas.org/pgdm

Grid: British West Indies
Projection: Transverse Mercator
Latitude of Origin: Equator
Longitude of Origin: 62 deg 00 min West of Greenwich
Scale factor on central meridian: 0.9995
False co-ordinates of Origin: 400,000 metres East, nil North
Unit of measurement: metre

Detailed surveys along Camps River were conducted by Dwight C. Francis Saddle, Village St. Kitts.

Detailed surveys along Bath Ghaut and its surroundings were conducted by Anwar Deonanan and Associated, 3rd Street, Barataria, Trinidad, West Indies.

Control points obtained from the Land and Surveys Department, St. Kitts/Nevis Government were used for placing the survey data on the National Grid.

Adapted from Nevis Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/nvfldmap.htm

Figure 8. Nevis Flood Hazard Map

NEVIS FLOOD HAZARD MAP EXPLANATORY NOTES (Figure 8 Notes)

Adapted from Nevis Flood Hazard Map, http://www.oas.org/pgdm/hazmap/flood/nvfldmap.htm

Flood Hazard Qualification

For the maximum 24 hour cumulative rainfall with a 100 year return period***, the mean water depth within hazard zones will be as follows:

Very high = exceeds 600 mm (about 2 feet).

High = between 300 mm and 600 mm (1 ft to 2 ft).

Moderate = between 150 mm and 300 mm (0.5 ft to 1 ft).

Low = between 75 mm and 150 mm (3 inches to 6 inches).

Very low = less then 75 mm (3 inches).

Equivalent water depths were estimated from runoff hydrographs that drained from surrounding lands into the flood plains. These runoff hydrographs were developed using the HEC-1 procedure developed by the U.S. Army Corps of Engineers (1990). The hydrographs were based on daily rainfall collected on St. Kitts; for distributing the daily rainfall over short time intervals as required (15 minutes in this case to match the times of concentration of the watersheds), the Type III temporal distribution curve from the National Resource Conservation Service, (formerly the Soils Conservation Service) United States, was used.

Some flood prone areas were considered temporary (shown cross-hatched), as they were not due to natural drainage limiting characteristics. Most are due to poor construction, inadequate or dilapidated hydraulic structures, or inappropriate land use zoning. The existing drainage hazards can readily be removed once the drainage is corrected.

Flood prone zones were identified mainly from field interviews, but they were also derived from digital slope data analyzed by ArcView Version 3.1 and the 3D Analyst 1.0 software. Flood prone areas from the latter method were ones with limited slopes (<0.5%). Watershed areas draining into the flood areas were determined using the same software.

The estimated flood levels within the zones are only approximate and should not be used for any detailed analysis.

The estimated flood levels represent the mean water elevations; elevations within the zone may be higher or lower as relief varies within the zones. Close to river banks and at depressions, water levels are expected to be highest; areas removed from the rivers (ghauts) would have lowered elevations.

The mean water elevations can be improved when daily rainfall data collected on Nevis become available. About ten (10) years of data are required to supplement the 2 years or records available from Newcastle Airport. Rainfall data on the south of the island, around Charlestown could be used for hazard zones in the south.

The water elevation estimations were based on assumption of the drainage capabilities of the zones, but they can be qualified with appropriate hydraulic analyses, such as was done for the areas mentioned below.

*** A 100 year flood return period storm has a 1/100 chance of occurring in any year. Storms with high return periods, though seldom occurring, have high rainfall amounts; small return period storms, which occur frequently, have small rainfall amounts.

Use of the Map

Owing to limitations in the availability in daily rainfall data and high resolution elevation data, the resulting map can only be considered preliminary. Nevertheless, it can be used for the following:

1. Ranking of areas on the island according to flood hazards.
2. Development of land use zoning plans.
3. Determination of areas for which detailed flood studies should be undertaken (or further development).
4. The map MUST NOT be used for estimating water levels for various storm return periods.
5. The map DOES NOT provide any information about localized flooding due to flash flooding.
6. The map DOES NOT make any declaration of erosion hazard due to flash flowing water currents.

Text Box 4. Nevis Flood Hazard Map Explanatory Notes

E. Legislative Framework

The following subsections present the legislative framework of Dominica, Antigua and Barbuda, and St. Kitts and Nevis.

Dominica

Dominica Water and Sewerage Company (DOWASCO) is the organization responsible for the management of the water resources in the country. An act of Parliament incorporated DOWASCO, which is a limited liability company. DOWASCO was created by the Government of the Commonwealth of Dominica, under the Water and Sewerage Act of 1989. The Minister of Communication and Works granted DOWASCO an exclusive license to abstract and utilize the water resources of the country. DOWASCO has responsibility to develop the water resources, to perform research, data collection, and maintenance, and make projections. Also, DOWASCO has no obligation to develop or provide water for agriculture.[76,77]

Antigua and Barbuda

The Ministry of Public Utilities has responsibility for the Antigua Public Utilities Authority (APUA). The Public Utility Act of 1973 establishes the right of the APUA to supply, allocate and manage water supplies, including controlling streams and ground water resources. The Water Division of the APUA has legal control over all water resources in the country and is mandated to provide supplies of water to meet the municipal needs of the country. The Planning and Development Section is responsible for hydrological studies, planning and drilling of wells and building of dams. The Division has no mandate or resources to manage the watersheds. Evaporation, stream flow, and rain gages, and meteorological data are not operated by the APUA.[78]

The Water Division occasionally utilizes private participation. Desalination building operations and ownership of the system go out to private companies for bid. However, the Water Division handles the quality of the final product, storage, chlorination, and distribution.[79]

Agriculture water needs are not handled by APUA. Agriculture is considered to be a commercial activity and irrigation generally does not have special preference in water allocation. The Ministry of Agriculture, Lands, Fisheries and Housing (MALFH) is responsible for technical assistance to farmers on irrigation, drainage, soil, and water conservation. The Caribbean Agricultural Research and Development Institute provides technical assistance to the MALFH.[80]

St. Kitts and Nevis

The St. Kitts and Nevis Department of Environment is responsible for environmental policies, management of watersheds and protected areas, and public education.[81] Several laws govern the work of the Department of Environment, including the National Environmental and Education Act, and the Development Control and Planning Act of 2000. The Water (Services) Department (WD) is tasked with implementing the designed tariffs, installing and managing water systems, constructing service reservoirs, conduits and maintenance of these same items. Also, WD is responsible for implementation of waste restrictions and rationing, and providing adequate water supply.[82] WD maintains strict control over water production and utilization.[83] Unlike other Caribbean islands, there are no laws or building codes for rooftop rainwater harvesting systems.[84]

Several additional departments have responsibilities that are related to water resources:

- Public Health Department (PHD) – Responsible for water quality. PHD analyzes the water supply for bacterial contamination.
- Agriculture and Planning Departments – Responsible for land conservation and prevention of deforestation.
- Department of Environment – Responsible for protection and preservation of the watersheds and ground water resources.[85]

The Department of Agriculture maintains a single mountain spring and a series of earthen dams. These dams are used for supplying irrigation water.[86]

III. Current Uses of Water Resources

A. Water Supply and Sanitation

Information on water supply and sanitation for Dominica, Antigua and Barbuda, and St. Kitts and Nevis are presented in the following subsections.

The high frequency of hurricanes requires concrete water storage tank on all the islands. Lightweight tanks, commonly used in Central and South America, are destroyed by the wind.[87]

Dominica

Rivers are the main source of water supply for potable use, irrigation, and hydropower in Dominica.[88] The country has a total of 365 rivers and streams. In addition to high rainfall (762 centimeters per year; 300 inches per year), Dominica has significant forest cover. These physical conditions assure an abundant freshwater supply for domestic consumption, export markets, hydropower, irrigation, and other uses.[89] The abundance of surface water has minimized the need to explore ground water resources, and hydrological studies have indicated limited aquifers with low yields.[90]

DOWASCO is a private organization responsible for potable water supply and sanitation services.[91] DOWASCO was assigned by the government to be the agency in charge of the water and sewerage systems for Dominica. The Ministry of Health (MOH) is responsible for the septic tanks, pit latrines and public sewerage services.[92] DOWASCO analyzes the water quality and provides the results to the MOH.

Water is supplied through a catchment system where stream water is captured by a small concrete weir.[93] Forty-three catchment areas provide potable water, with at least five of the catchments supplied by springs.[94] These forty-three catchment areas in Dominica are listed in table 4. These are the water systems owned and managed by DOWASCO. Due to scaling difficulties, these catchment areas have not been identified on the surface water map. The water is chlorinated. Turbidity is not controlled and becomes problematic particularly after rain events. The rain stirs up river sediment and causes the water supply to become slightly muddy.[95] Some of the catchments have rapid sand filtration systems. Sand filtration systems are needed at more catchments. Slow sand filtration is probably needed at these same catchments to filter more solids.

Table 4. The Forty-Three Catchment Areas in Dominica

Catchment	Population Served	Number of Standpipes	Basin Encompassed[1]
Roseau/Loubiere/Snug Corner Estate/Pointe Michel	10,888	112	Northwest (II), Layou (III), Roseau (IV)
Saint Joseph to Potters Ville/Goodwill/Bath Estate	16,978	20	Layou (III), Roseau (IV)
Salisbury	1,700	3	Northwest (II)
Coulibistri/Morne Raquette	900	10	Northwest (II)
Colihaut	900	10	Northwest (II)
Dublanc/Bioche	700	7	Northwest (II)
Picard/Portsmouth/Glanvillia	3,500	41	Northwest (II), Melville Hall (VI)
Guillet/Tanetane/Toucari	294	9	Lamothe (I)
Cottage	186	5	Lamothe (I)
Clifton	1,000	19	Lamothe (I)
Capucin	186	5	Lamothe (I)
Peineville	1,000	20	Melville Hall (VI)
Vieille Case	1,100	16	Melville Hall (VI)
Moore Park	300	4	Melville Hall (VI)
Thibaud/Paix Bouche/Dos D' Ane/Bornes	1,756	33	Melville Hall (VI)
Hampstead/Bense/Anse Du Me	780	12	Melville Hall (VI)
Calibishie	1,000	19	Melville Hall (VI)
Woodford Hill/Wesley	3,303	15	Castle Bruce (V), Melville Hall (VI)
Castle Bruce	1,864	20	Castle Bruce (V)
Marigot	3,554	21	Melville Hall (VI)
Good Hope/Saint Sauveur/Petite Soufriere	594	8	Castle Bruce (V)
Grand Fond	750	9	Castle Bruce (V)
Morne Jaune	260	8	Castle Bruce (V)
Riviere Cyriques	475	9	Castle Bruce (V)
La Plaine	1,299	27	Castle Bruce (V)
Delices	700	16	Castle Bruce (V)
Petite Savane	750	6	Castle Bruce (V)
Bagatelle Estate/Fond Saint Jean/Stowe	880	12	Castle Bruce (V)
Dubuc	90	4	Castle Bruce (V)
Grand Bay/Tete Morne/Pichelin	4,500	25	Castle Bruce (V)
Soufriere/Scotts Head Village/Galion	1,700	10	Roseau (IV)
Bellevue Chopin	433	6	Roseau (IV)
Giraudet/Eggleston	482	5	Roseau (IV)
Morne Prosper	500	5	Roseau (IV)
Wotten Waven	200	4	Roseau (IV)
Trafalgar	700	6	Roseau (IV)
Laudat	300	3	Roseau (IV)
Cochrane	280	7	Roseau (IV)
Des Por area	90	4	Roseau (IV)
Campbell	500	9	Roseau (IV)
Warner	450	2	Layou (III)
Carib Reserve	2,539	No information	Castle Bruce (V), Melville Hall (VI)
Boetica	267	No information	Castle Bruce (V)

Source: Damian Shillingford, Unpublished Data, Roseau, Dominica: Dominica Water and Sewerage Company, 2002.
[1] Basin locations are shown on figure C-1.

DOWASCO extracts over 10 million gallons per day (mgd) from 43 river intakes to satisfy the potable water supply demands for domestic, commercial and industrial needs. These water supply systems are more than adequate to meet the water demands of the country, except during the dry season. Urban areas require about 60 gallons per capita per day (gpcd), and rural areas require 45 gpcd. DOWASCO provides service for over 90 percent of the total population with 16,000 customer connections. DOWASCO is not responsible for providing water for agricultural purposes. Small communities not serviced by DOWASCO receive their water from small systems built by non-government organizations such as Save The Children Fund and Small Projects Assistance Team.

Water shortages may be experienced during the dry season occurring January to May with flows dropping about 30 percent. The water shortage is compounded as a result of increased water consumption during the dry season for watering of lawns and gardens and an increase in bathing.

The main uses of water in Dominica are domestic supply, hydropower and export. As a result, the entities requiring the most water include DOWASCO for domestic use and exporting water and the Dominica Electricity Services for hydropower generation.[98]

Table 5 presents data provided by DOWASCO for potable water consumption and distributions for 1995 through 2000.

Table 5. Potable Water Consumption and Distribution (1995–2000), gallons

Distribution	1995	1996	1997	1998	1999	2000
Domestic:						
Metered (# connections)	4,391	5,095	6,387	--	8,072	8,405
Non-metered (# connections)	6,605	6,318	5,717	--	6,189	5,231
Consumption (gal)	210,768	244,560	306,672	369,600	342,000	336,071
Industrial:						
Metered (# connections)	66	72	74	--	69	65
Consumption (gal)	39,600	43,200	44,400	48,000	54,060	35,648
Commercial:						
Metered (# connections)	464	562	604	--	498	449
Consumption (gal)	83,520	100,800	108,220	110,700	104,940	60,343
Government:						
Metered (# connections)	140	145	153	--	176	193
Consumption (gal)	84,266	87,276	92,076	92,076	90,000	69,158
Standpipes (#)	591	592	596	598	599	600
Consumption (gal)	164,006	164,294	165,127	166,237	165,324	123,993
Total Consumption (gal)	**582,160**	**640,130**	**716,495**	**786,613**	**756,324**	**625,213**

Source: Dominica Water and Sewerage Company
-- = information not available
= number

Of significance to note in table 5, the number of metered households increased by 91.4 percent during the time period from 1995 to 2000. Despite an increase in the number of domestic meters installed from 1997 to 2000, consumption declined.[99]

Sewage treatment is non-existent.[100] The only sewer network is in Roseau. It is old and in disrepair, with little maintenance conducted over the years. The sewage from the capital is discharged directly into the sea through 8 outfalls on the coast in Roseau. The Roseau Water and Sanitation project will rehabilitate the urban sewer and water system. It will also provide better disposal and treatment methods. This project started in 2000. The rest of the island has soakaways, pit latrines and septic tanks.[101,102] The more urban areas more commonly use septic tanks, while the more rural areas use latrines.[103] According to PAHO's Regional Report on the Global Assessment 2000 in the Region of the Americas, it was estimated that 86 percent of the urban population and 75 percent of the rural population had access to sanitation services.[104]

A large percentage of the water from catchments is lost during distribution. This figure was 40 percent according to the 1985 Government's National Structure Plan.[105] This high percentage loss is typical for Latin America and the Caribbean.

1. Domestic Uses and Needs

About 98 percent of the urban population and 58 percent of the rural population is connected to the water supply system in Dominica.[106] Bells, Morpo, and Deux Bras rural communities do not have access to potable water.

The water withdrawal per capita is 240 cubic meters (m^3), and most (or all, according to some reports) of that amount is used for domestic purposes.[107] The water is supplied by 43 catchment areas, which capture surface water. Some of the water is filtered, and all is chlorinated. The main quality problem is the excessive turbidity in the water at times. The amount of fertilizers, pesticides and insecticides in the water supply is of concern, particularly in the rural areas due to the amounts used in farming.

2. Industrial/Commercial Uses and Needs

The Dominica Port Authority has provided 33 million gallons per year to cruise ships since 1979. Cruise ship companies have been concerned with high turbidity in the water provided by the Port Authority. On occasion, ship captains have refused to purchase water due to concerns regarding the water quality.[108] Bottled water companies exist in Dominica, and much water is exported.

3. Agricultural Uses and Needs

The majority of Dominican agriculture is rain-fed.[110] Little to no irrigation exists. However, irrigation could greatly increase agricultural production. Small systems, fed by surface water, are used for farmers to grow vegetables.[111] Plans are being developed for irrigating about 1,000 acres to enhance banana and vegetable cultivations. The water used for irrigation will be gravity fed or pumped from rivers and streams.[112]

Antigua and Barbuda

Fresh water is a scarce resource in Antigua and Barbuda. These islands have a history of droughts and other water shortages. As a result, water costs for consumers are high, which has kept water conservation high. During prolonged droughts, one of which was in 1983-84, water had to be barged in from neighboring islands at a considerable cost. Due to a growing tourist industry, demands are increasing.[113,114,115]

Antigua relies heavily on desalinated water for water supply, while Barbuda is dependent predominantly on ground water.

Sewage treatment is non-existent. Septic tanks are used in Barbuda.[116] According to 2001 data, in Antigua, septic tanks and soakaways were used by about 60 percent of the population, with the remainder using pit latrines and pail closets. The coastal hotels and Holberton Hospital have their own sewage treatment plants.[117] Effluent is discharged into the sea through outfalls in the coastal areas of the capital cities of St. John's and Codrington.[118]

The deficiencies in proper sanitation have caused overflows from septic tanks into open gutters. Overflow problems are particularly acute in the more densely populated and tourist areas in St. John's. The low soil percolation rates exacerbate the situation.[119]

Antigua

Antigua's water supply comes from a combination of surface water, ground water and desalination plants.[120] Domestic and commercial water demands in Antigua are met by one desalination plant, three surface dams, multiple small ponds, and five well fields.[121,122] The desalination plant is owned, operated and maintained by ENERSERVE (Veolia Water Company). This plant supplies approximately 60 to 75 percent of Antigua's drinking water. The original plant capacity was extended in 1996, 1998, and 2001, reaching a presently installed capacity of 9,000 cubic meters per day (m^3/day).[123] The country has become more dependent on desalinated water, in spite of the increased water costs, due to undependable storage and supplies of surface water and ground water.[124] Ground water resources are limited and threatened by excessive use, saltwater intrusion, and pollution by chemicals and sewage.[125] The wells are gravel packed and are usually 60 ft deep in the coastal areas, and about 180 ft deep in the interior areas, with the deepest well about 180 ft deep. Some wells have been capped due to saltwater intrusion. The best producing well, Bendal's, yields about 70 gallons per minute (gpm) (100,000 gallons per day).

The total water supply produced from all three sources is about 4.1 to 4.5 mgd.[126] In 1998, it was estimated that 3.3 mgd was from desalination plants.[127] Water supply from each source varies, depending upon the season. The water from all three sources is blended for quality purposes.[128] See table 6.

Table 6. Antigua's Seasonal Water Supply

Source	Dry Season, %	Wet Season, %
Surface water	5	25
Ground water	20	15
Desalination	75	60

Source: Ivan Rodrigues, Antigua Public Utiities Aurhority

Three major reservoirs exist in Antigua. See table 7.

Table 7. Antigua's Major Reservoirs

Name	Size	Miscellaneous Information
Potworks Reservoir	1,100 million gallons	The largest lake
Bethesda Reservoir	140 million gallons	Used for irrigation
Collins Reservoir	90 million gallons	Used for aquifer recharge only

Source: Ivan Rodrigues, Antigua Public Utiities Aurhority

Water withdrawal per capita is about 80 m^3. Annual withdrawals of ground water and surface water are 48 percent of total available water.[130] The Water Division of APUA has responsibility for ensuring an adequate and sufficient water supply is available.[131] During drought periods, surface water impoundments have dried up and well capacity has been reduced to 30 percent. Low average rainfall and erratic distribution cause water supply shortages.[132]

During droughts, desalination plants provide up to 83 percent of potable water.[133] All water is metered and water costs are relatively high.[134] The cost for desalinated water is much higher than surface water and ground water.

During September 2002, during the site visit for this assessment, the Potworks Reservoir was visited. The lake was almost dry.[135] The reservoir has a capacity of 1,100 million gallons of water.[136]

Barbuda

Ground water is used for domestic purposes, and surface water is used for irrgation. Domestic and non-tourist water for the population of Barbuda is supplied from a single well that services the city of Codrington. The Central Board of Health monitors the water quality.[139,140] Plans exist to install a desalination plant in Barbuda for domestic use.[141] Rising sea levels are threatening the ground water resources in Antigua and Barbuda. In Barbuda, the ground water is less than 1.5 meters below ground surface. An increase in sea level could affect the salinity of the ground water.[142]

1. Domestic Uses and Needs

Antigua is dependent upon desalination for domestic water supply. Surface and ground water are also used to supplement water supply needs.[143] Barbuda depends on ground water resources.[144] In Antigua and Barbuda, residences have cisterns or individual rainwater catchments to supplement household water demands. The Development Control Authority mandates the inclusion of permanent rooftop water catchments in new residences. Particularly for Barbuda, this household rainwater harvesting is a substantial source of drinking water for the population.[145] In Barbuda, ground water wells provide water through a limited distribution system with the water used mainly for washing and flushing purposes because the quality is inadequate for consumption.[146] For both islands, about 60 percent of the total water withdrawals are supplied to the domestic sector.[147] Ninety-five percent of the urban population and 89 percent of the rural population have access to potable water.[148] For Antigua, APUA reports large losses in the distribution, believed to be mainly from illegal connections.[149]

2. Industrial/Commercial Uses and Needs

About 20 percent of the total water withdrawals are supplied to the industrial sector.[150] Industrial rates for water exceed rates for domestic and agricultural uses, promoting conservation in the industrial sector.[151] Hotels in Barbuda have their own desalination plants.[152]

3. Agricultural Uses and Needs

Due to high evapotranspiration and low rainfall, irrigation is necessary for growing crops.[153] About 20 percent of the total water withdrawals are supplied to the agricultural sector.[154] Irrigation is supplied by surface water resources with occasional use of ground water wells.[155] The surface water resources include over 500 ponds located in Antigua.[156] These ponds are private dug on farmers' land that are rain fed, and government dug ponds. There are about 200 farms currently on irrigation, out of about 1,000 farms available for irrigation. A typical farm is about 200 acres.[157] Desalinated water is generally too expensive to use for irrigation.

Overhead sprinkler and drip systems are the type irrigation systems used. The types of crops grown using irrigation include tomatoes, onions, peppers, eggplant, melons, squash, lettuce, cabbage, fruit trees, okra, carrots, herbs and spices. Most irrigated farmland is privately owned.[158] Reclamation and recycling of treated sewage has been identified as a possible source of water for agriculture.[159]

St. Kitts and Nevis

Until 1970, most of the water needs were met by surface water from spring water. As the population grew, ground water became the primary source of water supply after 1970. Ground water provides about 3 million Imperial gallons per day (Igpd), and surface water provides about 2 million Igpd. Neither St. Kitts nor Nevis has any natural reservoirs and desalination plants are not used on either island.[160]

The water resources are threatened by rising sea levels and increasing temperature causing higher evaporation rates. Due to limited surface water sources, the ground water resources need to be protected. Protection of ground water would involve the following actions:

- Rational use of available water enforced by the national water authority
- Controlled rate of pumping from aquifers
- Conservation of protective forests to allow for infiltration and aquifer recharge
- Protection from contamination by pollution sources (agricultural, human, etc.)[161]

The Public Works Department of the Ministry of Communications, Works and Public Utilities manages the water supply system. The Department chlorinates the water supply for bacteria and monitors the water quality according to World Health Organization (WHO) standards.[162,163]

Sewage treatment is non-existent with most of the country using septic tanks and water closets. Pit latrines were more widely used before 1980, but are also still used today to a lesser degree.[164]

St. Kitts
The primary source of fresh water on St. Kitts is rainfall. The surface water supplies are variable and insufficient to meet the water supply demands.[165] Average annual yields for surface water are 3.6 million m^3 and 20 million m^3 for ground water.[166]

The main ground water supply is from a coastal aquifer, with seven major ground water basins. The amount of ground water that can be pumped is about 10 mgd.[167] Table 8 shows ground water basin yields, and table 9 presents well capacities of the major aquifers.

Table 8. Ground Water Basin Yields, St. Kitts

Basin	Area (acres)	Average Rainfall (in)	Infiltration Recoverable Ratio	Yield Ratio	Safe Yield (Igpm)
Basseterre Valley	4,805	50	0.35	0.35	2,067
Cayon	3,599	55	0.20	0.20	341
Mansion	6,030	65	0.25	0.25	1,054
Northwest	10,385	70	0.30	0.30	2,815
Middle Island	6,054	75	0.25	0.25	1,221
Stone Fort	2,061	75	0.20	0.25	333
Camp	2,750	70	0.20	0.20	331
TOTAL	**--**	**--**	**--**	**--**	**8,162 (11.75 mgd)**

Source: St. Kitts Water Sector Analysis Report (1987) in = inches
Igpm = Imperial gallons per minute mgd = million gallons per day

Table 9. Well Capacities of the Major Aquifers per Ground Water Basin, St. Kitts

Basin Location	Estimated Yield (Igpm)	Well Capacity (Igpm)	Total Surplus (Igpm)
Basseterre Valley	2,067	1,845	222
Cayon	341	24	317
Lodge/Tabernacle	1,054	340	714
Profit/Sir Gillies	2,815	349	2,466
Con Phipps Estate/Wingfield	1,221	142	1,079
Stone Fort	333	150	183
West Farm/Buckleys	331	0	331
TOTAL	**8,162**	**2,850 (4.1 mgd)**	**5,312 (7.67 mgd)**

Source: St. Kitts Water Sector Analysis Report (1987) mgd = million gallons per day
Igpm = Imperial gallons per minute

Water is supplied to St. Kitts via six surface water intakes that supply five independent distribution systems. Five ground water wells supplement the water supply with a maximum yield of 16 million m^3 per year. The entire population of both islands has some form of access to water service. In some areas, water is supplied by a public standpipe located within 400 meters of the households served.[168] Table 10 presents water consumption for surface water and ground water in St. Kitts. Table 11 presents surface water by sources for St. Kitts.

Table 10. Water Consumption for St. Kitts by Type of Source (1977–2000)

Year	Ground Water (gal)	Surface Water (gal)	Total (gal)
1977	128,641	361,957	490,598
1980	77,611	596,496	674,107
1985	187,234	595,507	782,741
1990	361,459	597,873	959,332
1995	754,875	463,375	1,218,250
2000	1,011,350	468,000	1,479,350

Source: Water Department, St. Kitts, 2002 gal = gallons

Table 11. Surface Water by Sources for St. Kitts, thousands of gallons (1990–2000)

Year/ Location	Lodge	Franklands	Phillips	Wingfields River	Stone Fort	Total
1990	14,547	93,761	89,912	377,406	22,247	**597,873**
1991	10,253	87,891	72,961	309,056	20,802	**500,963**
1992	18,698	98,000	88,050	307,806	23,114	**535,668**
1993	16,722	96,131	66,131	296,806	22,536	**498,326**
1994	7,489	116,974	36,009	257,606	15,695	**433,773**
1995	9,361	117,913	45,591	273,873	16,637	**463,375**
1996	10,856	118,320	61,489	271,092	16,694	**478,451**
1997	16,411	107,886	78,474	377,155	20,868	**600,794**
1998[a]	15,088	92,888	67,860	324,305	19,968	**520,109**
1999[a]	10,000	115,000	60,000	280,000	15,000	**480,000**
2000[a]	--	--	--	--	--	**468,000**

Source: Statistical Review 2001, St. Kitts and Nevis, prepared by Statistics Division, Planning Unit, Ministry of Finance, Development and Planning

[a]1998 – 2000 Surface Water Data are estimates. -- data not available

Wingfields is the primary catchment system that serves Basseterre. The system produces about 5,000 gpm. The catchment is in a semi-developed national park, and the potential for pollution is very high due to the lack of control of visitors. Attempts are being made by the Conservation Officer to get the area under better control.[169] This catchment area is also at great risk of contamination by pesticides use due to agricultural activities in the area.[170] Phillips catchment has no treatment which is typical of rural community systems. Spring water is treated by rapid sand filtration and chlorination.[171]

Nevis

Nevis' water needs for domestic, industrial and agricultural purposes are met by surface water, rain, and ground water sources. Ground water accounts for 80 percent of the public piped supply, and surface water accounts for the remaining 20 percent. Saltwater intrusion is not a concern for the aquifers on Nevis.[172] Ground water quality problems with heavy metals, such as arsenic, have been reported.[173]

Four distribution networks service the island. The Nevis Peak-New River System services the southern portion of the island; the Maddens System services the northeast portion; the Camp Spring-Jessup System services the northwest portion; and Charlestown is supplied by its own ground water wells. In addition to the Charlestown wells, the water supply is supplemented by wells at Zion and Maddens.

Table 12 presents the Nevis water supply for 1990 and supply projected during 1990 for supply in 1991.

Table 12. Nevis Water Supply System

System	Period	Gallons Per Day
Maddens	1990	198,720
	1991[a]	371,520
Camp Spring-Jessup	1990	76,320
	1991[a]	112,320
Nevis Peak-New River	1990	273,600
	1991[a]	388,800
Charlestown	1990	172,800
	1991[a]	237,600
Total Current Supply	**1990**	**721,440**
1991 Projected Supply	**1991[a]**	**1,110,240**

Source: Mills, T., National Report on Integrating Water-Watershed-and Coastal Areas Management for United Nations Environment Programmes

[a]1991 values were projected during 1990

Nevis has lower annual rainfall and lower yielding water sources than St. Kitts. Rural communities experience water shortages during the dry season.[174]

1. Domestic Uses and Needs

The water supply of over one million Igpd is sufficient to meet the domestic water demands for Nevis, except during the dry season.[175,176] Domestic supplies are supplemented with water collected in roof catchment systems, particularly in Nevis.[177]

The water supplied to rural areas in St. Kitts and Nevis is untreated, and turbidity is a water quality concern.[178] According to the 1991 Population and Housing Census Report, 66.3 percent of the population has water piped into their homes, and 22.8 percent have access to public standpipes.[179] Domestic water consumption in 1992 for St. Kitts is presented in table 13. Table 14 presents the domestic water demand by zone for Nevis.

During the dry season in St. Kitts, the rural areas of Sadlers, Cayon, Old Road and St. Peter's do not have enough water. Insufficient water storage exists.[180] In Cayon, St. Kitts, desperately needed water storage was constructed in 2002-2003. The Cayon water system primarily serves the government-owned sugar cane factory, and all the water supply is diverted to the factory during production.[181]

Table 13. Domestic Water Consumption, St. Kitts

Quantity (gal)	Percent of Consumers	
	Basseterre	Rural
0 – 1,000	7.9	20.9
1,001 – 2,000	10.7	19.7
2,001 – 3,000	10.0	17.5
3,001 – 4,000	11.9	11.0
4,001 – 6,000	21.9	14.0
6,001 – 8,000	11.9	9.2
8,001 – 10,000	7.7	4.5
10,001 – 15,000	8.4	2.9
15,000 +	9.6	0.4
Total	**100**	**100**
Average (gal per month)	6,149	3,040

Source: Appraisal Report on Water Supply project – St. Kitts/Nevis (Dec 1992)
gal = gallons

Table 14. Nevis Domestic Water Demand by Zone

Zone	Population	Demand at 65 gpcd
Newcastle	250	16,250
Westbury	95	6,175
Cotton Ground-Jessup	1,247	81,055
Charlestown	2,392	155,480
Morning Star	1,010	65,650
Stoney Hill	1,767	114,855
Hardtimes	1,241	80,665
Butlers	344	22,360
Brick Kiln	362	23,530
Camps	407	26,455
Mount Lily	333	21,645
TOTAL	**9,448**	**614,120**

Source: Nevis Water Department, 1990 gpcd = gallons per capita per day

2. Industrial/Commercial Uses and Needs

No commercial businesses exist on either St. Kitts or Nevis that use significant amounts of water.[182]

3. Agricultural Uses and Needs

About 85 percent of the agriculture for St. Kitts and Nevis is rain fed, and 15 percent is irrigated by dams and springs. Drip flood irrigation is used in St. Kitts and Nevis for agriculture.[183] Sugar cane farming may be phased out and replaced with other crops that may require more water, fertilizer and pesticides. This increased need for irrigation water is causing concern.[184] The Wingfields catchment area, near the Wingfields River, may be contaminated with pesticides due to significant agricultural activities in the area.[185]

B. Hydropower

The dominant source of energy used in Dominica, Antigua and Barbuda, and St. Kitts and Nevis is petroleum.[186] See table 15. Lacking petroleum sources, they must import their energy or find alternative energy sources. As the reliance on petroleum imports limits their economic growth, local governmental, regional, and international agencies are exploring programs to minimize this limitation and expand their economies. A primary interest of these programs is renewable energy.[187] Hydroelectric energy is the most promising renewable energy source.

Table 15. Primary Energy Consumption in the Caribbean, 2001

Country/Territory	Total (trillion Btu)	Petroleum	Natural Gas	Coal	Hydroelectric
Antigua and Barbuda	7	100%	--	--	--
Dominica	1.6	75%	--	--	25%
St. Kitts and Nevis	1	100%	--	--	--

Source: Oil and Gas Journal, December 23, 2002 Btu = British Thermal Unit
-- = not applicable

Dominica

Development of hydropower, while technically feasible, is hampered by financial, institutional, and environmental considerations.[188] Precipitation and topographic relief are very high, but Dominica supplies only 25 percent of its own energy requirements through two hydroelectric stations. See table 15. Improvements in the efficient use of existing nonrenewable resources of energy supplement their energy policy.[189]

Prior to 1990, Dominica met 40 percent of its energy requirements through two hydroelectric stations, Trafalgar and Padu, both located along the Roseau River. A new facility was expected to raise their usage to 60 percent in the mid 1990s.[190]

Ti Tou Gorge is a narrow and deep channel in the headwaters of the Roseau River near Laudat. Water flowing through the gorge was first harnessed for power in the 1950s. Damming the gorge allowed the diversion of its water into canals and pipes leading to a power station. Raising the water level created a recreational swimming area and encouraged tourism to the site.[191]

Electrical generation in Dominica has risen 37 percent since 1995. A growth in diesel generation of 69 percent fueled the majority of that increase. Figure 9 illustrates hydroelectric generation dropping behind diesel generation since 1995.[192] However, the amount of hydroelectric generation in 2000 was about the same as in 1995.

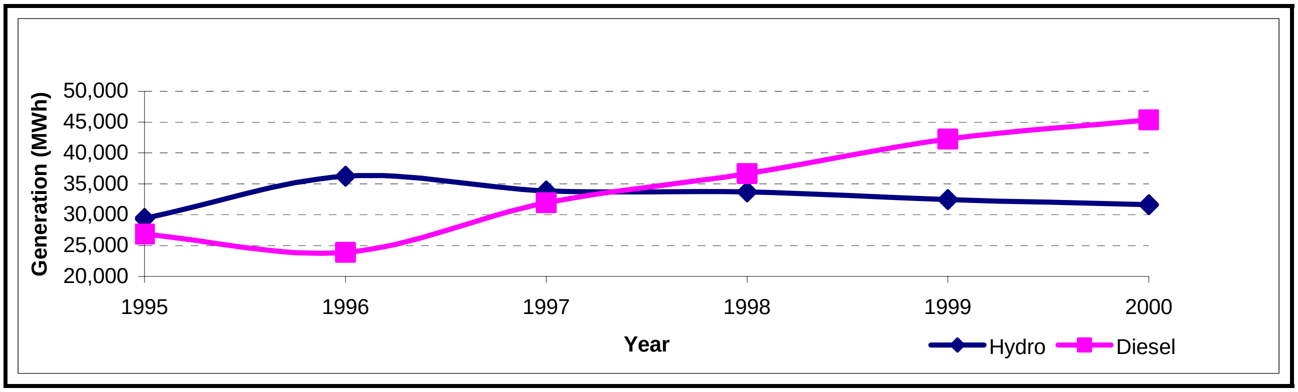


Figure 9. Electricity Generation in Dominica (1995-2000)
Source: The Gund Institute for Ecological Economies
MWh = Million watts per hour

Antigua and Barbuda

Due to a lack of significant surface water supplies, the islands of Antigua and Barbuda do not presently utilize hydropower. Instead, they use petroleum for 100 percent of their energy consumption.[193] Limited supplies of surface water preclude even small continuous hydroelectric generation.

St. Kitts and Nevis

Lacking significant surface water supplies, the islands of St. Kitts and Nevis do not presently utilize hydropower. Instead, they use petroleum for 100 percent of their energy consumption.[194]

C. Hydrological Monitoring

Minimal amounts of meteorological data have been collected in Dominica, Antigua and Barbuda, and St. Kitts and Nevis since the early 1900s.[195] Presently, the Caribbean Institute for Meteorology and Hydrology (CIMH) collects, analyzes, and archives meteorological and hydrological data from the member countries of the Caribbean Meteorological Organization, which include Dominica, Antigua and Barbuda, and St. Kitts and Nevis. Hourly and daily values of temperature, precipitation, stream flow, cloud types and coverage, wind speed and direction are the type of data archived. CIMH was formerly the Caribbean Meteorological Institute. Records at this Institute date back to 1970, with some earlier data available.[196]

CIMH produces an annual report that summarizes monthly averages and extremes. This is the climatological data that CIMH provides to engineers, agriculturists, architects, and other consultants requesting climatological data for projects.[197]

Presently, no systematic continuous collection and reporting of stream flow occur for the inland waterways of the three countries. As a result, governmental agencies and economic entities have minimal historical hydrological data available for planning purposes.[198]

Many short-term monitoring programs have been funded in the past 50 years for specific projects. These ventures have taken the place of systematic and continuous record keeping. Hydroelectric projects and environmental projects such as deforestation are short-term monitoring project examples. One specific project was a recent four-year program to monitor the impact of global climate change on the region, particularly sea level rise in coastal and marine areas. This began in the late 1990s, executed by the Organization for American States. Stations were installed along the coastlines of several Caribbean countries, including Dominica, Antigua, and St. Kitts. See figure 10. The intent was for the stations to record sea level, air and sea surface temperature, wind speed, barometric pressure, relative humidity and precipitation. Little data was collected because of equipment and training problems, and storm surge damage.[199]

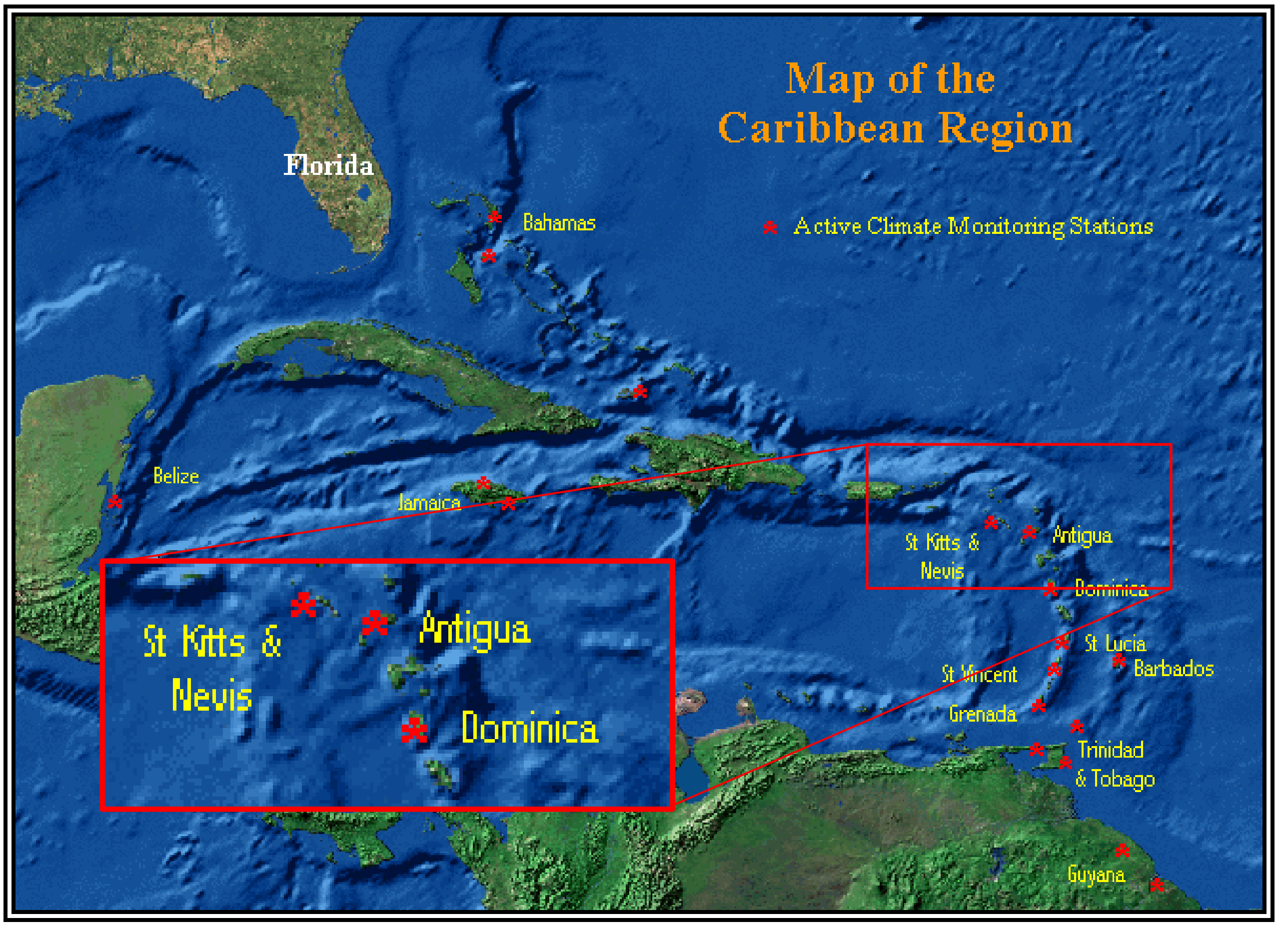


Figure 10. Coastal Stations for Monitoring Climate Change Impacts
Source: Caribbean Planning for Adaptation to Global Climate Change

Dominica

Attempts have been made in the last 50 years to collect hydrological data in Dominica. A two-year monitoring program of the Layou River watershed collected data from 1983 to 1985. Currently, DOWASCO measures stream flow on the Picard, Douce, and Springfield Rivers, and the Snug Corner. There are records for at least six other gaging stations throughout the country. In addition, Mr. Arlington James of Dominica's Forestry and Wildlife Division collects data on the Layou River.[200]

Antigua and Barbuda

Antigua and Barbuda do not have any permanent rivers, so the need for stream flow measurements is low.[201]

St. Kitts and Nevis

Most streams are ephemeral with flows occuring only during the wet season, so stream flow measurements are not systematically collected.[202]

D. Waterway Transportation

Commercial transportation along inland waterways in Dominica, Antigua and Barbuda, and St. Kitts and Nevis is nonexistent.[203,204,205] Dominica is one of the wettest Caribbean islands and is the only one of the three countries with perennial rivers.[206,207,208] However, Dominica's rivers are not navigable, being too narrow and swift for traffic.[209] See figure 11.

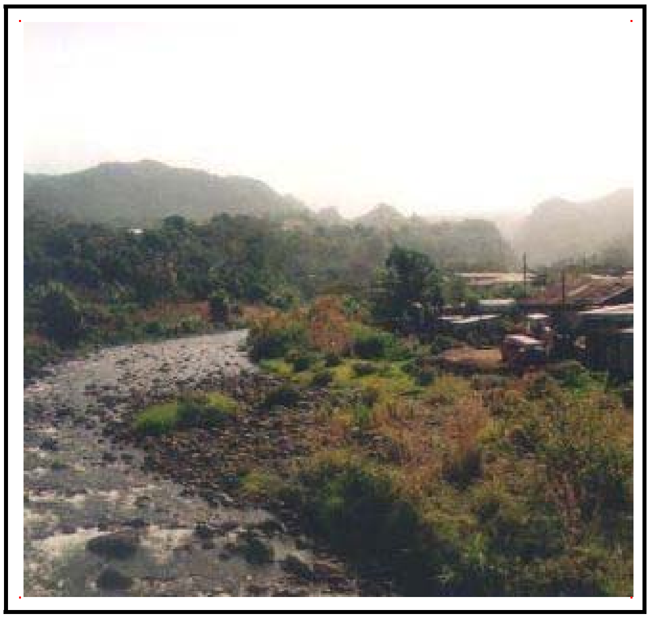


Figure 11. Roseau River Along Riverside, Dominica

Source: Roseau Photo Gallery, http://www.domnik.net/roseau/gall04.html

E. Recreation

Water recreational activities abound for the island countries of Dominica, Antigua and Barbuda, and St. Kitts and Nevis. Water related activities include snorkeling, scuba diving, windsurfing, and fishing. The island countries have also seen an increase over the past two decades in tourism associated with cruise ships. The countries have dredged, widened harbor channels, and opened new berths to accommodate the large cruise ships. Details of water related recreation are provided in the subsections for each country.[210,211]

Dominica

The abundant water resources on Dominica provide many opportunities for recreational activities. Dominica has numerous waterfalls, pools, lakes, national parks, rivers, and sulphur springs.[212] Morne Trois Pitons is a National Park in Dominica established in 1975. The park is a former volcano with fumaroles, hot springs, mud pots, and sulphur vents in the Valley of Desolation. Boiling Lake is a lake covered with clouds of steam. The water level and color of the lake vary depending upon the temperature of the water. Water from the Valley of Desolation drains into the Pointe Mulatre River and ultimately flows into the Atlantic Ocean. Other water features in the area include: Emerald Pool, Middleham Falls, and the Boeri and Freshwater Lakes. Fresh Water Lake is the largest and second deepest of Dominica's lakes. Morne Trois Pitons contains a major source of electric power for the island near Fresh Water Lake. Emerald Pool and Boiling Lake are popular hiking and walking areas.[213]

Antigua and Barbuda

Water recreation on the islands of Antigua and Barbuda is restricted to the coastal regions. Antigua and Barbuda established two national parks: Palaster Reef Marine Park and Diamond Reef Marine.[214] Palaster contains a shallow patch coral reef area and lies about 3 kilometers (2 miles) southeast of Cocoa Point, Barbuda. The federal government established the park on government property in 1973. Calcareous algae, filamentous algae, and boring algae typical of patch reefs and typical Caribbean reef fauna inhabit a marine park up to 50 meters (164 feet) in depth.

In Barbuda on the west side of the island, Codrington Lagoon is a very large lagoon, important for recreation and fishing.[215]

Diamond Reef Marine Park is made up of shallow calcium carbonate banks and extensive patch coral reefs and lies about 5 kilometers (3 miles) off the north coast of Antigua. The federal government established the park on government property in 1973. Calcareous algae, filamentous algae, and boring algae typical of patch reefs and typical Caribbean coral reef fauna populate a 2,000 hectare park up to 100 meters (328 feet) in depth. No information is available on visitors and visitor facilities, scientific research and facilities, staff, budget, and management for either park.[216]

St. Kitts and Nevis

Water recreation on the islands of St. Kitts and Nevis includes snorkeling, scuba diving, windsurfing, and fishing. Virgin reefs can be explored by snorkeling among pillar coral, sea fans and long slender tube sponges. A favorite place for snorkeling is White House Bay on St. Kitts' southeastern peninsula.

Scuba diving is popular among schools of snapper, angelfish, chubs, jacks and barracuda. Southern stingrays, eagle rays and numerous turtles can also be seen while scuba diving. A popular scuba dive spot is Sandy Point Town, which has an array of corals, sponges and reef fish as well as some coral-encrusted anchors from the colonial era. Among a handful of wreck dives in the bay is the freighter River Taw, which sank in 15 meters (50 feet) of water in 1985. Nevis has good diving locations on its western coast.[217,218]

St. Kitts and Nevis are situated in the Caribbean chain in a location advantageous for windsurfing the North Easterly Trade Winds. Oualie Bay, in the north of Nevis, catches the trade winds and offers windsurfing in shallow waters. When the wind is up, the opportunity for wave jumping is plentiful.[219,220]

The many reefs off St. Kitts and Nevis provide opportunity for reef fishing. The reefs create drop-offs which are good for game fish, such as Wahoo, Dorado, Tuna, Blue Marlin, White Marlin, Sailfish, and Kingfish.[221]

IV. Existing Water Resources

A. Surface Water Resources

1. Precipitation and Climate

The islands of Dominica, Antigua, Barbuda, St. Kitts, and Nevis all have humid tropical climates that are moderated by sea breezes from the northeast. Hurricane season for the islands runs from July to October. September and October have the greatest potential for hurricane force winds. Historical documentation of climatic patterns for the islands indicate that periodic droughts occur, which adversely impact recharge to surface and ground water resources. High flow typically occurs from June to October and low flow usually extends from November through May.

Dominica

Dominica has a variable climate. The wet season runs from June through October; August and September are the wettest months. The dry season runs from December to May; December and January are typically the driest months. High flows typically occur from July to October and low flows usually extend from December through May. Average annual precipitation ranges from 1,245 mm (49 inches) along the northwest coast to over 7,620 mm (300 inches) in the central mountain region. See figure 12.

In 2001, Dominica experienced its worst drought in 30 years.[222] In May 2001, the towns of Cabrits, Carholm, and Delices had 0.48 percent, 1.42 percent, and 2.52 percent, respectively, of the total annual rainfall for that year. Scores of fires occurred in the lower altitude scrub lands and in the rain forest during April and May. May was the driest month of the drought. During May, forests had heavy leaf fall along the southern and eastern coasts due to the lack of precipitation. The north central coast, which averages less than 1,270 mm (50 inches) of rainfall annually, is the area most suspectable to drought on the island.

Antigua and Barbuda

The climate in Antigua and Barbuda is characterized as moderate arid and tropical maritime. The average high temperature ranges from 24 degrees Celsius (75 degrees Fahrenheit) in December and January to 29 degrees Celsius (84 degrees Fahrenheit) in August and September. The annual rainfall for Antigua ranges from 890 to 1,400 mm (35 to 55 inches), one of the lowest in the Caribbean. The average annual rainfall for Antigua is about 1,040 mm (41 inches). See figure 13. Generally the wet season is from June to October and the dry season is from December to April. The average relative humidity is 82 percent. Antigua's evapotranspiration rates are high: 87 mm (3 inches) per month in November and 143 mm (6 inches) per month in March. On average, evapotranspiration exceeds precipitation 11 months of the year in Antigua. Barbuda has a lower rainfall average which ranges from 508 to 991 mm (20 to 39 inches). Barbuda's wet and dry seasons are similar to Antigua's.[223]

Antigua and Barbuda are prone to drought. Drought generally implies less than 826 mm (32.5 inches) of precipitation annually. Antigua has had three recent droughts (1983, 1993 to 1994, and 2001 to 2002).[224] In 1983, annual rainfall was 566 mm (22 inches). This was the lowest rainfall since 1874.[225] The 1983 drought left all the ponds and most reservoirs empty. Also, a large number of livestock, including cattle and pigs, died or were stressed due to water shortage. Water rationing was introduced, and the neighboring islands barged potable water to the island. In Barbuda, during the period from 1965 to 2000, annual rainfall fell below 706 mm

(28 inches) on ten occasions.[226]

During the 1993 to 1994 drought, the Vare Cornwall Bird International Airport recorded an average rainfall of 1,016 mm (40 inches) for 1993. This was a problem because approximately 33 percent of the rainfall for the year fell in May, so much of the precipitation was lost as runoff. This was followed in 1994 by an average precipitation of 775 mm (32 inches). The availability of desalinated water as a potable water source made up for the lack of recharge to surface and ground water supplies from precipitation for the islands' residents and tourists.

During the 2001 to 2002 drought, personnel from the U.S. Army Corps of Engineers Mobile District and the Topographic Engineering Center of the Corps' Engineer Research and Development Center made a field visit to Potworks Reservoir in September 2002. There, they observed that water levels were 85 percent lower than normal reservoir capacity, and that there were extensive mud cracks on the reservoir bottom. In 2001, OAS conducted field work to develop a drought risk map for Antigua and Barbuda.[227, 228] The high risk areas for drought are the northern, eastern, and southern regions of Antigua and the southern two-thirds of Barbuda which receive less than 1,016 mm (40 inches) of rainfall annually.

Both Antigua and Barbuda are located in the Tropical belt and are affected by hurricanes and tropical storms. Each hurricane can drop 254 to 762 mm (10 to 30 inches) of rain in a few days. These hurricanes and tropical storms can make drought conditions worse by removing the topsoil through runoff, by forming and deepening gullies, and by generally eroding soil. The effect is greatest where land has been cleared for farming, landscaping, or construction.

St. Kitts and Nevis

Distinct microclimates exist within St. Kitts. See figure 14. The southeast part of the island receives less than 1,020 mm (40 inches) of annual rainfall. Toward the central mountain ranges, the climate of St. Kitts becomes humid with annual rainfall approaching 3,810 mm (150 inches). The wet season is from June to October; the dry season runs from November to April. Average evapotranspiration is approximately 1,140 mm (45 inches) per year.[229]

Nevis has suffered three documented drought episodes since 1990.[230] Normal annual rainfall for the island is 1,170 mm (46 inches) per year. During the 1990 to 1991 drought, average rainfall for the 2-year period was 942 mm (37 inches). In 1993, average rainfall was 942 mm (37 inches), and it was 885 mm (35 inches) in 1997.

Precipitation on St. Kitts falls along the northeastern side of the island at high altitude. Deep, steep-sided channels drain the water toward the sea; however, these channels are usually dry. Only the Wingfields and Cayon Rivers flow almost to the sea and then only during the wettest part of the year.[231] Despite the small elevation differential, surface water is so critical for water supply that dams have been built to store surface water for irrigation purposes.[232]

Rainfall is mostly orographic on St. Kitts and Nevis. Orographic refers to rain falling when moisture-laden air is forced up and over mountains. The air currents in the region usually move in a westerly direction causing rainfall to occur on the eastern side of the islands. Annual rainfall is less than 1,016 mm (40 inches) in the southeastern peninsula of St. Kitts.

2. River Basins

Dominica

For this study, the island is divided into six hydrological basins. All the streams have a radial pattern. In other words, they flow away and downslope from a volcanic mountain peak in a radiating pattern. See figure C-1 and table C-1. Nearly all the streams (major and minor) on the island are perennial with very small to small quantities of fresh water year-round, with the exception of some unnamed streams in the southeast that provide meager to moderate quantities of water. Some of the island's rivers do not have formal names and therefore are not depicted. See figure C-1. Dominica relies totally on streams for its water supply. The mouths of the streams are subjected to constant inundation of brackish to saline water from the Caribbean Sea or Atlantic Ocean.

The Lamothe Basin (I) is in the far northwestern part of the island. Average annual rainfall in this region ranges from 1,270 to 3,810 mm (50 to 150 inches). The Lamothe River is the principal river in the basin. All streams are slightly meandering with flows originating from Morne Aux Diables, a volcanic mountain. Streams average 2 kilometers (1.2 miles) in length. Access may be difficult due to lack of road networks, heavy vegetation, and locally steep slopes. The primary city in this basin is Portsmouth.

The Northwest Basin (II) lies in the northwestern part of the island. Average annual rainfall in this region may be less than 2540 mm (100 inches) or may be as much as 7,620 mm (300 inches). Local relief is 1,587 meters (5,207 feet). Relief is the vertical difference in elevation between the summits and the lowlands of a given region. Principal rivers include the Picard, Dublanc, Batali, and Macoucheri Rivers. All rivers in this basin originate from the Morne Diablotins, a volcanic peak. Streams average over 8 kilometers (5 miles) in length and provide meager to very small quantities of fresh water year-round. Dominica has designated the Picard River to provide fresh potable water to cruise ships, which dock in Portsmouth. When needed for cruise ships, water from the Picard River flows through a pipeline at a rate of 0.06 to 0.08 cubic meter per second. Access to this river basin is extremely difficult due to steep slopes and inadequate road networks.

The Layou Basin (III) is located in the west-central part of the island. Average annual rainfall in the region ranges from 1,270 to 7,620 mm (50 to 300 inches). Local relief is approximately 1,390 meters (4,560 feet). The Layou River is the major river and one of the largest rivers on the island with an estimated drainage area of 70 square kilometers (27 square miles).[233] The upper reaches of the Layou River are split into two branches. The south branch of the river flows from the volcanic peak of Morne Trois Pitons, and the north branch of the river flows from the Morne Diablotins. A major landslide in 2002 dammed a small tributary flowing into the Layou River and created a lake-like reservoir behind the blockage of landslide debris. Erosion of rock and debris has occurred from the adjacent cliffs of the affected area. The dam could be breached and flood the valley and towns below if a landslide deposited more material into this lake. The Government of Dominica is studying the area closely to find a mitigating solution. Access to the upper reaches of the basin requires all-terrain vehicles or access by foot.

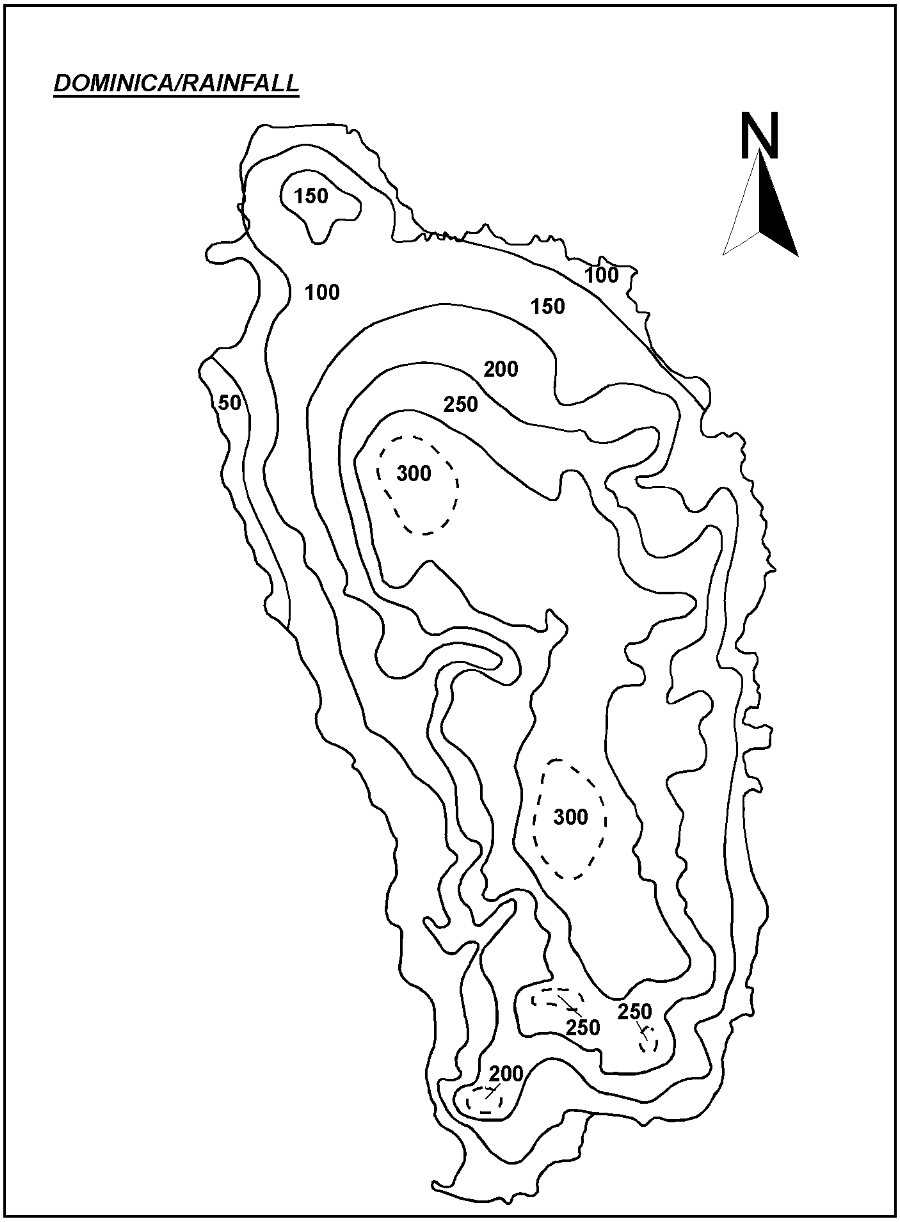


Figure 12. Precipitation Map of Annual Rainfall, Dominica
Rainfall isohyets in inches (One inch = 25.4 millimeters) Years of data pre-1991.

Precipitation estimates at higher altitudes were extrapolated from known areas of precipitation. These areas are designated by dashed lines.

Source: Caribbean Conservation Association, *Dominica Country Environmental Profile,* St. Michael, Barbados: 1991, p. 8.

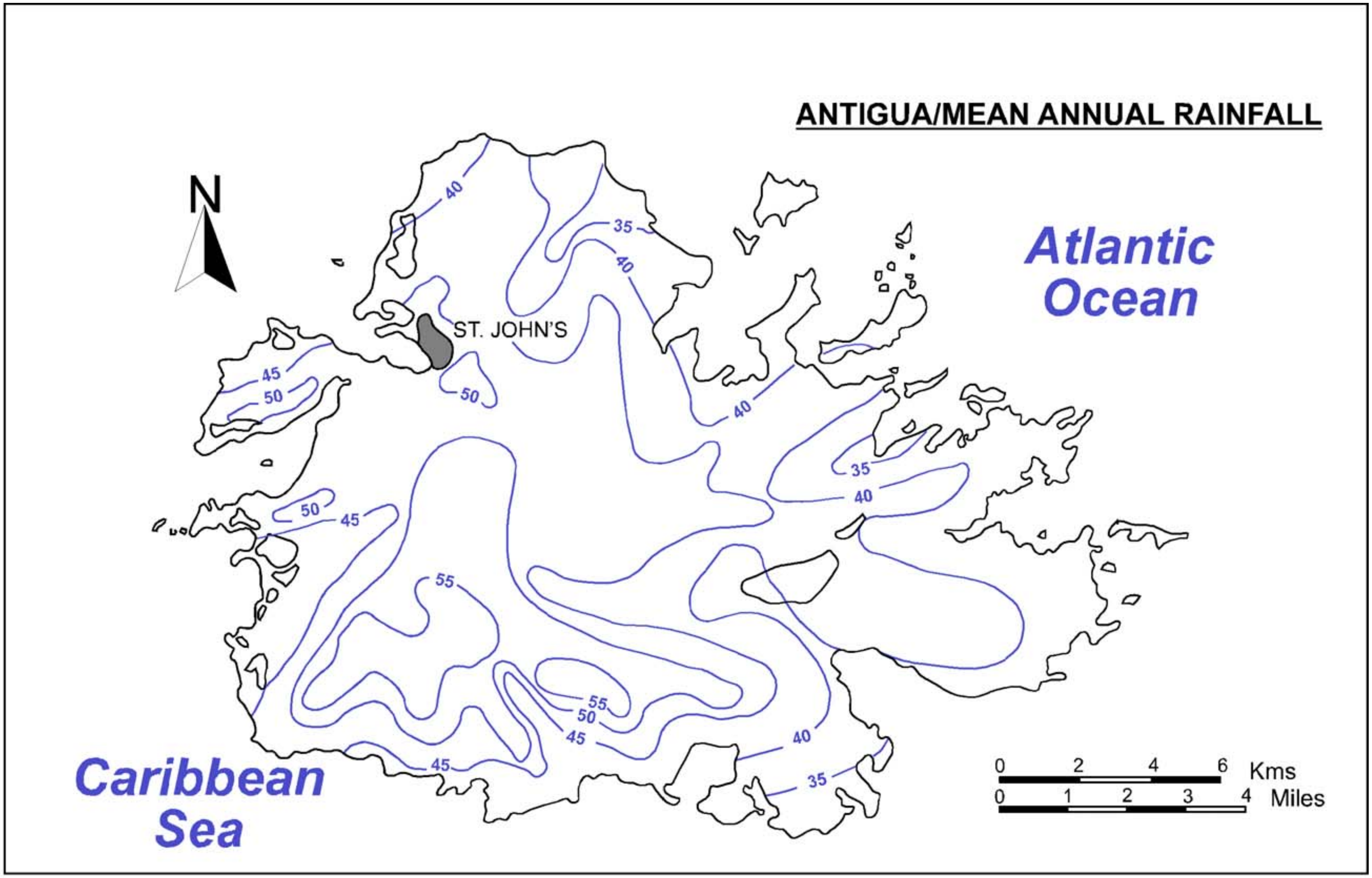


Figure 13. Precipitation Map of Annual Rainfall, Antigua
Rainfall isohyets in inches (One inch = 25.4 millimeters). Years of data pre-2001.

Source: Cooper, B. and V. Brown, *Integrating Management of Watersheds and Coastal Areas in Small Island Developing States of the Caribbean,* St. John's, Antigua: Ministry of Tourism and Environment, 2001, p. 6.

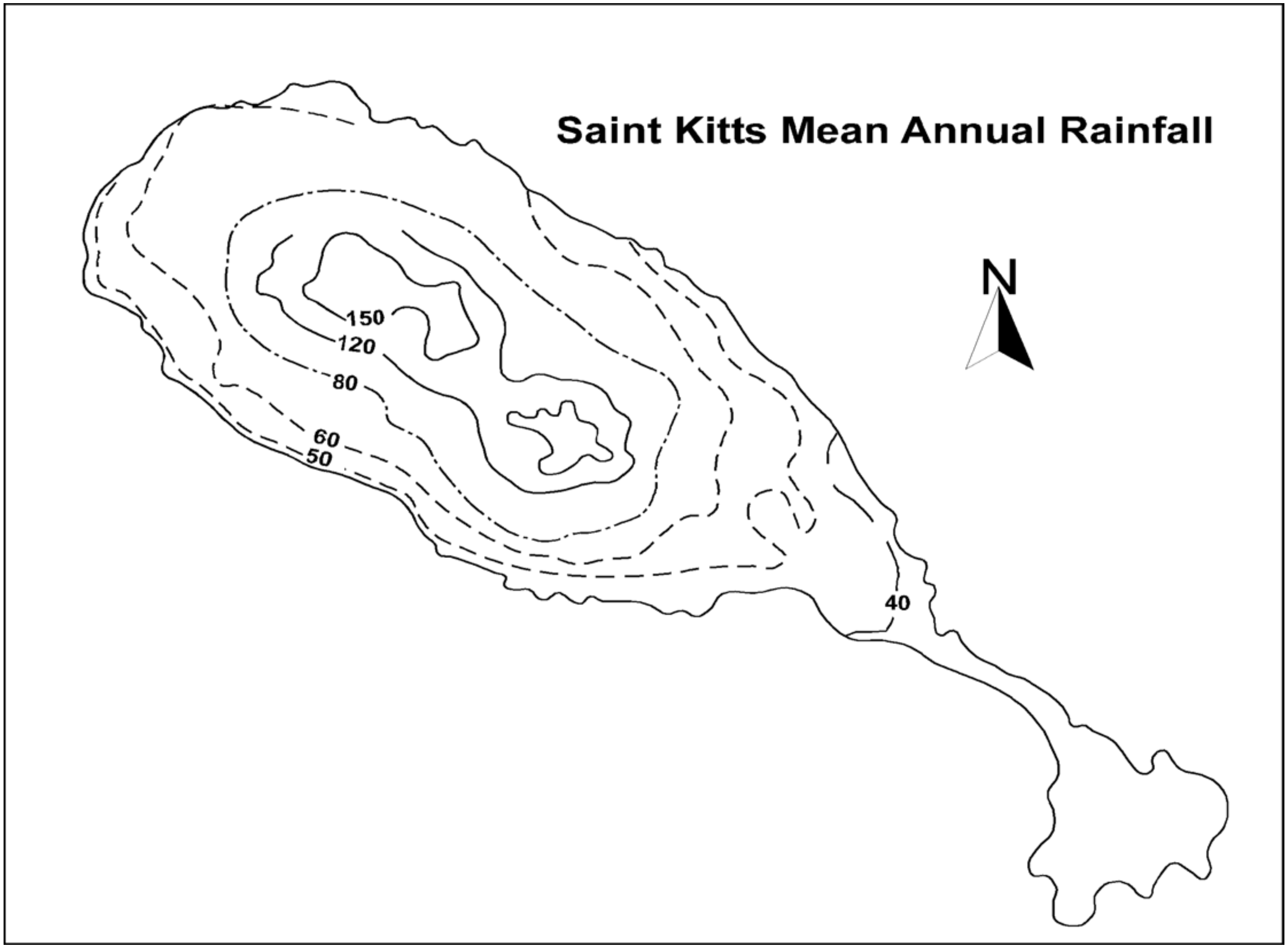


Figure 14. Precipitation Map of Annual Rainfall, St. Kitts
Rainfall isohyets in inches (One inch = 25.4 millimeters). Years of data pre-1985.
Precipitation above 500 feet are conjectural and have been estimated largely on the basis of vegetation.

Source: Blair, E. *An Assessment of Water Resources on the Island of St. Christopher (St. Kitts),* Washington, DC: Organization of American States, 1985, p. 6.

The Roseau Basin (IV) encompasses the southwestern part of the island. Average annual rainfall in the region ranges from 1,270 to 7,620 mm (50 to 300 inches). Local relief is approximately 1,360 meters (4,460 feet). Principal rivers include Belfast, Roseau River, Claire River, Check Hall River, and Ravine Sibouli. The Morne Trois Pitons, Watt Mountain, and Morne Cola Anglais mountains are the source areas for many of these rivers. The city of Roseau derives its water from two surface water intakes on the Roseau River: one intake is close to the Springfield Estate on the Check Hall River (north of Roseau), and the other intake is located on an unnamed river adjacent to the Snug Corner Estate (south of Roseau). Both of these intakes have a combined capacity of 16,650,000 liters per day (0.19 cubic meters per second) of withdrawal. This water system also provides potable water at a rate of 9,250,000 liters per month (9,250 cubic meters per month) from November to April to incoming cruise ships which dock at Roseau. The city lacks an effective filtering system for sediments. The drinking water supply often becomes turbid after a rainfall event, resulting in a temporary rise in the bacteria count unless additional chlorine is added to the system. Therefore, the city's water is chlorinated. Open dumping has been reported in the Roseau River outside the Roseau city limits.[234] Since 1991, about 8,000 tons of processed grapefruit pulp has been discharged into the Roseau River. The upper reaches of all the river systems in the basin are difficult to access due to thick vegetation and lack of roads.

The Castle Bruce Basin (V) covers the east and southeast side of the island. Average annual rainfall in the region ranges from 1,270 to 7,620 mm (50 to 300 inches). Local relief is similar to that for the Roseau Basin (IV). Principal rivers include Belle Fille, Clarke's, Geneva, La Rivere Blanche, and Ouayaneri Rivers. The sources of these rivers are the volcanic peaks of Morne Cola Anglais, Watt Mountain, Morne Trois Pitons, and Morne Fraser. Small seasonal streams north of Grand Bay provide meager to moderate quantities of fresh water during the high flow period from June to October. Drainage from two freshwater lakes in Basin (V), the Boeri Lake and the Fresh Water Lake, is diverted to the Roseau Basin (IV) via creosote treated wood stave pipes, and powers the hydroelectric power plants along the Roseau River. Further discussion of the lakes is provided under Section 3, "Reservoirs, Lakes, Ponds, and Swamps."

The Melville Hall Basin (VI) lies on the northeast part of the island. Average annual rainfall in the region ranges from 1,270 to 7,620 mm (50 to 300 inches). Local relief is 1,587 meters (5,207 feet). Principal rivers include the Beauplan, Hampstead, Mamelabou, Toulaman, Melville Hall, Canal, Saint Marie, and Pagua Rivers. The Morne Diablotins is the source area for these rivers. Most streams provide very small to small quantities of water. Small seasonal streams in the northern part of the basin provide meager to moderate quantities of fresh water during the high flow period from June to October. Herbicides are widely used because of the extensive cultivation of coconuts, citrus, vegetables, and coffee. However, no recent water sampling has been conducted to gauge the impact of herbicide use on drinking water quality. Open garbage dumping also occurs in many rural areas. Additionally, significant landslides have occurred in the upper reaches of many of these rivers, which would contribute to the turbidity of the water. Access to the headwaters of these rivers is difficult due to steep slopes, dense vegetation, and inadequate road network.

Antigua and Barbuda

Antigua is divided into four hydrological basins. See table 16 and figure C-1. Because evapotranspiration rates exceed precipitation rates, all major streams are intermittent or ephemeral and yield meager to very small quantities of fresh water for a few months after a heavy rainfall event. Minor intermittent streams yield unsuitable to meager quantities of fresh water after a heavy rainfall event. Antigua's rivers make up one-third of the public water supply for the island. Like Dominica, however, the mouths of the major rivers are frequently inundated with brackish to saline water along coastal areas. Access to all rivers is relatively easy due to the nearly flat topography with small hills and the lack of dense vegetation. Most of the creeks and rivers do not have formal names and thus are discussed as unnamed rivers and creeks in this report.

Table 16. Antigua Surface Water Storage Capacity for 1992*

Hydrological Basin	Existing Water Storage, m^3	
	Agricultural	Municipal
North Basin (VII)	524,626	--
West Basin (VIII)	261,519.3	547,452
South Basin (IX)	8,877.6	61,650
East Basin (X)	741,033	4,944,330

Source: Organization of American States, *Antigua Natural Resources and Agricultural Development Project, Watershed Districts (Map)*, Scale 1:50,000 Saint John's: Organization of American States and Antigua Ministry of Agriculture, Lands, Fisheries, and Housing, 1992.
Note:
* = Excludes data from desalination plants.
Dash indicates information is not known.

The North Basin (VII) encompasses the northern part of the island. Average annual rainfall ranges from 889 mm (35 inches) in the north coastal areas to 1,270 mm (50 inches) southeast of Saint John's. Local relief is approximately 444 meters (1,457 feet). Fitches Creek is the major river in the basin. Water quality of small streams within the vicinity of Saint John's is affected biologically by effluent from overloaded septic systems.[235] Most of the land within the basin is utilized for grazing, which contributes to elevated fecal coliform counts for the watersheds.

The West Basin (VIII) covers the western part of the island. Average annual rainfall ranges from 1,143 mm (45 inches) along the coastal areas to 1,397 mm (55 inches) within the interior hills. Local relief is approximately 400 meters (1,312 feet). The streams within the basin all flow to the northwest. Limited amounts of pesticides are used on food and vegetable crop plantations in the interior parts of the basin. It is not known if water quality is affected by this pesticide use.

The South Basin (IX) covers the southern part of the island. Average annual rainfall ranges from 889 mm (35 inches) along the southeast coast by English Harbour Town to 1,397 mm (55 inches) in the hills along the northwest side of the basin. Local relief is 402 meters (1,319 feet). Streams flow southward and have an average length of 3 kilometers (2 miles). Within the vicinity of Carlisle, various small agricultural fields exist where limited amounts of pesticides are used. It is not known if water quality is affected by this pesticide use.

The East Basin (X), located in the eastern part of the island, is undoubtedly the largest hydrological basin in terms of water storage capacity, because all of the island's major reservoirs are situated here.[236] Each reservoir is discussed in Section 3, "Reservoirs, Lakes, Ponds, and Swamps." Average annual rainfall is 889 to 1,397 mm (35 to 45 inches). Local relief is approximately 103 meters (338 feet). Ayers Creek, the major stream within the basin, flows east. The western half of the basin is used extensively for grazing, so the fecal coliform count might impact stream water quality in this area. The east half of the basin is mainly woodland with scattered pasturelands. Water quality in this area has not been thoroughly documented.

Barbuda has relatively flat topography, so surface runoff is minimal; therefore, the entire island is considered to be one hydrological basin, the Barbuda Basin (XI). The island also has very little potential for surface water storage because of the permeable nature of the soils. Unsuitable quantities of fresh water are available throughout most of the island. Very small to very large quantities of brackish to saline water are available along coastal areas.

St. Kitts and Nevis

St. Kitts is divided into three hydrological basins. See table C-1 and figure C-1 for further details on the surface water resources. Like Dominica, the streams flow in a radial pattern originating from volcanic peaks in the central part of the island. Some of the streams do not have formal names and are not labeled on figure C-1. Most water channels are deep and steep sided and are usually dry along all or most of their stretches.[237] However, most of the rivers do flow after a heavy rainfall event, and usually the duration of flow lasts a few months during the wet season from June to October. Meager to moderate quantities of fresh water are seasonally available from all major streams during the high flow period, which runs from June to October. Meager quantities are available during the low flow period from November to April. The tributaries of these major streams yield unsuitable to meager quantities of fresh water after major continuous storm events between September and October. The coastal areas of St. Kitts are subjected to saltwater intrusion. The mouths of all streams are inundated by brackish to saline water from the Caribbean Sea and Atlantic Ocean. Sugar cane farming causes erosion problems and high amounts of silt in nearby rivers, especially during the wet season. Access to the headwaters of all rivers is difficult due to dense vegetation, lack of roads, and steep slopes.

The Northeast Basin (XII) covers the northeast side of the island. Average annual rainfall in this area ranges from 1,020 mm (40 inches) along coastal areas to 3,810 mm (150 inches) in mountainous regions. Local relief is 1,264 meters (4,147 feet). Parson’s Ghut and Cayon River are the major streams within the basin.

The Southwest Basin (XIII) covers the southwest side of the island. Average annual rainfall in this region is similar to that of the Northeast Basin (XII). Local relief approaches 1,000 meters (3,281 feet). The Wingfields River, the principal river in the basin, is the longest river in St. Kitts and is approximately 10 kilometers (6.2 miles) in length.

The Southeast Basin (XIV) covers the southeast peninsula of the island. This basin is the driest on the island in terms of rainfall, which averages less than 1,016 mm (40 inches) per year. Local relief is 349 meters (1,145 feet) with generally flat topography and small hills. The watersheds in the other basins of the island are much smaller in size and length. Salt ponds are common within this basin. See Section 3, “Reservoirs, Lakes, Ponds and Swamps.”

Nevis is divided into two hydrological basins. See table C-1 and figure C-1 for further details on the surface water resources. Nevis is a volcanic island with all ephemeral streams flowing in a radial pattern from Nevis Peak to the Atlantic Ocean. Some of the streams do not have formal names and are not labeled on figure C-1. Like its sister island St. Kitts, all streams flow after heavy rainfall events. Meager to moderate quantities of fresh water are seasonally available from all major streams during the high flow period from June to October. Meager quantities are available during the low flow period from November to May. The tributaries to these major streams yield unsuitable to meager quantities of fresh water after major continuous storm events between September and November. The mouths of all streams are inundated by brackish to saline water intrusion from the Caribbean Sea and Atlantic Ocean. Very steep slopes and lack of roads hinder access to the headwaters of the streams. Specific rainfall patterns for different basins are not documented, but Nevis is drier in climate than St. Kitts. See Section 1, “Precipitation and Climate.”

The Charlestown Basin (XV) encompasses the western half of the island. Local relief is 965 meters (3,166 feet). Sulphur Ghut is the major stream in this basin. All streams vary in length from 2.5 to 5 kilometers (1.6 to 3.1 miles).

The Fountain Basin (XVI) encompasses the eastern half of the island. Local relief approaches 1,077 meters (3,534 feet). Two streams, which are both named Fountain Ghut, are the principal rivers in the basin. All the streams in Fountain Basin are similar in length and size to those in Charlestown Basin.

3. Reservoirs, Lakes, Ponds, and Swamps

Dominica

A few small lakes exist in the Castle Bruce Basin (V). Small quantities of fresh water are available from Boeri Lake and Fresh Water Lake year-round. Both lakes are classified as open lakes (i.e., both lakes are fed by small streams and drain into streams). However, the government of Dominica diverts the drainage flow of both lakes, via a weir and pipeline, to feed the hydroelectric power stations at Laudat and Trafalgar Falls at the headwaters of the Roseau River. Boiling Lake, a very small geothermal lake measuring 67 meters (220 feet) in diameter, is the largest boiling lake in the world. Two small streams feed this boiling lake, which is situated inside a volcanic crater.

Antigua and Barbuda

Antigua has ten small reservoirs; however, only three reservoirs are important in meeting agricultural and municipal needs.[238] Meager to moderate quantities of fresh water are available seasonally during the wet periods from June to October. All three reservoirs are situated in the East Basin (X). Potworks Reservoir is the largest reservoir with a storage volume of 5 cubic kilometers (km^3) when full. This reservoir serves as the island's main surface water supply behind desalinated water. Due to the recent drought in 2002, the water in Potworks Reservoir was used for irrigation, and caused a near depletion of the water volume. Bethesda Reservoir is the second largest reservoir on the island with a storage volume of 0.7 km^3 when full. Water from Bethesda Reservoir is used primarily for agricultural irrigation; however, during some drought periods, water may be diverted to the island's main water supply network. Water from the Collins Reservoir, with a storage volume of 0.4 km^3 when full, supplements the island's water supply network. Additionally, Antigua has numerous ponds on its west coast; however, all of these ponds are brackish to saline.

Barbuda's low-lying topography has created numerous swamps, marshes, and saline lakes, primarily in the southeastern part of the island.[239] Four very small saline lakes are north of Gravenor Bay (located on the southeast coast of Barbuda). Also north of Gravenor Bay lies a large salt marsh, and north of this marsh is a series of freshwater swamps. Two large lagoons are situated northwest of Codrington.

St. Kitts and Nevis

St. Kitts has a few scattered ponds. Two small ponds, each less than 1 kilometer (3,281 feet) in diameter, are located northeast of Basseterre in the Northeast Basin (XII). The Southeast Basin (XIV) contains a few saline ponds with the Great Salt Pond being the largest one.

Nevis has sparse small ponds throughout the island. Some of these ponds are in coastal areas and, therefore, are subject to inundation by seawater.

4. Deforestation Effects

Deforestation has historically been a problem on each of the islands since colonization began.[240] The clearing of the forests for timber and then for the production of sugar cane and bananas led to dramatic erosion problems resulting in significant soil loss. However, with the exception of Dominica, the rate of deforestation has dramatically decreased on the islands over the last century. Decreasing rates of deforestation and improved agricultural practices have helped stabilize the rate of soil erosion and improve the rate of infiltration by rainfall. However, deforestation still occurs, usually on marginal land, which causes rainfall to run off the ground surface at a faster rate. This causes streams to achieve larger peak discharges at a faster rate, increasing the intensity of flooding. In addition, most streams have increased sediment loads due to this problem, and it harms the coral reefs and mangrove swamps. Deforestation also decreases the productivity of the soil on the cleared land and lessens the amount of infiltration, causing drier than expected conditions. Debris and sediment from deforestation can also clog drainage systems and create unnecessary flooding.

Dominica

Approximately 30 percent of the island's land area is considered suitable for cultivation. The remaining 70 percent of the land is either too steep or contains poor soils which are not conducive to agriculture. Settlement growth, especially in the northeast, is encroaching on the scarce agriculturally suitable land, while less suitable land is being increasingly cultivated. Clearing trees and burning secondary growth for planting crops such as banana trees have led to an increase in soil erosion and a decrease in soil stability. Approximately 37 percent of the island has a very high erosion risk. The high-risk areas are in the island's steep interior on the windward (eastern) side of the island. Once deforested, these areas will lose much of the current soil cover and will not be able to recharge the aquifers as efficiently.

Antigua and Barbuda

Previous centuries of deforestation for planting sugar cane in these islands had historically resulted in severe degradation of the soil. This stabilized in the late 1800s, as most of the suitable land for agriculture was cultivated. Deforestation caused higher sediment loads in streams and an increase in agricultural contamination, which damaged offshore biospheres. With the rapid colonization of coastlines since 1960, coastal deforestation leaves shorelines unprotected and vulnerable to erosion. As a result, more mangrove swamps and offshore reefs have now been damaged or killed than in all previous island history.

St. Kitts and Nevis

St. Kitts and Nevis have no remaining undisturbed forests. Intensive land use on these islands has removed all natural vegetation leaving only secondary growth and agricultural crops, primarily sugar cane. At the time of colonization, erosion became severe, but has since decreased due to improved agricultural practices. The cultivation of sugar cane, which is a member of the grass family, aids in the stabilization of the islands soil. Currently, quarries are the primary sources of sedimentation in the streams. This is causing offshore reef degradation and the destruction of mangrove swamps.

B. Ground Water Resources

Ground water resources vary throughout the five islands. In Dominica, with the exception of a spring near Loubiere that is being exploited for bottled water, ground water is not the primary source of water. In Antigua, ground water makes up nearly 9 percent of the fresh water sources, whereas in Barbuda, ground water is nearly the only fresh source with the other minor source being rainwater.[241] In 2002, the St. Kitts Water Services Department reported ground water from wells supplied 60 percent of the island's fresh water source, with surface water supplying 40 percent. Throughout the five islands, ground water quality is generally fresh and free of contamination.

The quantity of ground water is scarce or lacking throughout the five islands. Exploratory costs for drilling wells are very high due to resistant volcanic rocks and the lack of primary porosity in aquifer material. Heated ground water from geothermal regions in Dominica, St. Kitts, and Nevis present some hazards to ground water exploration in these areas, such as the rapid corrosion of metals from the low pH of geothermal ground water. Saltwater intrusion along coastal areas is a major problem for all five islands. Well pumps have to be periodically turned off to prevent the freshwater and saltwater interface from migrating close to the bottom of the wells during pumping.

1. Aquifer Definitions and Characteristics

To understand how ground water hydrology works and where the most likely sources of water may be located, short aquifer definitions and aquifer characteristics are presented and are followed by specific island attributes.

Ground water supplies are developed from geologic formations that qualify as aquifers. An aquifer is made up of saturated beds or formations, either individual or in groups that yield water in sufficient quantities to be economically useful. To qualify as an aquifer, a geologic formation must contain pores or open spaces (interstices) that are filled with water, and these interstices must be large enough to transmit water toward wells at a useful rate. An aquifer may be imagined as a huge natural reservoir or system of reservoirs in rock whose capacity is the total volume of interstices that are filled with water. Ground water may be found in one continuous body or in several distinct rock or sediment layers within the borehole, at any one location. It exists in many types of geologic environments, such as intergrain pores in sand and gravel, cooling fractures in basalts, solution cavities in limestone, and systematic joints and fractures in metamorphic and igneous rock. Unfortunately, rock masses are rarely homogeneous, and adjacent rock types may vary significantly in their ability to hold water. In certain rock masses, such as some types of consolidated sediments and volcanic rock, water cannot flow, for the most part, through the mass; the only water flow sufficient to produce usable quantities of water may be through fractures or joints in the rock. Therefore, if a borehole is drilled in a particular location and the underlying rock formation (bedrock) is too compact (consolidated with little or no primary porosity) to transmit water through the pore spaces and the bedrock is not fractured, then little or no water will be produced. However, if a borehole is drilled at a location where the bedrock is compact and the rock is highly fractured and has water flowing through the fractures, then the borehole could yield sufficient water to be economically useful.

Since it is difficult or impossible to predict precise locations that will have fractures in the bedrock, photographic analysis can be employed to assist in selecting more suitable well site locations. Other methods are available but are generally more expensive. Geologists use aerial photography in combination with other information sources to map lithology, faults, fracture traces, and other features that aid in well site selection. In hard rock, those wells sited on fractures, and especially on fracture intersections, generally have the highest yields. Correctly locating a well on fracture intersections generally results in the highest yields. Correctly locating a well on a fracture may make not only the difference between producing high versus low water yields, but may make the difference between producing some water versus no water at all. On-site verification of probable fractures further increases the chance of siting successful wells.

Overall, the water table surface is analogous to but considerably flatter than the topography of the land surface. Ground water elevations are typically only slightly higher than the elevation of the nearest surface water body within the same drainage basin. Therefore, the depth to water is greatest near drainage divides and in areas of high relief. During the dry season, the water table drops significantly and may be marked by the drying up of many smaller surface water bodies fed by ground water. The drop can be estimated based on the land elevation, on the distance from the nearest perennial stream or lake, and on the permeability of the aquifer. Areas that have the largest drop in the water table during the dry season are those that are high in elevation, far from perennial streams, and consist of fractured material. In general, some of these conditions can be applied to calculate the amount of drawdown to be expected when wells are pumped.

2. Hydrogeology

Variations in geological structures, geomorphology, rock types, and precipitation contribute to a wide variety of ground water conditions in different parts of the island. The primary aquifer systems in Dominica, Antigua, Barbuda, St. Kitts, and Nevis are as follows:

- Tertiary to Quaternary age limestone and Recent age beach sand (map unit 1);
- Oligocene to Recent age mixed volcanic rocks with minor amounts of Recent age alluvium (map unit 2);
- Pliocene to Pleistocene age clay and tuff (map unit 3); and
- Oligocene to Pleistocene mixed volcanic and sedimentary rocks (map unit 4).

Map units are presented in table C-2 and on figure C-2.

Access to existing and potential well sites is dependent upon geography, density of vegetation, and road networks. Other factors such as geothermal activity and landslides may impact ground water exploration. Lowland areas generally have improved roads and less dense vegetation than highland areas.

a. Limestone and Sand Aquifers (map unit 1)

Fresh water is scarce or lacking from Tertiary to Quaternary age limestone. Generally very small quantities of fresh water are available. Small quantities of fresh water are available from locally fractured rock units. These aquifers are located in the northeastern one-third of Antigua, southwestern Barbuda, and a small area in western St. Kitts. In Antigua, depth to the aquifers varies from greater than 1 meter to 20 meters (greater than 3 feet to 66 feet) near coastal areas to 40 meters (131 feet) inland. In Barbuda, depth to aquifer ranges from 7 meters to less than 10 meters (23 feet to less than 33 feet). In St. Kitts, depth to aquifer ranges from less than 1 meter to 60 meters (less than 3 feet to 197 feet).

b. Mixed Volcanic Rock Aquifers (map unit 2)

Meager to small quantities of fresh water are available from Oligocene to Recent age volcanics with minor amounts of Recent age alluvium. Aquifers are located in nearly all areas of Dominica, the southwestern one-third of Antigua, and nearly all of St. Kitts and Nevis. In Dominica, depth to aquifer varies considerably from the ground surface to less than 200 meters (656 feet). In Antigua and Barbuda, depth to aquifer ranges from greater than 1 meter to 20 meters (3 to 66 feet) near coastal areas, and 20 to 50 meters (66 to 164 feet) in the small hills. In St. Kitts and

Nevis, previous test hole drilling showed depth to aquifer ranges from 2 meters (7 feet) near coastal areas to 70 meters (230 feet) in mountainous terrains. The fresh water/saltwater interface is approximately 20 meters (66 feet) deep in the coastal areas of St. Kitts and Nevis. Yields can be improved by siting wells along or at the intersection of fractures in this unit. Extreme caution should be used during drilling, installation, and pumping to prevent saltwater intrusion, which could permanently ruin the aquifer in the area.

c. Clay and Tuff Aquifers (map unit 3)

Meager quantities of fresh water are available from Pliocene to Pleistocene age clay and tuff. This unit is only located in the central areas of Antigua. Depth to aquifer ranges from less than 1 meter to 20 meters (less than 3 feet to 66 feet) near coastal areas, and increases up to 40 meters (131 feet) inland.

d. Volcanic and Sedimentary Aquifers (map unit 4)

Very small to very large quantities of brackish to saline water are available from the following: Miocene to Pliocene age basalt, dykes, and ash, and Pliocene age coral reef limestone and conglomerate in Dominica; Oligocene age limestone as well as Recent age beach sand and alluvium in Antigua; Pleistocene age limestone in Barbuda; Pliocene to Pleistocene age clay and tuff in Antigua and Barbuda; and Recent age beach sand in Barbuda, St. Kitts, and Nevis. These units are found in coastal areas of these countries and inland in Barbuda. Depth to aquifer is less than 1 meter (3 feet) in Dominica and from the ground surface to less than 20 meters (66 feet) in Antigua, Barbuda, St. Kitts, and Nevis.

C. Water Quality

1. Surface Water Quality

Dominica

The significant threat to Dominica's water quality is turbidity. Documented studies have shown many of the upland areas are prone to landslides during the wet season from June to October.[242]

Such landslides allow considerable amounts of sediment to be introduced at the headwater of many streams in affected areas. Additionally, some rural communities deforest steep slopes for cultivation of crops, which further contributes to the sediment load in rivers.

Open dumping of solid and industrial wastes in rural communities (e.g., Marigot, Castle Bruce, La Plaine, etc.) also contributes to the pollution of streams. Rural communities have no central collection service for refuse. Streams provide easy outlets for household garbage. Industrial establishments such as rum distilleries, auto repair garages, and furniture manufacturers openly dump their effluents and by-products into adjacent streams.

The impact of pesticide use on water quality has not been determined. No formally mandated monitoring procedures to test for pesticides and fertilizers exist. Pesticides are used for the cultivation of bananas, citrus, coconuts, and other crops. In January, 1990, the Consortium for International Crop Protection (CICP) conducted limited sampling for selected pesticides (paraquat, glyphosphate, cabamates, organochlorides, and organophosphates) on selected rivers.[243] Results of such sampling revealed no detectable pesticide residues. However, CICP investigators expressed concern over organochloride concentrations in wildlife.

Antigua and Barbuda

Pesticide use occurs on cultivated croplands. Most of the pesticide use is concentrated in the eastern half of Antigua and interior lowlands of Barbuda. One documented case of a fish kill at the Potworks Reservoir in Antigua could have been caused by the use of agro-chemicals. However, the severity of pesticide concentration in surface waters is not fully documented due to lack of available water testing data.

In Bendals, Antigua, a government-owned asphalt plant is a potential pollution source for nearby surface waters.[244] Residents of Bendals are concerned with the potential for contaminants from tar chemicals and leaky fuel drums migrating into the community via the ground and surface waters. In 2001, government officials in Antigua contracted environmental sampling work to a private firm at the plant. The private firm conducted limited sampling of soil, ground water, and surface water. Only two nearby surface water bodies, a pond and a creek were sampled. The surface water sampling test results showed no detectable levels of oil, gas, or volatile organic compounds. Turbidity, however, was elevated for the pond and the creek at 31.5 and 12.7 NTU (nephelometric turbidity units), respectively. The turbidity is thought to be the result of quarrying activities at the plant. However, semivolatile compounds such as benzo(a)pyrene, a primary constituent of asphalt and tar, as well as a known carcinogen, were not tested for in water samples.

St. Kitts and Nevis

The greatest concern to water quality problems in St. Kitts and Nevis is turbidity.[245] Many small ghuts north of Basseterre, St. Kitts, and those in Nevis have severe erosion problems resulting in excessive silt being transported along the watersheds. Human habitation along the banks of ghuts predisposes the watersheds to erosion and degradation. Also, massive deforestation in the Southeast Basin of St. Kitts accelerates erosion of hillsides and the eventual sediment loading of the ponds.

2. Ground Water Quality

The predominant factor affecting ground water quality in the islands is saltwater intrusion along or near coastal areas. Saltwater from the Caribbean Sea and Atlantic Ocean can easily invade at least 1 kilometer inland from the coasts, substantially increasing the total dissolved solids in the ground water. Extreme caution should be used during well drilling, installation, and pumping to ensure that the fresh water aquifer is not permanently contaminated by saltwater intrusion. Pumping should be monitored and kept at a suitable rate and yield to avoid saltwater intrusion from overpumping.

Dominica

Within Dominica, pesticides and fertilizers have the potential to impact ground water quality in rural areas where most of the farming takes place. It is difficult to gauge the severity of this impact because of the lack of qualified people to sample and send the ground water samples to appropriate laboratories for analysis.

Antigua and Barbuda

Other factors affect the ground water quality in Antigua and Barbuda. Hurricanes have the potential to introduce severe flooding. Such floodwaters tend to propagate into wells, which serve as conduits for aquifer contamination. In Antigua near Bendals, a government quarry and asphalt plant site contained leaky diesel and old tar drums, which had the potential to contaminate ground water there and off-site unless remediation was done. Ground water contamination from fertilizers and pesticides needs evaluating to determine the impact. Barbuda generally has dug wells, and many of these are not sufficiently covered and sealed to prevent bacterial contamination.

St. Kitts and Nevis

St. Kitts and Nevis also have ground water quality problems. Spring water might be biologically contaminated. The St. Kitts Department of the Environment has reported some heavy metals such as arsenic in the ground water of Nevis.

V. Water Resources Maps and Tables

A. Introduction

This chapter summarizes the water resources information of the islands, which can be useful to water planners as a country-wide overview of the available water resources. Figure C-1, Surface Water Resources, divides the country into surface water categories identified as map units 1 through 5, which group areas by similar surface water characteristics. Table C-1, which complements figure C-1, details the quantity, quality, and seasonality of the significant water features within each map unit and describes accessibility to these water sources. Figure C-2, Ground Water Resources, divides the country into ground water categories identified as map units 1 though 4, which group areas by similar ground water characteristics. Table C-2 which complements figure C-2 details predominant ground water characteristics of each map unit including aquifer materials, aquifer thickness, yields, quality and depth to water. The scale of the maps and the density of the features determine the amount of detail that the graphics can clearly represent. Qualitative terms are designated on the degree of total dissolved solids (TDS) and hardness on the degree of calcium carbonate in the water.

B. Water Conditions By Map Unit

1. Surface Water Resources and Ground Water Resources Maps

Figure C-1, Surface Water Resources, divides the islands into five map unit categories based on water quantity, water quality, and seasonality. Map unit 1 depicts areas where fresh surface water is seasonally available in meager to moderate quantities. Map units 2 through 5 depict areas where fresh water is scarce or lacking, and fresh to saline water is available in unsuitable to very large quantities.

Each individual island's surface water map depicts selected major streams, drainage basins, capital, major populated places, and any gaging stations with flow and/or water quality data. Gaging stations are designated as small triangular symbols with numbers assigned. The corresponding numbers correlate to the numbers listed in table C-1, in the Quantity column. For each selected gaging station in table C-1, the discharge rate in cubic meters per second and/or the analytical results of chemical parameters is presented. For figure C-1, delineation of hydrological basins is based on topography, drainage characteristics, and rainfall patterns of each island discussed in the report. Map unit 1 contains the greatest amount of fresh water and map unit 5 has the least.

Figure C-2, Ground Water Resources, divides the islands into four map unit categories based on water quantity, water quality, and aquifer characteristics. Fresh water is scarce or lacking throughout the islands. Map unit 1 in Antigua and Barbuda appear, at a country scale, to be the most favorable areas for ground water exploration. At the local level, map units 2 and 3 may be suitable for ground water exploration, but they require additional site-specific investigations. Map unit 4 areas have brackish to saline water.

Each island's ground water map depicts selected major streams, the capital, major populated places, and locations of selected wells or springs with flow and/or water quality data. The locations of springs or wells with flow and/or water quality data are designated as small triangular symbols with numbers assigned. These symbols with the corresponding numbers correlate with those described in table C-2. For each well or spring designated in table C-2, the flow in liters per second and/or the analytical results of chemical parameters are presented. Each map unit and corresponding number reflects the relative abundance of fresh, brackish, or saline ground water, the nature of the geology, the depth range of the aquifer(s) involved, and any other pertinent information. The relative abundance of fresh water corresponds to the map unit number. Map unit 1 represents the areas with the best available water, and map unit 4 represents areas with lesser amounts of fresh water.

2. Tables

The maps and tables are complementary and are to be used together. The tables provide supplemental information to areas designated on the maps.

The surface water resources table (table C-1) categorizes each surface water resource unit in the left column that corresponds to the surface water resources map (figure C-1). For the islands in this study, the units fall into either the Fresh Water Seasonally Available category or the Fresh Water Scarce or Lacking category. Each unit is then characterized by (1) Sources, (2) Quantity, (3) Quality, (4) Accessibility, and (5) Remarks for each island. Within the Sources column, the individual islands are divided into the representative basins. The primary surface water resource features within these basins are noted along with their corresponding latitude and longitude coordinates to assist the user in locating the feature on the surface water map (figure C-1). Within the Quantity column, the same division of islands and subdivisions of basins exist. Discharge information for known points is provided with the corresponding number and triangular symbol for the surface water resources map (figure C-1). Data within the Quality column is divided into individual islands, and known contamination issues are outlined. The information in the Accessibility column advises the user in general terms on how easily one can reach the sources of water. This column is directed more toward the operators in charge of logistically supporting large vehicles such as water tankers, drill rigs, or reverse osmosis water purification units (ROWPUs). The Remarks column captures important points that do not necessarily fit into any of the previous columns for surface water resources.

The ground water resources table (table C-2) categorizes each ground water resource unit in the left column that corresponds to ground water resources map (figure C-2). For the islands in this study, the units fall into the category Fresh water scarce or lacking. Each unit is then characterized by (1) Map Unit, (2) Aquifer Characteristics, (3) Quantity, (4) Quality, (5) Aspects of Ground Water Development, and (6) Remarks for each island. Within the Map Unit column, the individual countries are divided into the representative ground water potential categories, 1 through 4. Within the Aquifer Characteristics column, the characteristics of each aquifer are discussed in general terms. For each island, the aquifer is described in terms of the rock units that it represents. Within the Quantity column, yield information for known points is provided with the corresponding number and triangular symbol noted along with their corresponding latitude and longitude coordinates to assist the user in locating the feature on the ground water resources map (figure C-2). Data within the Quality column is divided into individual countries, and known contamination issues are outlined. For specific ground water quality points, the number triangle system is used again. The information in the Aspects of Ground Water Development column documents the depth to water, drought conditions, and saltwater intrusion issues by island. The Remarks column captures any important points that do not necessarily fit into any of the previous columns for ground water resources.

Water quantity and quality are described for each island by the following terms:

Surface Water Quantitative Terms:

Enormous	= >5,000 cubic meters per second (m^3/s) (176,550 cubic feet per second (ft^3/s))
Very large	= >500 to 5,000 m^3/s (17,655 to 176,550 ft^3/s)
Large	= >100 to 500 m^3/s (3,530 to 17,655 ft^3/s)
Moderate	= >10 to 100 m^3/s (350 to 3,530 ft^3/s)
Small	= >1 to 10 m^3/s (35 to 350 ft^3/s)
Very small	= >0.1 to 1 m^3/s (3.5 to 35 ft^3/s)
Meager	= >0.01 to 0.1 m^3/s (0.35 to 3.5 ft^3/s)
Unsuitable	= $\leq$0.01 m^3/s (0.35 ft^3/s)

Ground Water Quantitative Terms:

Enormous	= > 100 liters per second (L/s) (1,600 gallons per minute (gal/min))
Very large	= > 50 to 100 L/s (800 to 1,600 gal/min)
Large	= > 25 to 50 L/s (400 to 800 gal/min)
Moderate	= >10 to 25 L/s (160 to 400 gal/min)
Small	= >4 to 10 L/s (64 to 160 gal/min)
Very small	= >1 to 4 L/s (16 to 64 gal/min)
Meager	= >0.25 to 1 L/s (4 to 16 gal/min)
Unsuitable	= $\leq$ 0.25 L/s (4 gal/min)

Qualitative Terms:

Fresh water	= maximum TDS $\leq$1,000 milligrams per liter (mg/L); maximum chlorides $\leq$600 mg/L; maximum sulfates (SO_4) $\leq$300 mg/L
Brackish water	= maximum TDS >1,000 mg/L, but $\leq$15,000 mg/L
Saline water	= TDS >15,000 mg/L

C. Water Conditions by Island

The following section is compiled for each major island from figures C-1 and C-2 and tables C-1 and C-2. The write-up for each island consists of a general and regional summary of the surface water and ground water resources, derived from a country-scale overview. The summaries should be used in conjunction with figures C-1 through C-2 and tables C-1 through C-2. Additional information is necessary to adequately describe the water resources of a particular island. Recommended ground water pumping rates are based on average precipitation values. For all areas that appear to be suitable for tactical and hand pump wells, local conditions should be investigated before beginning a well-drilling program.

Dominica

Area:	750 square kilometers
Population (2001):	71,727
Population Density:	96 people per square kilometer
Capital:	Roseau
Location:	Caribbean, island between the Caribbean Sea and the North Atlantic Ocean, about one-half of the way from Puerto Rico to Trinidad and Tobago.
Geographic Location:	15° 25' 00" N 61° 20' 00" W

Surface Water:

Fresh water is abundant. The island is divided into six hydrologic basins: the Lamothe; Northwest; Layou; Roseau; Castle Bruce; and the Melville Hall Basin. Nearly all of the island's streams are perennial and typically discharge into the ocean. Dominica is totally dependent upon surface water for its water supply. Very small to small quantities of fresh water are available from map unit 2. Map unit 2 contains the Lamothe River of the Lamothe Basin; the Batali, Dublanc, Macoucheri, and Picard Rivers of the Northwest basin; the Layou River of the Layou Basin; the Belfast, Check Hall, Claire, Ravine Sibouli, and Roseau of the Roseau Basin; the Belle Fille, Clarke's, Geneva, La Rivere Blanche, and Ouayaneri Rivers in the Castle Bruce Basin; and the Beauplan, Canal, Hampstead, Mamelabou, Melville Hall, Pagua, Saint Marie, and Toulaman Rivers in the Melville Hall Basin. The areas of map units 1 and 2 would be good locations for the construction of small surface impoundments during troop engineering exercises. Areas upstream of agricultural activities, deforestation activities and populated places would be the best locations for minimizing impacts of increased turbidity and biological and chemical contamination. Most of Dominica lies within map unit 3, where meager to very small quantities of water are available after major continuous storm events, generally occurring from September to November. Map unit 5 lies along the coastal areas of the island, where very small to very large quantities of brackish to saline water are available. Map unit 5 represents the lower reaches of all streams that are subject to tidal influences and gradually degrade in quality from fresh to brackish to saline close to the ocean. This coastal map unit also includes several small brackish to saline ponds and marshes. Rainfall is high. Average annual precipitation ranges from 1,245 mm (49 inches) along the northwest coast to over 7,620 mm (300 inches) in the central mountain region. Steep cliffs along coastal areas make access difficult in some locations. Biological contamination of rivers is high, as the rivers are used as sewage drainage in the country due to the lack of treatment and disposal facilities.

Ground Water:

Fresh ground water supplies are very limited on the island. Meager to small quantities of fresh water are available from aquifers of volcanic origin throughout the island from map unit 2. Depth to water is variable and can range from near the ground surface to less than 200 meters (656 feet), depending on topography. Most reported wells on the island are drilled into this unit. Within geothermal areas ground water temperatures exceed 30 degrees Celsius (86 degrees Fahrenheit) and have a low pH. Map unit 4 represents aquifers composed of mixed volcanics such as basalt and ash. Primarily on the west coast, aquifers in map unit 4 may be composed of coral reef limestone and conglomerate. Quantities range from very small to very large volumes of brackish to saline water. Depth to aquifer is less than 1 meter.

Antigua

Area:	280 square kilometers
Population (1999):	68,500
Population Density:	245 people per square kilometer
Capital:	Saint John's
Location:	Caribbean, islands between the Caribbean Sea and the North Atlantic Ocean, east-southeast of Puerto Rico.
Geographic Location:	17º 50' 00''N, 61º 45' 00''W

Surface Water:

Fresh water is only available from streams after a significant rain event or for a few months from the more significant streams on the island. Antigua is divided into four hydrological basins. Meager to moderate quantities of fresh water are available from map unit 1 from Bethesda, Collins, and Potworks Reservoirs. Reservoirs clustered in the eastern portion of the island offer perennial supplies of fresh water. Fitches Creek in the North Basin, Ayers Creek in the East Basin, and Indian Creek in the South Basin in map unit 3 have meager to very small quantities of fresh water intermittently throughout the year, especially after major storm events between September and October. In map unit 4 unsuitable to meager quantities of fresh water are available from several unnamed minor streams throughout the island. The lower reaches of all streams in map unit 5 are subject to tidal influences and gradually degrade in quality from fresh to brackish to saline close to the ocean. Very small to very large quantities of water are available from the lower reaches of Fitches Creek in the North Basin, the lower reaches of Indian Creek in the South Basin, and the lower reaches of Ayers Creek in the East Basin. Agro-chemicals are the primary cause of contamination of surface water resources on the island. The terrain of the island is typically flat, making access to streams and reservoirs relatively easy. Antigua is prone to drought and has an average annual rainfall ranging from 890 to 1,400 mm (35 to 55 inches). The average annual rainfall for Antigua is about 1,040 mm (41 inches). The soil is porous and absorbs much of the precipitation after a rainfall event.

Ground Water:

Fresh ground water supplies are very limited on the island. Map unit 1, located in the northeastern third of the island, is the best area for ground water exploitation in Antigua. Map unit 1 is composed of limestone and sand aquifers from which very small quantities of water may be obtained. Meager to small quantities of fresh water may be available from map unit 2, located in the middle third of the island. The aquifer material is composed of a series of mixed volcanic rocks that include andesite, basalt, tuff, agglomerate and dacite. Depth to water varies from greater than 1 meter along the coast to 50 meters (164 feet) inland. Meager quantities of fresh water are available from clay and tuff aquifers in the central portion of the island in map unit 3. Depth to water from this unit varies from less than 1 to 40 meters (less than 3 to 131 feet). Map unit 4 depicts aquifers that yield very small to very large quantities of brackish to saline water from limestone, clay, tuff, and sand aquifers. Due to limited resources, the wells are typically clustered into well fields to maximize yields. During periods of drought, wells stop pumping to avoid saltwater intrusion near coastal areas.

Barbuda

Area:	161 square kilometers
Population (1999):	1,500
Population Density:	9.3 people per square kilometer
Capital:	Saint John's, Antigua
Location:	Caribbean, islands between the Caribbean Sea and the North Atlantic Ocean, east-southeast of Puerto Rico.
Geographic Location:	17º 38' 00''N, 61º 50' 00''W

Surface Water:

Fresh water is only available from streams after a significant rain event or for a few months from the more significant streams on the island. Barbuda lies within one hydrologic basin, the Barbuda Basin. Most of the island lies within map unit 4, where unsuitable quantities of fresh water are present. The coastal areas of the island lie within map unit 5 where very small to very large quantities of brackish to saline water are available. Scattered throughout the island are numerous swamps, marshes, and lakes, all of which are brackish to saline in quality. There are no named streams on the island. The terrain of Barbuda is relatively flat and rolling with porous sandy clay soil. Access to streams is considered easy due to the flat terrain and lack of thick vegetation. Average annual rainfall is 508 to 990 mm (20 to 39 inches), and most precipitation falls during the wet season from June to October. Small surface impoundments are not recommended on Barbuda.

Ground Water:

Most of Barbuda lies within map unit 4 where the groundwater is brackish to saline. Very small to very large quantities of water are available from map unit 4. Groundwater exploration is not recommended in these areas. In the southwest corner of the island is a small area lying in map unit 1, where very small quantities of fresh water are available from limestone and sand aquifers at depths ranging from 7 to less than 10 meters (23 to less than 33 feet). The area lying in map unit 1 would be the only area recommended for groundwater exploration. During periods of drought, wells need to be carefully monitored to ensure that over pumping and salt water contamination does not occur.

St. Kitts

Area:	176 square kilometers
Population (1991):	31,824
Population Density:	181 people per square kilometer
Capital:	Basseterre
Location:	Caribbean, island in the Caribbean Sea, about one-third of the way from Puerto Rico to Trinidad and Tobago.
Geographic Location:	17° 20' 00" N 62° 45' 00" W

Surface Water:

Fresh water is available in meager to moderate quantities throughout the island. St. Kitts is divided into three hydrological basins. Meager to moderate quantities of fresh water are available from map unit 1 from streams and reservoirs during the high flow period. High flow period occurs from June to October. Meager quantities of fresh water are available from streams and ghuts during low flow period. Low flow period runs from November to May. Map unit 1 contains the Wingfields River in the Southwest Basin and the Cayon and Parson's Ghut Rivers in the Northeast Basin. Fresh water is available in unsuitable to meager quantities throughout the majority of the island from unnamed streams and ponds in map unit 4. Streams in map unit 4 generally only flow in response to major continuous storm events. The streams of the southeast basin are smaller and are more prone to drought than the remainder of the island. The lower reaches of Parson's Ghut, the Cayon and Wingfields Rivers, and the Great Salt Pond are subject to tidal influences and gradually decline in quality from fresh to brackish and eventually saline near the coast. The southeast part of the island receives less than 1,020 mm (40 inches) of annual rainfall. This portion of the island is prone to drought. Toward the central mountain ranges, the climate becomes humid with annual rainfall approaching 3,810 mm (150 inches). Access to the headwaters of all rivers is difficult due to dense vegetation, lack of roads, and steep slopes.

Ground Water:

Fresh ground water supplies are very limited on the island. Meager to small quantities of fresh water are available from aquifers of volcanic origin throughout the island from map unit 2. Depth to water is variable and can range from 2 meters (6 feet) along the coast to 70 meters (230 feet) further inland. Most reported wells and well fields on the island are drilled into this unit. Map unit 4 represents aquifers composed of Recent age beach sand. Quantities range from very small to very large volumes of brackish to saline water. Depth to water varies from the ground surface to less than 20 meters (66 feet). Near coastal areas, the freshwater and saltwater interface is approximately 20 meters (66 feet) below the ground surface.

Nevis

Area:	93 square kilometers
Population (1991):	8,794
Population Density:	95 people per square kilometer
Capital:	Basseterre
Location:	Caribbean, islands in the Caribbean Sea, about one-third of the way from Puerto Rico to Trinidad and Tobago.
Geographic Location:	17° 10' 00" N 62° 35' 00" W

Surface Water:

Fresh water is available in meager to moderate quantities throughout the island. The island has suffered three droughts since 1990. The island is divided into two hydrologic basins; the Charlestown and Fountain Basins. All streams flow in a radial pattern from Nevis Peak in response to heavy rainfall and discharge into the ocean. Meager to moderate quantities of fresh water are available from Sulphur Ghut, Fountain Ghut, and another stream called Fountain Ghut shown in map unit 1. The lower reaches of these same streams are designated in map unit 5, which represents the lower reaches of all streams that are subject to tidal influences. Water quality in map unit 5 gradually degrades in quality from fresh to brackish to saline close to the ocean. Map unit 5 also includes several small brackish to saline ponds and marshes. Map unit 4 includes several small unnamed ponds and steams that are generally fresh, but only offer unsuitable to meager quantities of water. Average rainfall for the island is 1,170 mm (46 inches) per year, but during the drought years the average rainfall was 885 to 942 mm (35 to 37 inches). Very steep slopes and lack of roads hinder access to the headwaters of the streams.

Ground Water:

Fresh ground water supplies are very limited on the island. Meager to very small quantities of fresh water are available from aquifers of volcanic origin throughout the island from map unit 2. These aquifers range in depth from 2 meters (6 feet) along the coast to 70 meters (230 feet) further inland. Most reported wells on the island are drilled into this unit. The government has stated that heavy metals, including arsenic, may occur in the ground water supplies. Map unit 4 represents aquifers in Recent age beach sand that are typically fresh water lenses. Quantities range from very small to very large volumes of brackish to saline water. Depth to water varies from the ground surface to less than 20 meters (66 feet) below the ground surface. Near coastal areas, the freshwater and saltwater interface is approximately 20 meters (66 feet) below the surface of the ground.

VI. Recommendations

A. General

Most of the agencies and organizations interviewed during visits to the various countries are keenly aware of the need to apply more resources to planning, development, and management of their water resources. A water law and a national strategy are critically needed on each island. While each country included in this assessment has a primary agency that oversees potable water supplies, other aspects of water resource management may be under a different agency that has little regulatory authority to protect these supplies. Providing coordination along with technical and administrative training to the institutions involved in the management of all water resources is recommended. A national water resources program that would provide a single agency with regulatory authority over all public drinking water for each nation is one solution.

Surface water contamination is found throughout each country. Much of the cause and source of this contamination is human and farming encroachment into watersheds along with untreated domestic waste disposal. Regulation and enforcement of waste disposal are necessary to slow the increasing discharge of pollutants into each nation's waterways and coastal areas. Among other devastating consequences, any indiscriminate clearing of the forests in the watersheds may cause excessive sediment loads in the rivers.

Some specific recommendations and suggestions are as follows:

- Establish an environmental water monitoring system to include both surface and ground water;
- Obtain an accurate baseline assessment of the water quality;
- Create maps delineating various water quality problems (e.g. metals, sulfates, nitrates, etc.) preferably in a Geographic Information System (GIS);
- Characterize water contamination risks;
- Measure the volumes of extraction and releases for all uses and for all users;
- Establish, support, and regulate a permit system for wastewater discharge;
- Develop hydrologic plans by watershed;
- Adopt standards and building codes with strict enforcement and construction quality control for septic tanks and latrines;
- Delineate hydrologic risk zones:
    a) Identify and classify the watershed flood areas;
    b) Establish a classification of the uses of the land, limits in the use, and hydrologic studies;
    c) Establish watershed protection zones;
    d) For Dominica, design and implement a flood warning system and an evacuation plan for the downstream area of the natural reservoir on the Matthieu River in the central part of the island (on Matthieu River, about 8 kilometers (5 miles) from where it joins the Layou River).

B. National Water Resources Management and Policy

Laws have not been established to protect drinking water supplies nor have national commissions for potable water and sanitation been established. The water authority usually maintains data related to production from wells or surface water systems, but other records pertaining to pollution sources, water chemistry, or land use issues may be kept separately. As a result, lack of coordination exists between agencies and users, as well as within the different sectors. This creates duplication of effort and a lack of exchange of technical knowledge and data.

The potential benefits of improved water resources management and policy would be enormous. The broad goals would focus on public health, economic development, social well being, and environmentally sustainable development. With an established framework, certain national policy issues and management strategies would emerge. This would require an assessment of the purposes of various water resources projects such as water supply, water quality, irrigation, navigation, hydropower, and fish and wildlife. The in-country evaluation of all needs could lead to a restructuring of the water resources management and to a more defined national interest and policy.

Water resources management and policy are the core of efficient and equitable development. Recommended approaches for gradual improvement of the current management system are as follows:

- Form national commissions for potable water and sanitation.
- Establish a national water law for each country.
- Form a water resources council chaired by the agency that has juridiction under water law.
- Conduct comprehensive water resources evaluations.
- Establish national clearinghouses for water resources data at a single location within each country.
- Sponsor national and international meetings.
- Form task forces to address water resources issues.

These approaches are explained in the following paragraphs.

1. National Water Commissions

Due to the lack of national commissions, the various water users of the countries act and use the water resources independently. Ideally, the users should be unified under one commission. The users would include tourism, hydropower, domestic water supply, institutional needs, irrigation, and industry.

2. National Water Law

Several attempts have been made to establish national water laws. Meetings and discussions with managers have indicated good, practical water laws are needed, but the laws must be uncomplicated and enforceable. To protect water resources for the future, this type of law must be established and a single regulatory agency given enforcement. Included in the law should be watershed protection as well as point and non-point source pollution.

3. Water Resources Council

Formation of a water resources council at the national or international level would encourage information exchange and possibly shared organizational funding for common needs. The council should be made up of high-level executives from member entities. At the national level, candidate members would be heads of national offices and development corporation presidents. The focus of this council would be to discuss water resources activities in the member islands and act as policy advisor to the national leaders. It is conceivable that member nations or other entities could contribute to a fund that would finance common water resources development or interrelated needs. Examples of common needs are (1) development of a multinational database for hydrology and hydraulics information, (2) conservation of soil and water resources, and (3) environmental enhancement. The permanent establishment of a Water Resources Council to oversee the water resources policy is encouraged.

4. Comprehensive Water Resources Evaluations

The potential savings that could result from conducting comprehensive evaluations of all water resources and interrelated activities are enormous. These evaluations would require staffing for several years or a significant outside staffing contract. Objectives would be to analyze all ongoing and proposed water resources activities in the country. This would require discussions with all entities involved. These discussions would be followed with extensive field evaluations. After all the necessary field information is collected, the long and arduous task of research and analysis could begin. This task would uncover many commonalities and duplications, which could then be eliminated, allowing for a more cost-effective operation. Potential exists for significant savings due to economy of scale, such as consolidating numerous similar or identical efforts into one.

5. National Clearinghouse

Another method of assimilating information among various national and international entities would be through the establishment of a water resources data clearinghouse. The first duty of this office would be to develop a mailing list of all entities with shared interests in a particular subject matter. Next, the parties involved in water resources development would be encouraged to forward their respective water resources proposals. Then the office would simply mail pertinent data to appropriate parties upon request. A primary difficulty with this alternative would be the high expenses for the staffing required. Another difficulty would be the process of obtaining uniform cooperation from all those involved. The only known examples of success with clearinghouses are in environments where the use of the process is mandated by force of law.

6. National and International Meetings

National and international symposia or meetings are established formats for encouraging the exchange of information. These meetings can be an excellent forum for scientists, engineers, and water managers to exchange ideas, concepts, and successful water resources management experiences. However, for effectiveness, the subject matter must not be too theoretical. Proposals should be realistic and able to be immediately implemented, and suggestions for long-range projects established. A national gathering, with selected international participation, would be a good initial meeting. This meeting would also be a good forum to discuss other national water policy alternatives, i.e., water resources council, comprehensive water resources evaluations, and national clearinghouses. The meetings should be rotated among host islands and held in an easily accessible place. Suggested topics and workshops to be covered include: national water policy issues, water conservation, drought management, major water resources projects either planned or under construction, desalination, wastewater treatment, experiments in changing crops, reforestation, soil erosion, irrigation techniques, well drilling, water quality, water treatment, and hydropower.

7. Formulation of Task Forces

This approach is somewhat similar to others previously discussed. The difference is that one major national agency on each island would have to take the initiative to lead the program. The first step would be to identify the national needs that would be of widespread interest to all entities. Such needs might include national water laws, national education programs, national databases for technical data, national surveys and mapping, national programs for soil and water conservation and national programs for waste and sewage treatment and disposal. The lead agency would then need to correspond with the various national and international entities to co-sponsor the project by assigning members of their organization to the task force.

Another variation of the task force and the water resources council concept is to establish a water resources commission. The task of this commission would be to evaluate the same national water policy issues discussed in the previous paragraph, with a view toward making recommendations on water policy and the appropriate level of federal involvement. These recommendations should be documented in a report by the commission. The commission would consist of three to six high-level officials on each island. The President would appoint the commission members for 1 to 3 years with staggered terms for consistency and fresh approaches. They should have a blend of various backgrounds; engineers, scientists, agricultural scientists, university professors, politicians, economists, and geologists are all good candidates. This commission would need a small staff to manage the details of the commission operation and to prepare and disseminate reports. The commission members would hold a series of public meetings and/or use a format of requesting testimony from a wide spectrum of professionals, agencies, and the public. They would also solicit input from various national and international agencies. This commission, in effect, could result in a cost-free task force representing a variety of entities. From this pool of manpower, several committees and subcommittees could be formed to thoroughly evaluate various subjects related to national water policy, water agencies involvement, and other national water resources needs.

8. Suggested Strategy

It is difficult to suggest a strategy because of a lack of knowledge of the reality of the bureaucracy and the political arena on each of the islands. A well-designed program in any of the areas discussed could conceivably be worthwhile. From the perspective of an outsider, it appears a two-pronged approach consisting of the permanent establishment of a National Water Commission and the passing of a National Water Law would produce the greatest results.

C. Watershed Protection and Management

A common concern of most government officials and technical experts is the impact of deforestation and agricultural and human encroachment into the watersheds, on the environment and water resources. This is especially true on Dominica and St. Kitts. Integral watershed management is needed to control deforestation and the resulting erosion and sedimentation. Development of comprehensive watershed and basin management plans is needed to curb these impacts. Anthropogenic pollution must also be considered. The intent of a watershed management plan is to achieve a comprehensive view of water and land resource problems within a watershed and to identify opportunities and authorities to address such problems. Watershed planning is a systematic approach to (1) evaluating alternative uses of water and land resources, (2) identifying conflicts and trade-offs among competing uses, and (3) making contemplated changes through informed decisions.

Plans should include (1) short-term measures (i.e., erosion stabilization, small water supply systems, hydrologic and meteorological stations, including the repair of the existing gages); (2) interim measures (i.e., sediment control programs, floodplain management, small reservoirs); and (3) long-term measures (i.e., reforestation, large impoundment for flood control, hydropower, water supply, improved sanitation, and sewage disposal and treatment).

D. Troop Exercise Opportunities

1. Well Exercises

In Antigua and St. Kitts, additional wells may possibly benefit the existing water systems. Each island has areas that are underdeveloped with respect to existing ground water resources. The size and depth of anticipated wells fit the capability of the military well drilling detachments. Because some of the rivers are contaminated and surface water availability is declining, more of the water supply needs of these islands will be dependent upon ground water resources. For the reasons stated above, water wells may be a valuable addition to a troop exercise. Locations for any additional wells would have to be planned and coordinated with the appropriate agency. The size of the wells drilled have limitations based on the equipment mobilized, but wells of 15 to 20 centimeters (6 to 8 inches) in diameter could be completed. A well of this diameter could support a yield of 3 to 9 liters per second (50 to 150 gpm) provided the local aquifer is capable of this rate. The quality of ground water varies throughout each island. Saltwater intrusion would have to be considered at all sites. Small wells could be completed in isolated areas where the demand is low and electrical power may not be available or is not reliable, particularly in rural areas. Installing small hand pump wells, especially in rural areas as part of U.S. troop engineering exercises, could be of great benefit. All new wells installed should be designed to protect against surface water contamination. The wells should have a sufficient grout seal to protect the aquifer from becoming contaminated from surface water runoff or from the shallow aquifer. If possible, this seal should be at least 100 feet thick. These wells could be a source of safe potable water to replace contaminated surface water supplies in certain areas of the country.

2. Small Surface Impoundments

In certain areas of Dominica and St. Kitts, the construction of additional small impoundments for capturing water for water supply may be considered. Numerous existing systems may need modification or upgrading through the use of sand filters or other water treatment. Some rural, low maintenance treatment options are discussed in the water supply manual available on the website identified in the preface of this assessment. Construction of water storage and distribution from existing systems could also be included in the programs. Mountain ranges cover much of the land surface causing difficulties in accessibility. In these mountainous areas, depth to aquifers may be too great for troop exercises. Surface impoundments may also be beneficial for decreasing surface runoff and erosion. Extreme caution should be exercised in site selection because of the potential for water contamination. These impoundments should be considered only in areas where the surface water is not heavily polluted, such as in the volcanic highlands, upstream from populated places, away from untreated domestic wastewater discharge, and away from industrial sites and major cities. The impoundments should be sited where water contamination would not be a problem. Design of these impoundments would not be difficult, and construction techniques would be very similar to local construction techniques. One change to the usual recommended practice would be to use concrete storage tanks instead of prefab fiberglass tanks due to the high probability of storm damage to the fiberglass units. The other main factors are selecting a suitable site, sizing the embankment, and designing the outlet structures. The construction of these sites could be accomplished by U.S. troops.

E. Water Quality and Supply Improvement

Much of the population lacks access to water supply and sanitation services, which directly affects the quality of life. Wastewater and sewage treatment is also lacking throughout the country, with much effluent discharged into the waterways and bays without treatment. Wastewater treatment is needed to improve the quality of the surface water resources of the country, because much of the population uses surface water for water supply needs. As the quantity of available surface water decreases and the population continues to grow, the need for ground water resources and desalination increases.

The establishment of an environmental water monitoring system is recommended. Water is critical as a main source of life and of the socio-economic development of a country. Water and its intended use should be protected and managed responsibly and in a sustainable way. The following is a list of recommended actions:

- Obtain a general perspective of the quality of surface and ground water.
- Prepare detailed maps with different water quality problems (metals, sulfates, nitrates, etc.).
- Estimate the nutrient transport in rivers.
- Characterize the potential water contamination risks.
- Reinforce and modernize the activities of the evaluation of the water resources with respect to quantity and quality in order to know their availability and use.
- Measure the volumes of extraction and releases for all uses and for all users, to increase the efficiency in using water.
- Establish a permit system for wastewater discharge.

VII. Summary

The water resources situation of the islands is critical and of great concern. Many reasons for this include:

- Uneven rainfall distribution and periodic drought conditions on some islands;
- Degradation of the watersheds caused by high rates of deforestation;
- Lack of single agency responsible for comprehensive management of water resources;
- Poor water resources management;
- Lack of wastewater and sewage treatment, and proper waste disposal;
- Lack of adequate data to make informed decisions;
- Poor irrigation supply network leading to underdevelopment of sector;
- Rapid growth in urban areas increasing demand beyond system capacity;
- Huge growth in tourism, which stresses the current water supply and sanitation services and resources;
- Lack of national water laws to protect and preserve the resources; and
- Poor and aging water distribution and sanitary system networks.

Critical issues are the lack of access to water and sanitation, the extensive environmental damage caused by human encroachment into watersheds, and the lack of a comprehensive and enforceable water law. Solutions to these issues present significant challenges to the managers of the water resources of the islands.

The lack of policy and water laws constitutes one of the largest weaknesses in managing the water resources. This situation results in uncontrolled exploitation and use of the water.

The recommendations offered in this report present some of the opportunities to improve the water resources situation. If adopted, these actions could have positive long-term impacts. Many of the other issues discussed in this report will require long-term institutional commitments to effect change. Proper management of the abundant water resources of the islands can provide adequately for the needs of the countries.

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Appendix A

List of Officials and

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Many individuals in the public and private sectors were consulted and provided exceptional cooperation and support:

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Appendix B

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Glossary

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Glossary

agglomerate	A pyroclastic rock deposit that is composed of volcanic fragments.
andesite	A dark colored, fine-grained volcanic rock.
aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
arsenic	A mineral that is considered a native metallic element and is silverish-gray in color. Arsenic is poisonous and a known carcinogen.
basalt	A very fine-grained, hard, dense, dark-colored, extrusive igneous rock, which occurs widely in lava flows. Usually has poor hydrogeological properties and is difficult to drill through.
basin (hydrologic)	The drainage area of a stream.
brackish water	Water that contains greater than 1,000 milligrams per liter but not more than 15,000 milligrams per liter of total dissolved solids.
borehole	A circular hole made by a boring that may be used as a water well.
brackish water	Water that contains more than 1,000 milligrams per liter but not more than 15,000 milligrams per liter of total dissolved solids.
calcium carbonate	A chemical compound consisting of calcium (Ca) and carbonate (CO_3). When dissolved in water, it is used to express water hardness and alkalinity. In the solid state, it is the chief chemical component of limestone.
catchment	The drainage area of a basin.
chloride	A negatively charged ion present in all natural waters. Excessive concentrations are undesirable for many uses of water. Chloride may be used as an indicator of domestic and industrial contamination.
cisterns	A tank used for catching and storing rainwater.
clay	As a soil separate, the individual particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that contains 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.
deforestation	The process by which large tracts of land are cleared of trees and forest. One consequence of deforestation is soil erosion, which results in the loss of protective soil cover and the water holding capacity of the soil.
desalination	A water purification process which removes dissolved salts from brackish or saline water to improve water quality.
drawdown	The lowering of the water level in a well as a result of withdrawal of water.
evapotranspiration	Loss of water from a land area through transpiration of plants and evaporation.
fault	A fracture or fracture zone of the Earth along which there has been displacement of one side with respect to the other.
fecal coliform	A group of bacteria, which is normally abundant in the intestinal tracts of humans and other warm-blooded animals. Fecal coliform is used as an indicator (measured as the number of individuals per milliliter of water) when testing the sanitary quality of water.
flood plain	Nearly level land on either side of a channel, which is subject to overflow flooding.
formation	A body of rock strata that consist dominantly of a certain lithologic type or combination of types.

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fracture	A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress.
fresh water	Water that contains 600 milligrams per liter or less of chlorides, 300 milligrams per liter or less of sulfates, and 1,000 milligrams per liter or less of total dissolved solids.
fumaroles	Vents from which volcanic gas escapes into the atmosphere.
geothermal	Pertaining to the heat of the interior of the earth.
ghaut	Ephemeral stream in a steep-sided valley.
ghut	Ephemeral stream in a steep-sided valley.
ground water	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
hardness (water)	A property of water due to the presence of ions of calcium and magnesium
igneous	A class of rocks formed by the solidification of molten material. If the material is erupted onto the Earth's surface, the rock is called extrusive or volcanic; if the material solidifies within the Earth, the rock is called an intrusive or plutonic rock. If not fractured or weathered, it will normally yield only small amounts of ground water.
intermittent (stream)	Describes a stream or reach of a stream that flows only at certain times of the year, as when it receives water from springs or from some surface source, such as rain.
joint	A fracture or parting in a rock, without displacement.
limestone	(1) For military purposes, the rock types which refer to all carbonate sedimentary rocks. (2) Soft to moderately hard rock primarily composed of calcium carbonate mainly in the form of shells, crystals, grains, or cementing material. Colors range from white through shades of gray to black. Commonly thick bedded, jointed, and containing fossils. Limestone is often highly fractured and soluble..
marsh	An area of saturated ground dominated by grasslike aquatic plants.
meander	One of a series of sinuous curves or loops in a course of a mature stream.
metamorphic	Rocks formed in the solid state from previously existing rocks in response to pronounced changes in temperature, pressure, and chemical environment.
Miocene	A division of geologic time from 5 to 24 million years ago, during which certain rocks were formed. The Miocene falls chronologically after the Oligocene and before the Pliocene. Included in the Tertiary Period.
mud pot	A hot spring that takes the form of a viscous, bubbling slurry.
nitrate	A salt of nitric acid containing the univalent, negative radical NO_3.
NTU	An abbreviation for nephelometric turbidity units. A unit of measure that gages turbidity by estimating how light is scattered by suspended particulate material in water.
Oligocene	A division of geologic time from 23.8 to 33.7 million years ago. Falls chronologically after the Eocene and before the Miocene. Included in the Tertiary period.
organochlorides	Chlorinated organic compounds created by combining chlorine with the organic molecules in wood.
orographic rainfall	Precipitation caused by moist air lifting up and over mountains.
perennial stream	A stream that flows throughout the year.
permeability (rock)	The property or capability of a porous rock for transmitting a fluid. Permeability is a measure of the relative ease of fluid flow under unequal pressure. The customary unit of measure is a millidarcy.

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pesticide	A class of substances used to destroy insects, weeds, and other pest like rodents. Includes insecticides and herbicides. In small amounts, pesticides may be harmful to human health.
pH (potential of hydrogen)	A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale ranges from 0 to 14.
Pleistocene	A period of geologic time, which began during the Quaternary Period, two or three million years ago, after the Pliocene, and lasted until the start of the Holocene about 8,000 years ago.
Pliocene	A division of geologic time from 1.8 to 5.3 million years ago.
porosity	The ratio of the volume of the openings (voids, pores) in a rock to its total volume; usually stated as a percentage.
potable water	Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
Quaternary Period	A division of geologic time from the present to 1.6 million years ago, during which certain rocks were formed or sediments deposited. Falls chronologically after the Tertiary. Includes the Pleistocene and Holocene Epochs. The Quanternary Period is the youngest division of the Cenozoic Era.
recharge	Addition of water to the zone of saturation from precipitation, infiltration from surface streams, and other sources.
relief	The difference in elevation of an area between tops of hill and bottom of valleys.
Recent	The second epoch of the Quaternary Period, beginning approximately 10,000 years ago and continuing to the present time.
reverse osmosis	A process where water is cleaned by forcing water through an ultra-fine semi-permeable membrane which filters out impurities.
runoff	Rainfall that flows across the ground surface rather than be absorbed by the soil .
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion	Displacement of fresh surface or ground water by the advance of saltwater due to its greater density. Saltwater intrusion usually occurs in coastal and estuarine areas where it contaminates freshwater wells.
sand	As a soil separate, individual rock or mineral fragments with 0.05- to 2-millimeter diameters. The soil textural classification that determines a soil to be sand requires that 85 percent or more of the soil be sand and that it not consist of more than 10 percent clay. Most sand consists of quartz.
sedimentary (rocks)	A class of rocks formed from the accumulation and solidification of a variety of sediments.
soakaways	A hole where wastewater can drain away by filtering down through the soil.
spring	A place where ground water flows from a rock or the soil onto the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, especially permeable and impermeable strata; on the position of the water table; and on the topography.
sulfate	A salt of sulfuric acid containing the divalent, negative radical SO_4.
swamp	An area saturated with water for at least part of the year and dominated by trees and shrubs.
tar	Natural bitumen.

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Tertiary	The first period of the Cenozoic Era which covers a time between 65 million and 2 million years ago.
Total dissolved solids (TDS)	The sum of all dissolved solids in water or wastewater.
tuff	A soft light-colored, extrusive igneous rock formed from the compaction of pyroclastic (ash and dust) material.
turbidity	The total suspended solid or suspended matter in water.
Volatile organic compounds	Compounds that vaporize at normal household room temperatures. Commonly referred to as VOCs.
volcanic	Pertaining to the activities, structures, or rock types of a volcano.
water table	The depth or level below which the ground is saturated with water in an unconfined aquifer.
weir	A shallow dam constructed to control stream flow.
yield	The volume per unit time (ex. Liters per second) of water produced from a well.

Appendix C

Surface Water and Ground Water Resources

Tables and Figures

Prepared by: U.S. Army Topographic Engineering Center
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Table C-1. Surface Water Resources

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water seasonally available	All intermittent and ephemeral streams and reservoirs.	Meager to moderate quantities of fresh water are available from streams and reservoirs during high flow period, which generally occurs from June to October. Meager quantities are available from streams and ghuts during low flow period from November to May. Selected stream gaging stations and stream characteristics are listed below.	The water from the following islands is fresh, soft, and has a low pH.		
(Dominica)	Dominica **Castle Bruce Basin (V):** Several unnamed minor streams. **Melville Hall Basin (VI):** Several unnamed minor streams.	Dominica Discharge rates are highly variable between high and low flow periods. High flows occur June to October. Low flows occur November to May.	Dominica No studies have been conducted to determine how pesticide and fertilizer use may impact water quality. Soil erosion after heavy rainfall increases turbidity in the water, which can increase bacterial counts. Expect high sediment loads in the streams during the wet season from June to October.	Dominica In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder accessibility. Steep coastal cliffs pose a landslide hazard.	Dominica Equipment (surface water intakes, reverse osmosis water purification units (ROWPUs), etc.) should be protected from debris. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting.
(Antigua)	Antigua Primarily reservoirs in the eastern region of Antigua. **East Basin (X):** Bethesda Reservoir (1703N06145W)[3] Collins Reservoir (1704N06144W) Potworks Reservoir (1704N06145W)	Antigua Bethesda Reservoir has a storage capacity of 0.54 Mm^3. Collins Reservoir has a storage capacity of 0.34 Mm^3. Potworks Reservoir has a storage capacity of 4.14 Mm^3.	Antigua One documented case of a fish kill at Potworks Reservoir resulted from possible agro-chemicals migrating into the surface water. Pesticides, herbicides, and fertilizers are used on farm fields adjacent to streams.	Antigua Access is generally not difficult due to an adequate road network and flat topography.	Antigua Recurrent droughts every few years render these reservoirs dry. Many of the reservoirs are not holding water effectively due to poor design of the embankment, spillway, etc. Water from the Bethesda Reservoir is used strictly for agricultural irrigation. Water from the Potworks Reservoir is used as the main surface water supply for the country.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water seasonally available (continued) (St. Kitts and Nevis)	St. Kitts **Northeast Basin (XII)** Cayon River (1721N06243W) Parson's Ghut (1724N06248W) Several unnamed streams. **Southwest Basin (XIII)** Wingfields River (1719N06248W) Several unnamed streams. Nevis **Charlestown Basin (XV)** Sulphur Ghut (1707N06237W) Several unnamed streams. **Fountain Basin (XVI)** Fountain Ghut (1712N06233W) Fountain Ghut (1706N06233W) Several unnamed streams.	St. Kitts Current average discharge rate for the Wingfields River was reported to be 0.038 m^3/s in 2002. Nevis No data on specific discharge rates. Because the streams are situated in similar climates and have similar morphology as those in St. Kitts, it is presumed the discharge rates for the streams in Nevis are similar to those in St. Kitts.	St. Kitts and Nevis Open garbage dumping is evident in river basins.	St. Kitts and Nevis In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder accessibility. Steep coastal cliffs pose a landslide hazard.	St. Kitts The Wingfields River supplies water to Old Road (1719N06247W), Sandy Point Town (1721N06250W), and Basseterre (1717N06243W). St. Kitts and Nevis Expect high sediment loads in the streams during the wet season from June to October. Equipment (surface water intakes, reverse osmosis water purification units (ROWPUs), etc.) should be protected from debris. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting.
2 Fresh water scarce or lacking (Dominica)	Major perennial streams and small lakes throughout the islands. Dominica **Lamothe Basin (I):** Lamothe River (1537N06128W)	Very small to small quantities of fresh water are available. Selected stream gaging stations and stream characteristics are listed below. Dominica **Northwest Basin (II)** **▲1** Macoucheri River measured at its mouth had a discharge rate of 0.6 m^3/s on 18 December 1986.	Water is fresh, soft, and has a low pH. Dominica No studies have been conducted to determine how pesticide and fertilizer use may impact water quality. Soil erosion after heavy rainfall increases	In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder accessibility. Steep coastal cliffs pose a landslide hazard.	Equipment (surface water intakes, reverse osmosis water purification units (ROWPUs), etc.) should be protected from debris. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water scarce or lacking (continued) (Dominica, continued)	Dominica **Northwest Basin (II)** Batali River (1527N06127W) Dublanc River (1531N06128W) Macoucheri River (1525N06126W) Picard River (1533N06128W) **Layou Basin (III):** Layou River (1523N06126W) **Roseau Basin (IV):** Belfast River (1522N06125W) Check Hall River (1520N06124W) Claire River (1518N06122W) Ravine Sibouli (1515N06123W) Roseau River (1518N06124W) **Castle Bruce Basin (V):** Belle Fille River (1525N06116W) Boeri Lake (1521N06120W) Clarke's River (1522N06117W) Fresh Water Lake (1521N06119W) Geneva River (1514N06119W) La Rivere Blanche (1516N06116W) River Ouayaneri (1520N06115W) Several unnamed minor streams. **Melville Hall Basin (VI):** Beauplan River (1535N06124W)	Dominica **Layou Basin (III):** ▲**2** Layou River measured at its mouth had a discharge rate of 6.4 m^3/s on 27 August 2002. **Roseau Basin (IV):** ▲**3** Roseau River measured 1.5 km northeast of Roseau (1518N06124W) had a discharge rate of 3.3 m^3/s on 4 September 2002. **Melville Hall Basin (VI):** ▲**4** Mamelabou River measured at its mouth had a discharge rate of 0.9 m^3/s on 13 November 1997. ▲**5** Melville Hall River measured at its mouth had a discharge rate of 2.6 m^3/s on 13 November 1997. ▲**6** Toulaman River measured at its mouth had a discharge rate of 0.8 m^3/s on 13 November 1997.	Dominica turbidity in the water, which can increase bacterial counts. High fecal coliforms (from 40 to 300 fecal coliforms per 100 mL of samples) were reported in water sampled from various locations near the mouth of the Roseau River in 1989. Expect high sediment loads in the streams during the wet season from June to October.		

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water scarce or lacking (continued) (Dominica, continued)	<u>Dominica</u> Canal River (1532N06118W) Hampstead River (1535N06122W) Mamelabou River (1535N06120W) Melville Hall River (1532N06118W) Pagua River (1531N06117W) Saint Marie River (1530N06117W) Toulaman River (1533N06118W)				
3 Fresh water scarce or lacking	Major intermittent streams, small ponds, and small reservoirs.	Meager to very small quantities of fresh water may be available after major storm events generally from September to October.	Water is generally fresh, and ranges from soft to hard.		
(Dominica)	<u>Dominica</u> **Lamothe Basin (I):** Several unnamed minor streams and ponds. **Northwest Basin (II):** Several unnamed minor streams and ponds. **Layou Basin (III):** Several unnamed minor streams and ponds. **Roseau Basin (IV):** Several unnamed minor streams and ponds. **Castle Bruce Basin (V):** Several unnamed minor streams and ponds. **Melville Hall Basin (VI):** Several unnamed minor streams and ponds.		<u>Dominica</u> No studies have been conducted to determine how pesticide and fertilizer use may impact water quality. Soil erosion after heavy rainfall increases turbidity in the water, which can increase bacterial counts. Expect high sediment loads in the streams during the wet season from June to October.	<u>Dominica</u> In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder accessibility. Steep coastal cliffs pose a landslide hazard.	<u>Dominica</u> Equipment (surface water intakes, reverse osmosis water purification units (ROWPUs), etc.) should be protected from debris. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water scarce or lacking (continued) (Antigua)	Antigua **North Basin (VII):** Fitches Creek (1707N06147W) Several unnamed streams. **West Basin (VIII):** Several unnamed streams. **South Basin (IX):** Indian Creek (1700N06144W) Several unnamed streams. **East Basin (X):** Ayers Creek (1704N06142W) Several unnamed streams.		Antigua Water in the eastern one-third of Antigua has moderate pH. Pesticides, herbicides, and fertilizers are utilized on farm fields within watersheds.	Antigua Access is generally not difficult due to an adequate road network and flat topography. Nearly flat terrain with small hills makes accessibility to water features easy.	Antigua Very warm climate, high evaporation rates, and permeable subsoils do not allow streams to flow for prolonged periods. Every few years droughts render these intermittent streams dry.
4 Fresh water scarce or lacking (Antigua and Barbuda)	Minor intermittent streams and ponds. Antigua **North Basin (VII):** Several unnamed minor streams and ponds. **West Basin (VIII):** Several unnamed minor streams and ponds. **South Basin (IX):** Several unnamed minor streams and ponds. **East Basin (X):** Several unnamed minor streams and ponds. Barbuda **Barbuda Basin (XI):** Small pools in low depressions that form after rainfall events.	Unsuitable to meager quantities of fresh water are only available after major continuous storm events, generally from September to November. Barbuda Unsuitable quantities of fresh water are present.	Water is generally fresh but ranges from moderate to high pH. Pesticides, herbicides, and fertilizers are utilized on farm fields within watersheds. Antigua Water is hard in the eastern one-third of the country due to calcium carbonate derived from the limestone bedrock. Considerable pollution from septic tank effluent drains into the harbor at Saint John's (1707N06151W), which eventually migrates to the mouths of nearby river systems.	Antigua and Barbuda The relatively flat terrain combined with an adequate road network, lack of thick brush, and low banks makes accessibility to water features easy.	Warm climate, high evaporation rates, and permeable subsoils do not allow streams to flow for prolonged periods. Every few years droughts render these intermittent or ephemeral streams dry.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water scarce or lacking (continued) (St. Kitts and Nevis)	St. Kitts **Northeast Basin (XII):** Several unnamed minor streams and ponds. **Southwest Basin (XIII):** Several unnamed minor streams and ponds. **Southeast Basin (XIV):** Several unnamed minor streams and ponds. Nevis **Charlestown Basin (XV):** Several unnamed minor streams and ponds. **Fountain Basin (XVI):** Several unnamed minor streams and ponds.		St. Kitts and Nevis Water is soft.	St. Kitts and Nevis The relatively flat terrain combined with an adequate road network lack of thick brush, and low banks makes accessibility to water features easy.	
5 Fresh water scarce or lacking (Dominica)	Mouths of major and minor perennial and intermittent streams, which drain into coastal areas and ponds, lakes, and lagoons. Dominica **Lamothe Basin (I):** Lower reaches of Lamothe River (1537N06128W) **Northwest Basin (II):** Lower reaches of Batali River (1527N06127W)	Very small to very large quantities of brackish to saline water are available at or near the coastal areas. Dominica **Castle Bruce Basin (V):** Boiling Lake (1518N06118W) has a diameter of 67 m.	Water is brackish to saline near and within the coastal areas of the five islands. Dominica Boiling Lake has high sulfur content.	Dominica Coastal areas have steep cliffs making access difficult to impossible.	Equipment (surface water intakes, reverse osmosis water purification units (ROWPUs), etc.) should be protected from debris. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting. Desalination equipment is required to treat brackish and saline water. Dominica The location of Boiling Lake is approximate, and therefore not included on figure C-1.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water scarce or lacking (continued) (Dominica, continued)	Dominica Lower reaches of Dublanc River (1531N06128W) Lower reaches of Macoucheri River (1525N06126W) Lower reaches of Picard River (1533N06128W) **Layou Basin (III):** Lower reaches of Layou River (1523N06126W) **Roseau Basin (IV):** Lower reaches of Belfast River (1522N06125W) Lower reaches of Check Hall River (1520N06124W) Lower reaches of Ravine Sibouli (1515N06123W) Lower reaches of Roseau River (1518N06124W) **Castle Bruce Basin (V):** Boiling Lake (1518N06118W) Lower reaches of Belle Fille River (1525N06116W) Lower reaches of Clarke's River (1522N06117W) Lower reaches of Geneva River (1514N06119W) Lower reaches of La Rivere Blanche (1516N06116W) Lower reaches of River Ouayaneri (1520N06115W) Other unnamed streams. **Melville Hall Basin (VI):** Lower reaches of Beauplan River (1535N06124W)				

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water scarce or lacking (continued) (Dominica, continued)	Dominica Lower reaches of Hampstead River (1535N06122W) Lower reaches of Mamelabou River (1535N06120W) Lower reaches of Melville Hall River (1533N06118W) Lower reaches of Pagua River (1531N06117W) Lower reaches of Saint Marie River (1530N06117W) Lower reaches of Toulaman River (1533N06118W) All coastal areas of the island.				
(Antigua and Barbuda)	Antigua **North Basin (VII):** Lower reaches of Fitches Creek (1707N06147W) Several unnamed major and minor streams, ponds, lagoons, and lakes. **West Basin (VIII):** Several unnamed major and minor streams, ponds, lagoons, and lakes. **South Basin (IX):** Lower reaches of Indian Creek (1700N06144W) Several unnamed major and minor streams, ponds, lagoons, and lakes. **East Basin (X):** Lower reaches of Ayers Creek (1704N06142W) Several unnamed major and minor streams, ponds, lagoons, and lakes. All coastal areas of the island.		Antigua Open dumping along rivers results in debris at the mouths of some rivers. Considerable pollution from septic tank effluent drains into the harbor at Saint John's (1707N06151W), which eventually migrates to the mouths of nearby river systems.	Antigua and Barbuda The relatively flat terrain combined with an adequate road network lack of thick brush, and low banks makes accessibility to water features easy.	Antigua A private firm is operating an active desalination plant at Crabs Peninsula (1707N06145W) by utilizing reverse osmosis. The plant was built in 1993 and has one surface water intake in the Atlantic Ocean, and two 7,570,000 L storage tanks at the plant. The pH of the desalinated water is 6.7.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water scarce or lacking (continued) (Barbuda, continued)	Barbuda All coastal areas of the island.				
(St. Kitts and Nevis)	St. Kitts **Northeast Basin (XII):** Lower reaches of Cayon River (1721N06243W) Lower reaches of Parson's Ghut (1724N06248W) Several unnamed major and minor streams, ponds, lagoons, and lakes. **Southwest Basin (XIII):** Lower reaches of Wingfields River (1719N06248W) Several unnamed major and minor streams, ponds, lagoons, and lakes. **Southeast Basin (XIV):** Great Salt Pond (1714N06239W) Several unnamed major and minor streams, ponds, lagoons, and lakes. All coastal areas of the island. Nevis **Charlestown Basin (XV):** Lower reaches of Sulphur Ghut (1707N06237W) Several unnamed major and minor streams, ponds, lagoons, and lakes. **Fountain Basin (XVI):** Lower reaches of Fountain Ghut (1712N06233W)			St. Kitts and Nevis The relatively flat terrain combined with an adequate road network lack of thick brush, and low banks makes accessibility to water features easy.	

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water scarce or lacking (continued) (St. Kitts and Nevis, continued)	Nevis Lower reaches of Fountain Ghut (1706N06233W) Several unnamed major and minor streams, ponds, lagoons, and lakes. All coastal areas of the island.				

[1]Quantitative Terms:
Enormous = >5,000 m^3/s (176,550 ft^3/s)
Very large = >500 to 5,000 m^3/s (17,655 to 176,550 ft^3/s)
Large = >100 to 500 m^3/s (3,530 to 17,655 ft^3/s)
Moderate = >10 to 100 m^3/s (350 to 3,530 ft^3/s)
Small = >1 to 10 m^3/s (35 to 350 ft^3/s)
Very small = >0.1 to 1 m^3/s (3.5 to 35 ft^3/s)
Meager = >0.01 to 0.1 m^3/s (0.35 to 3.5 ft^3/s)
Unsuitable = $\leq$0.01 m^3/s (0.35 ft^3/s)

[2]Qualitative Terms:
Fresh water is max TDS $\leq$1,000 mg/L; max chlorides $\leq$600 mg/L; and max sulfates $\leq$300 mg/L
Brackish water is max TDS >1,000 mg/L but $\leq$15,000 mg/L
Saline water is TDS >15,000 mg/L

Hardness Terms:
Soft is 0 to 60 mg/L $CaCO_3$
Moderately hard is 61 to 120 mg/L $CaCO_3$
Hard is 121 to 180 mg/L $CaCO_3$
Very hard is >180 mg/L $CaCO_3$

Conversion Chart:

To Convert	Multiply By	To Obtain
cubic meters per second	15,800	gallons per minute
cubic meters per second	60,000	liters per minute
cubic meters per second	35.31	cubic feet per second

U.S. Surface Water Criteria:
The Safe Drinking Water Act states that the number of coliforms must be less than 1 per 100 milliliters for water to be considered potable.

[3]Geographic coordinates list latitude first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or Western (W) Hemisphere. For Example:

Bethesda Reservoir …. (1703N06145W)

Geographic coordinates for the Bethesda Reservoir that are given as 1703N06145W equal 17° 03' N, 61° 45' W and can be written as a latitude of 17 degrees and 3 minutes north and a longitude of 61 degrees and 45 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

Note:
$CaCO_3$ = calcium carbonate
ft^3/s = cubic feet per second
km = kilometers
L = liter
m = meter
m^3/s = cubic meters per second
mg/L = milligrams per liter
mL = milliliters
Mm^3 = million cubic meters
pH = hydrogen-ion concentration
St. = Saint
TDS = Total Dissolved Solids

Table C-2. Ground Water Resources

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water scarce or lacking	Generally Tertiary to Quaternary age limestone as well as Recent age beach sand.	Generally very small quantities of ground water are available. Small quantities of ground water might be locally present in rocks that are heavily jointed and/or fractured.	Ground water is generally fresh but is hard due to $CaCO_3$ with high pH. Near coastal areas, overpumping of wells can lead to increased TDS concentrations approaching those of saline water.	Caution should be used during well drilling, installation and pumping to ensure that the fresh water aquifer is not permanently contaminated by saltwater intrusion.	Aquifers are recharged by rainfall and by percolation from rivers. Ground water exploration from July to October presents a potential danger from hurricane-force winds and flash flooding. Heavy precipitation from August to September and high risk of earthquakes may trigger landslides in mountainous areas. Limestone aquifers are suitable for hand-pump wells.
(Antigua and Barbuda)				<u>Antigua</u> Depth to aquifer ranges from >1 to 20 m near the coast, and up to 40 m inland. <u>Barbuda</u> Depth to aquifer ranges from 7 to <10 m.	
(St. Kitts)	<u>St. Kitts</u> The major aquifer is the Pleistocene age Brimstone Limestone (coral reef limestone) that is situated 1 mi southeast of Charles Fort (1721N06249W)[3].		<u>St. Kitts</u> Ground water is generally fresh.	<u>St. Kitts</u> Depth to aquifer ranges from <1 to 60 m.	
2 Fresh water scarce or lacking	Miocene to Recent age mixed volcanic rocks with minor amounts of Recent age alluvium.	Meager to small quantities of ground water are available.	Ground water is generally fresh, soft, and has low pH. Ground water meets or exceeds World Health Organization criteria.	Caution should be used during well drilling installation to prevent saltwater intrusion into an overlying fresh water aquifer. Care should be taken to	Aquifers are recharged by rainfall and by percolation from rivers. Ground water exploration from

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued)				avoid excessive pumping near coastal areas where saline water underlies fresh water zones. In the near-coastal areas, reverse osmosis purification units (ROWPUs) may be needed to treat non-potable saline water. In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder access. Hard rock drilling methods are recommended such as air rotary or percussion drilling.	July to October presents a potential danger from hurricane-force winds and flash flooding. Heavy precipitation from August to September and high risk of earthquakes may trigger landslides in mountainous areas. In mountainous areas, lack of an adequate road network, steep slopes, and dense vegetation hinder accessibility. Steep coastal cliffs pose a landslide hazard. High risk of earthquakes might trigger landslides in mountainous areas.
(Dominica)	Dominica Miocene to Pleistocene age mixed volcanics to include basalt, dykes, dacite, andesite, ignimbrite, ash, tuffs, and pumice. Geothermal areas at Morne Prosper (1518N06121W), Soufriere (1514N06122W), and Valley of Desolation (1518N06118W).	Dominica ▲**4** One spring near Loubiere (1516N06123W) had a discharge rate of 2 to 3 L/s on 6 March 1993. Discharge in 2002 was 3.9 L/s.	Dominica Within geothermal areas, ground water temperatures exceed 30°C with low pH. Fertilizers and pesticides might contaminate ground water resources in rural areas. ▲**1** One hot sulphur spring in a geothermal region northeast of Morne Prosper had the following analytical results from a water sample collected on 22 November 2000: pH 3, T 94.7 °C. ▲**2** One hot sulphur spring in a geothermal region	Dominica Depth to aquifer is highly variable from the ground surface to <200 m depending upon the topography and structural conditions of the bedrock.	Dominica Previous test drilling in the area indicated ground water exploration costs are very expensive and not economically feasible. Geothermal activity in the mountainous areas of Dominica (e.g. Morne Prosper) might make drilling hazardous.

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued) (Dominica, continued)			Dominica near Soufriere (1514N06122W) had the following analytical results from a water sample collected on 22 November 2000: pH 2, T 68°C. ▲**3** One hot sulphur spring in a geothermal region within the Valley of Desolation (1518N06118W) had the following analytical results from a water sample collected on 22 November 2000: T 68 °C. ▲**4** One spring near Loubiere (1516N06123W) had the following analytical results from a water sample collected 11 March 1993: pH 6.84, Mg 4.5 mg/L, Na 13.0 mg/L, Ca 12.0 mg/L, SO_4 3.0 mg/L, Sr 0.03 mg/L, Cl^- 8.5 mg/L, Br 0.05 mg/L. The spring area is protected against biological and chemical wastes. Spring is used commercially as a bottled water source and for making beer.		
(Antigua and Barbuda)	Antigua In the southwestern one-third of Antigua, the Oligocene age Volcanic Series of the Southwest	Antigua A well field with five active wells in alluvium are located at Cades Bay (1701N06151W)	Antigua A government quarry and asphalt plant near Bendals (1704N06150W) contained leaky drums of	Antigua Depth to aquifer ranges from >1 to 20 m near coastal areas, 20 to 50 m in the small hills.	Antigua Antigua and Barbuda have had recurrent droughts, which may significantly decrease

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued) (Antigua and Barbuda, continued)	Antigua District is the major aquifer. The aquifer consists of mixed volcanic rocks such as andesite, basalt, tuff, agglomerate, and dacite. Recent alluvium is scattered in major river valleys.	Antigua and Claremont (1701N06149W). This well field supplies potable water to the villages of Old Road (1701N06150W), Urlings (1702N06152W), Johnson's Point (1702N06153W), and Crab Hill (1702N06153W). In 1997, the five active wells in the area yielded a total of 1.32 L/s. A well field with five active wells at a location between the villages of John Hughes (1703N06149W) and Swetes (1703N06148W) yielded a total of 1.5 L/s in 1984. A well field with 20 active wells is reportedly in a valley between Jennings (1705N06152W) and Ffryes (1703N06143W). A well field with 13 active wells at Bendals (1704N06150W) yielded a total of 1.5 L/s in 1984. A pump test conducted in Christian Valley (1703N06151W) in 1970 yielded a transmissivity of 7,595 cm^2/s and a storage coefficient of 1×10^{-4}. A pump test conducted in Yorks (1705N06152W) in 1970 yielded a transmissivity range from 3,869 to 9,601 cm^2/s and a storage coefficient of 2×10^{-3}.	Antigua diesel and partially buried old tar drums which might impact future ground water quality. One spring at an unknown location near Follys (1702N06148W) is privately used as a bottled water source.	Antigua During drought seasons, well pumps need to be periodically turned off to avoid salt-water intrusion into the wells.	Antigua water levels in wells.

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued) (Antigua and Barbuda, continued)		Barbuda No specific quantity information given, but quantities were estimated from similar bedrock geology in the eastern one-third of Antigua.			
(St. Kitts and Nevis)	St. Kitts Major aquifers include the following late Miocene and Pliocene age rock units: Old Basement Volcanics and Undifferentiated volcanics are primarily present in the south-eastern portion of the island. Monkey Hill Intrusion (andesite), Southeast Range Deposit (pyroclastics), and Ottley Mountain Intrusion (andesite) occur 6 mi northwest of Basseterre (1718N06243W). Other major aquifers (probably Pleistocene to Recent age) include: Brimstone Hill Andesite, Sandy Point Hill Dome (mixed volcanics), Mount Misery Cone Deposits, Basseterre Tuffs, Mount Misery Mud Flows, and Central Range Cone Deposits. Undifferentiated volcanics of unknown age.	St. Kitts A well field in a big valley east of Basseterre consists of two active wells. In 1999 transmissivities ranged between 1,320 and 3,863 m^2/d and hydraulic conductivities between 74 and 171 m^2/d for the entire well field. Other recorded observations in March 1988 include: Four wells between the Con Phipps Estate (1720N06249W) and Wingfield Estate (1720N06247W) yielded between 3.2 to 7.9 L/s. One well located between Lodge (1721N06245W) and Tabernacle (1723N06246W) yielded between 3.2 to 6.3 L/s. Ten wells between the Profit Estate (1724N06248W) and Sir Gillies (1722N06251W) yielded between 3.2 to 9.5 L/s. One well at Stone Fort Estate (1718N06247W) yielded 6.3 L/s.	St. Kitts Ground water from an undetermined number of old wells at Monkey Hill (1719N06243W), exhibited the following concentrations in 1977: Mg 46.2 mg/L, Fe 0.4 mg/L, SO_4 46.0 mg/L. TDS in areas towards the Great Salt Pond (1714N06239W), exhibit concentrations as high as 2,220 mg/L. Some springs might be susceptible to biological pollution if they are near farms.	St. Kitts and Nevis Previous test hole drilling showed depth to aquifer ranges from 2 m near coastal areas to 70 m in mountainous terrain. Near coastal areas, the fresh water and saltwater interface is approximately 20 m below the ground surface. Caution should be used during well drilling, installation and pumping to ensure that the fresh water aquifer is not permanently contaminated by saltwater intrusion. Overpumping a well may cause saltwater intrusion. Existing wells are naturally developed (e.g. no gravel pack is used).	St. Kitts and Nevis Geothermal ground water within Pleistocene Basseterre Tuffs in a large valley east of Basseterre might make drilling hazardous.

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued) (St. Kitts and Nevis, continued)		Nevis Approximately 0.5 mi north of Butlers (1710N06233W), one production well yielded 3.8 L/s in November 1985. This well was abandoned and another well was drilled a short distance away. This new well yielded 9.5 L/s between November 1985 and May 1986. ▲**5** A spring at Camps (1711N06234W) continuously yielded 3.8 L/s in 1990. One production well at Charlestown (1708N06237W) yielded 3.4 L/s between November 1985 and May 1986. Approximately 0.5 mi northeast of Hichmans (1708N06233W), one production well yielded 6.1 L/s between November 1985 and May 1986. ▲**6** A spring at Jessup Estate (1710N06236W) continuously yielded 0.3 L/s in 1990. ▲**7** A spring west of Maddens Estate (1710N06233W) continuously yielded 1.0 L/s in 1990. ▲**8** A spring located 0.5 mi northeast of Nevis Peak (1710N06235W) continuously yielded 3.0 L/s in 1990. One production well at New River (1708N06233W) yielded 2.3 L/s between November 1985 and May 1986.	Nevis The St. Kitts and Nevis Department of Environment reported that Nevis has potential heavy metals (especially arsenic) in ground water supplies. Approximately 0.25 mi northeast of Vaughans (1709N06237W), one production well exhibited the following concentration in May 1986: S 0.0019.		Nevis Undifferentiated volcanics of unknown age.

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water scarce or lacking (continued) (St. Kitts and Nevis, continued)		Nevis Approximately 0.25 mi northeast of Vaughans (1709N06237W), one production well yielded 1.9 L/s in May 1986.			
3 Fresh water scarce or lacking (Antigua)	Antigua Pliocene to Pleistocene age clay and tuff cover the central portion of Antigua.	Antigua Meager quantities of fresh water are available.	Antigua Ground water is generally fresh except near coastal areas where it is brackish to saline. The pH is low to moderate and the water is soft to moderately hard.	Antigua Depth to aquifer ranges from <1 m to 20 m near coastal areas to 40 m inland. Caution should be used during well drilling, installation and pumping to ensure that the fresh water aquifer is not permanently contaminated by saltwater intrusion. Overpumping a well may cause saltwater intrusion. In areas near the coast, reverse osmosis purification units (ROWPUs) may be needed to treat nonpotable saline water. In mountainous areas, lack of adequate road network, steep slopes, and dense vegetation hinder accessibility.	Antigua This map unit is only found in Antigua. Aquifers are recharged by rainfall and by percolation from rivers. Ground water exploration from July to October presents a potential danger from hurricane-force winds and flash flooding. Heavy precipitation from August to September and high risk of earthquakes may trigger landslides in mountainous areas.
4 Fresh water scarce or lacking	Aquifers are located in Oligocene to Pleistocene age mixed volcanic, limestone, and sedimentary aquifers.	Very small to very large quantities of brackish to saline water are available.	Water quality is brackish to saline.	If desalination or reverse osmosis water purification of the ground water is provided, limestone, sand, alluvium, and conglomerate aquifers might be suitable for hand pump wells.	Aquifers are recharged by rainfall and by percolation from rivers. Ground water exploration from July to October presents a potential danger from hurricane-force winds and flash flooding. Heavy precipitation from August to September and high risk of

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
4 Fresh water scarce or lacking (continued)					earthquakes may trigger landslides in mountainous areas. Steep coastal cliffs pose a landslide hazard.
(Dominica)	Dominica Predominately mixed volcanics that range from Miocene to Pliocene age basalt, dykes, and ash. Other aquifers include Pliocene age coral reef limestone and conglomerate primarily on the west coast.		Dominica Ground water is generally brackish to saline along coastal areas. Ground water is hard with high pH in the coral reef limestone. For the rest of the aquifers, ground water is soft with low pH.	Dominica Depth to aquifer is <1 m along coastal areas. Caution should be used during well drilling, installation and pumping to ensure that the fresh water aquifer is not permanently contaminated by saltwater intrusion. Overpumping a well may cause saltwater intrusion. In the coastal areas, reverse osmosis purification units (ROWPUs) may be needed to treat nonpotable saline water.	
(Antigua and Barbuda)	Antigua Various kinds of aquifers along coastal areas include the limestone Oligocene age Antigua Formation, Pliocene to Pleistocene clay and tuff, Recent age fossiliferous beach sand, and Recent age alluvium. Barbuda The Pleistocene age Codrington Formation (shelly and sandy limestone) and the Pleistocene age		Barbuda ▲**9** One well just south of Codrington (1737N06149W) had the following water sample in July 1984: Cl^- 807 mg/L. ▲**10** One well in Dulcina (1735N06149) had the following water sample in July 1984: Cl^- 1,419 mg/L.	Antigua and Barbuda Depth to aquifer ranges from the ground surface to <20 m below the ground surface.	

Table C-2. Ground Water Resources, Continued

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
4 Fresh water scarce or lacking (continued) (Barbuda, continued)	Barbuda Highlands Formation (massive and shelly limestone) are present.				
(St. Kitts and Nevis)	St. Kitts and Nevis Recent age beach sand is situated along coastal areas.		St. Kitts and Nevis Ground water may be brackish to saline.	St. Kitts and Nevis Depth to aquifer ranges from the ground surface to <20 m below the ground surface.	

[1]Quantitative Terms:

Enormous	= >100 liters per second (L/s) (1,600 gallons per minute (gal/min))
Very large	= >50 to 100 L/s (800 to 1,600 gal/min)
Large	= >25 to 50 L/s (400 to 800 gal/min)
Moderate	= >10 to 25 L/s (160 to 400 gal/min)
Small	= >4 to 10 L/s (64 to 160 gal/min)
Very small	= >1 to 4 L/s (16 to 64 gal/min)
Meager	= >0.25 to 1 L/s (4 to 16 gal/min)
Unsuitable	= ≤0.25 L/s (4 gal/min)

[2]Qualitative Terms:

Fresh water	= maximum TDS ≤1,000 mg/L maximum chlorides (Cl) ≤600 mg/L; and maximum sulfates (SO_4) ≤300 mg/L
Brackish water	= maximum TDS >1,000 mg/L but ≤15,000 mg/L
Saline water	= TDS >15,000 mg/L

Hardness Terms:

Soft	= 0 to 60 mg/L $CaCO_3$
Moderately hard	= 61 to 120 mg/L $CaCO_3$
Hard	= 121 to 180 mg/L $CaCO_3$
Very hard	= >180 mg/L $CaCO_3$

[3]Geographic coordinates list latitude first for the Northern (N) Hemisphere and longitude second for the Western (W) Hemisphere. For example:

Charles Fort …. (1721N06250W)

Geographic coordinates for Charles Fort that are given as 1721N06250W equal 17° 21' N, 62° 50' W and can be written as a latitude of 17 degrees and 21 minutes north and a longitude of 62 degrees and 50 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

Conversion Chart:

To Convert	Multiply By	To Obtain
liters per second	15.84	gallons per minute
liters per second	60	liters per minute
liters per second	950	gallons per hour
gallons per minute	0.063	liters per second
gallons per minute	3.78	liters per minute

Table C-2. Ground Water Resources, Continued

Note:

Br	= bromine	mg/L	= milligrams per liter
^{o}C	= degrees Celsius	mi	= mile
Ca	= calcium	Na	= sodium
$CaCO_3$	= calcium carbonate	pH	= hydrogen-ion concentration
Cl^-	= chloride	S	= storativity
cm^2/s	= square centimeters per second	SO_4	= sulfate
Fe	= iron	Sr	= strontium
L/s	= liters per second	St.	= Saint
M	= meters	T	= temperature
M^2/d	= square meters per day	TDS	= total dissolved solids
Mg	= magnesium		