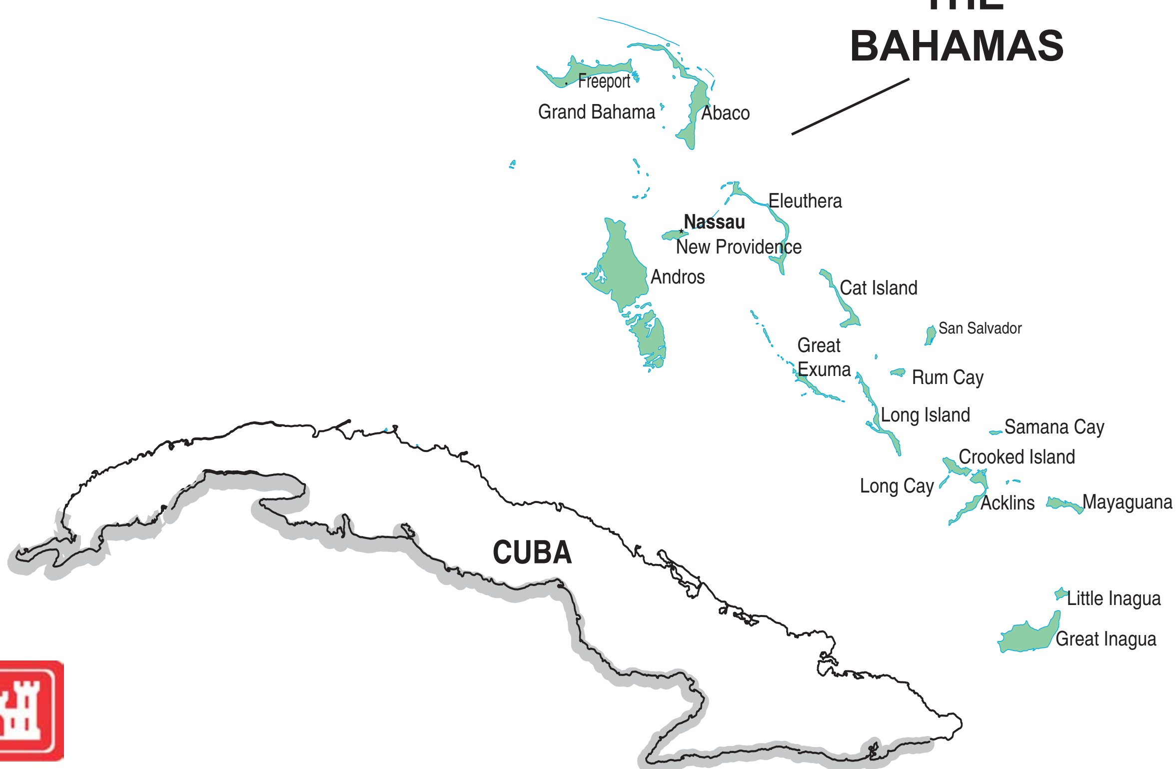
# WATER RESOURCES ASSESSMENT OF THE BAHAMAS

UNITED STATES SOUTHERN COMMAND




**US Army Corps of Engineers**
Mobile District &
Topographic Engineering Center

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# Executive Summary

Freshwater resources are finite and vulnerable in The Bahamas. The extent of freshwater resources is limited to very fragile freshwater 'lenses' in the shallow karstic limestone aquifers. The 'freshwater' is actually derived from precipitation, lying on top of the shallow saline water as a 'lens', less than 5 feet from the ground surface. Fresh surface water is basically non-existent. The country, therefore, relies on a single source of water.

Water availability is so low that it is considered 'scarce', according to United Nations criteria. Precipitation decreases from north to south through the archipelago. The southernmost islands, therefore, have greatly reduced freshwater supplies. Inagua, the southernmost island, is practically a desert. The availability of water is a limiting factor for economic and social development.

Several scenarios for supplying water exist in the various islands. The main ones include:

- Ground water provided via water authority on a large scale
- Private water wells
- Ground water barged from one island to another
- Fresh ground water blended with brackish ground water
- Ground water piped from one island to another by underwater lines
- Desalination (usually RO)
- Water trucking from one part of island to another
- Bottled water for drinking and cooking

Water losses, particularly unaccounted-for-water loss, are great. For New Providence, water loss is estimated at 53%, which is roughly equivalent to the amount barged from Andros. This high percentage of water loss, however, is typical for Latin America and the Caribbean.

Over-abstraction of the limited freshwater reserves is a concern. Over-abstraction can cause saltwater intrusion into the freshwater aquifer, creating abandonment of wellfields permanently or for numerous years. Saltwater intrusion due to over-abstraction is already occurring on New Providence where the greatest water demands of the country exist. Sea level rise due to climate change will exacerbate the situation. The aquifers are very shallow, and are at great risk of becoming inundated with saline water even with a small rise in sea level. Less precipitation over the years in some islands due to climate change is also reducing freshwater availability.

Other types and sources of contamination also threaten the limited freshwater reserves. The nature of the geology and the lack of proper sewage collection and treatment are contributing to the contamination of the ground water. Natural disasters and severe weather, such as hurricanes, however, are probably the most threatening to the health of the freshwater reserves. Once polluted, ground water is very expensive to clean up. Protecting the resource from contamination is preferable and more cost effective than remediation. Little, if anything, however, can be done to protect the ground water from natural disasters. As a result of these and other factors, RO is key for the future of water supply for New Providence and many other islands in The Bahamas, particularly the central and southernmost islands. Grand Bahama, Abaco, and Andros have enough fresh ground water reserves to meet their demands.

The correlation between the ground water resources and wetlands is not fully understood or at least adequately documented. Wetlands play a beneficial role in pollution control, the retention of peak run-off flows, and erosion and sediment control. With the increasing developments

throughout the country, the number of healthy wetland ecosystems has dramatically declined. An absence of wetlands policy is a significant deterrent in protecting the wetlands. As a result, the National Wetlands Committee is presently evaluating guidelines to promote the conservation and wise use of wetlands, provide a framework for wetland inventory, and produce guidelines to encourage local participation in the management of wetlands.

Tourism is the mainstay of The Bahamas' economy. The industry is heavily dependent on adequate supplies of good quality water for survival. Water is more critical to the industry than other elements, such as telecommunications and human resources. Agriculture, which is heavily dependent on water and irrigation, is also a very important economic element of the country. Water is, therefore, a vital economic resource of The Bahamas.

A lack of data exists in the water resources area. A lack of compilation, organization, and availability of data or a combination of the above could also contribute to this "lack of data". The collection and monitoring of historical data is weak.

The need for regulating and protecting the water resources is essential. Regulating the resource through integrated ground water management is recommended. Ignoring the over exploitation and protection will have severe repercussions, such as health issues from water-borne diseases and much greater water costs. The greatly increased cost of water will be due to treatment incurred as a result of ground water contamination, from the necessity to use RO, and/or barging more water to meet demand. Failure to act will result in even higher costs being incurred. Proper land use planning and regulations, which are currently lacking, will play an important role in the protection of the resource. The formation of a new department, Department of Environmental Planning and Protection, is proposed by the Ministry of Health and the Environment, to regulate ground water abstraction and pollution control. Regulation is justified in this case as the water situation in The Bahamas needs attention, and regulations and a regulatory body to address the situation do not currently exist. Current laws and regulations, particularly regarding land use and it's planning, governing the water lack clarity and are inadequate. Overall, ground water should be treated as a strategic national resource.

# 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 The Bahamas. 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 Government of The Bahamas 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 Topographic Engineering Center, conducted the water resources investigations in 2003 and 2004 and subsequently prepared the report. Visits were made to Nassau and Freeport in July 2003 by Laura Roebuck and Joy Pochatila, to meet with the numerous agencies, organizations, companies, 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

| | |
|---|---|
| $ | Dollar (1 Bahamian Dollar = 1 US Dollar) |
| % | Percent |
| BEST | The Bahamas Environment, Science and Technology Commission |
| BOO | Build Own and Operate (Agreement) |
| cm | centimeters |
| CPACC | Caribbean Planning for Adaptation to Global Climate Change |
| DEHS | Department of Environmental Health Services |
| DEPP | Department of Environmental Planning and Protection |
| DPW | Department of Public Works |
| EBR | Emerald Bay Resort Holding Ltd. |
| EHA | Environmental Health Act |
| ft | feet |
| gpm | gallons per minute |
| GBUC | Grand Bahama Utility Company |
| GDP | Gross Domestic Product |
| gpd | gallons per day |
| HVAC | heating, ventilation and air conditioning |
| IGD | Imperial Gallons per Day |
| JWQPCU | Joint Water Quality and Pollution Control Unit |
| Kig | thousand imperial gallons |
| km | kilometers |
| $km^2$ | square kilometers |
| L/s | liters per second |
| MGD | million gallons per day |
| MIGD | million imperial gallons per day |
| MLW | mean low water |
| MOH | Ministry of Health |
| m | meters |
| mm | millimeters |
| $mi^2$ | square miles |
| $m^3$ | cubic meters |
| mg/L | milligrams per liter |
| NAPL | non-aqueous phase liquid |
| NGO | non-government organization |
| NPDC | New Providence Development Company |
| PAHO | Pan American Health Organization |
| ppm | parts per million |
| PU | Paradise Utilities |
| PUC | Public Utilities Commission |
| QA/QC | quality assurance and quality control |
| RO | reverse osmosis |
| TDS | total dissolved solids |

| | |
|---|---|
| UFW | unaccounted-for-water |
| US | United States |
| W&SC | Water and Sewerage Corporation |

# List of Place Names

This is a list of names and geographic coordinates that are mentioned in the text of this document, excluding the appendices. These coordinates were obtained from the GEOnet Names Server (GNS), website http://gnpswww.nima.mil/geonames/GNS/index.jsp. Please see the example explanation at the end of this list for more information.

| Place Name | Geographic Coordinates |
|---|---|
| Abaco Island | 2628N07705W |
| Abrahams Bay (Mayaguana) | 2222N07258W |
| Acklins Island | 2226N07400W |
| Adelaide (New Providence) | 2500N07729W |
| Anderson (Acklins) | 2237N07352W |
| Andros Island | 2426N07757W |
| Andros Town (Andros) | 2442N07746W |
| Arthurs Town (Cat) | 2438N07542W |
| August Cay (Grand Bahama) | 2639N07754W |
| Berry Islands | 2534N07745W |
| Bight of Acklins (Acklins and Crooked) | 2230N07415W |
| Bimini (Island) | 2542N07915W |
| Bluff Settlement (Eleuthera) | 2530N07644W |
| Bullets Hill (Crooked) | 2244N07405W |
| Cat Island | 2423N07530W |
| Cay Point (New Providence) | 2459N07725W |
| Cedar Harbour (Abaco) | 2655N07739W |
| Chesters (Acklins) | 2243N07355W |
| Church Grove (Crooked) | 2245N07413W |
| Clarence Town (Long) | 2306N07459W |
| Cockburn Town (San Salvador) | 2402N07431W |
| Cold Rock (Acklins) | 2228N07356W |
| Colonel Hill (Crooked) | 2246N07413W |
| Crooked Island | 2245N07413W |
| Crossing Rocks (Abaco) | 2608N07711W |
| Current Settlement (Eleuthera) | 2526N07647W |
| Delectable Bay (Acklins) | 2226N07359W |
| Devils Point (Cat) | 2407N07528W |
| Dundas Town (Abaco) | 2633N07705W |
| Eleuthera Island | 2510N07614W |
| Exuma Island | (see Great Exuma) |
| Fairfield (Crooked) | 2247N07413W |
| Freeport (Grand Bahama) | 2632N07842W |
| Freeport Harbour (Grand Bahama) | 2629N07843W |
| Freetown Settlement (Cat) | 2417N07525W |
| Fresh Creek (Andros) | 2444N07747W |
| George Town (Exuma) | 2330N07546W |
| Gorda Cay | 2605N07733W |
| Governors Harbour (Eleuthera) | 2510N07614W |
| Great Bahama Bank | 2315N07730W |

# List of Place Names (Continued)

| Place Name | Geographic Coordinates |
|---|---|
| Grand Bahama Island | 2638N07825W |
| Grand Lucayan Waterway (Grand Bahama) | 2633N07833W |
| Great Bay (Crooked) | 2244N07406W |
| Great Exuma Island (and Little) | 2330N07545W |
| Great Inagua Island | 2105N07318W |
| Guinea Schooner Bay (Abaco) | 2611N07710W |
| Hardhill (Acklins) | 2236N07352W |
| Hatchet Bay Pond (Eleuthera) | 2520N07626W |
| Hole in the Wall (Abaco) | 2551N07710W |
| Inagua Island (Same as Great Inagua Island) | 2105N07318W |
| James Cistern (Eleuthera) | 2519N07622W |
| Lake City (Abaco) | 2619N07710W |
| Lake Killarney (New Providence) | 2503N07727W |
| Lake Rosa (Great Inagua) | 2102N07328W |
| Landrail Point (Crooked) | 2248N07421W |
| Little Abaco (same as Abaco Island) | 2628N07705W |
| London Creek (Andros) | 2457N07756W |
| Long Cay (Crooked) | 2237N07420W |
| Long Island | 2315N07504W |
| Majors Cay (Crooked) | 2243N07407W |
| Mangrove Cay (Andros) | 2415N07739W |
| Marsh Harbour (Abaco) | 2633N07703W |
| Matthew Town (Great Inagua) | 2057N07340W |
| Mayaguana Island | 2223N07257W |
| McQueens Settlement (Cat) | 2410N07528W |
| Moore’s Island | 2618N07733W |
| Morant Bay (Acklins) | 2224N07402W |
| Moss Town (Crooked) | 2248N07415W |
| Mount Alvernia (Cat) | 2418N07525W |
| Nassau (New Providence) | 2505N07721W |
| New Providence Island | 2502N07724W |
| Normans Castle (Abaco) | 2642N07726W |
| North Bight (Andros) | 2427N07742W |
| Ocean Bight (Exuma) | 2337N07355W |
| Old Bight (Cat) | 2415N07521W |
| Pinefield Point (Acklins) | 2239N07352W |
| Pompey Bay (Acklins) | 2225N07401W |
| Ragged Island | 2211N07543W |
| Red Bay (Andros) | 2508N07811W |
| Rum Cay | 2340N07453W |
| San Salvador Island | 2402N07430W |
| Snow Bay (San Salvador) | 2356N07429W |
| Snug Corner (Acklins) | 2232N07353W |

# List of Place Names (Continued)

| Place Name | Geographic Coordinates |
| --- | --- |
| Spanish Wells (North Eleuthera) | 2412N07645W |
| Spring Point (Acklins) | 2227N07358W |
| Stafford Creek (Andros) | 2554N07756W |
| Sweetings Pond (Eleuthera) | 2521N07631W |
| The Bluff Settlement (Andros) | 2407N07733W |
| The Bluff Settlement (Eleuthera) | 2530N07644W |
| Treasure Cay (Abaco) | 2640N07716W |
| United Estates (San Salvador) | 2406N07427W |
| West End (Grand Bahama) | 2641N07858W |
| Winding Bay (Crooked) | 2243N07408W |

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 theWestern (W) Hemisphere. For example:

**Abrahams Bay (Mayaguana).............. 2222N07258W**

Geographic coordinates for Abrahams Bay (Mayaguana) that are given as 2222N07258W equal 22°22' N 72°58' W and can be written as a latitude of 22 degrees and 22 minutes north and a longitude of 72 degrees and 58 minutes west. Geographic coordinates are approximate but are sufficiently accurate for locating features on the country-scale map. The coordinates for most other features are generally at the central most point.


**Figure 1. Country Map**

# Water Resources Assessment of The Bahamas

# 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 short supply of usable potable water could result in the most devastating natural disaster since history has been accurately recorded, 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 and income-generating potential.[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 (m) away. If the water source is more than 1,000 m 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 (mg/L). As TDS values increase over 1,000 mg/L, 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.

Clean water prevents widespread outbreaks of:

- 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
- Less productive work hours spent hauling water great distances and dealing with illness

Proper water supply development and management of water resources is important in alleviating poverty.[4]

The purpose of this assessment is to document the general overall water resources situation in the Commonwealth of The Bahamas. 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 (U.S.) on the part of several water resources professionals.

The organization of this Water Resources Assessment consists of Chapters I through VII with associated tables and figures and 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 storm surge, legislative framework and hydrological monitoring and climate change.
- Chapter III presents current uses of water resources including water supply and distribution for domestic, industrial and commercial, and agricultural uses (including quality and sanitation); hydropower; 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 7 and Figures 1 through 6 are provided within the document following the text reference.
- Appendices A through C provide supporting information for the report:

  Appendix A – List of 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 country's water resources and to assist military planners during troop engineering exercises. The water resources maps (Figures C-1, C-2 and C-3), complemented by the table in Appendix C, should be useful to water planners as overviews of available water resources on a country scale.

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 the country 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.

English and metric units are used throughout this assessment. The reason for using both units is for consistency with the individual source documents. This assessment is a compilation of already existing data from a wide variety of sources. The various references use English or metric, or a combination of both. When using information from a particular source, the units used in the source are then used in this assessment. In some cases, both units are provided, with one unit in parenthesis.

# II. Country Profile

## A. Geography

The Bahamas, officially the Commonwealth of The Bahamas, consists of about 700 islands and cays, with only a small percentage of the islands being inhabited. The total land area encompasses 13,939 square kilometers ($km^2$)[5], making it about the size of Connecticut, USA. The Bahamas is divided into three geographical areas: New Providence Island, where the capital of Nassau is located; Grand Bahama, home of the popular Freeport; and the Family Islands, which is the name given to all of the other islands and cays.[6] (See Figure 2.)

The chain of islands that comprises the country extends from 80 kilometers (km) east of Florida southeasterly to 80 km northeast of Cuba.[7] This amounts to 3,542 km of coastline.[8] The islands are located in the western section of the North Atlantic Ocean, scattered over about 80,000 square miles ($mi^2$).[9] They are bordered by the U.S. to the west, Cuba to the southwest, and by Haiti and the Turks and Caicos Islands to the southeast.

The archipelago is comprised of surface plateaus from fourteen marine banks. The largest of these is the Great Bahama Bank.[10] Deepwater channels, mainly the Tongue of the Ocean and the Providence Channels, separate these banks. There are extensive coral reefs surrounding the islands. Patches of reefs and extensive sea grass beds are found on the interiors of the banks. In fact, The Bahamas provides the largest body of coral reef (as well as other marine organisms) in the Atlantic and Caribbean regions.[11]

The land of has a foundation of fossil coral, but much of the rock is oolitic limestone. This limestone is derived from the disintegration of coral reefs and seashells.[12] The landscape is mostly flat, elevations of less than ten meters, with few rolling hills and ridges. The islands of the southeast and central Bahamas are typically at higher elevations than in the north. The highest point, on Cat Island, is only 63 m above sea level.[13]

The flat lands generally consist of rock, from the coral formations, or mangrove swamp with low shrubs. Timber, one of the country's three natural resources, is found in abundance on four of the northern islands; Grand Bahama, Great Abaco, New Providence, and Andros. On some of the southern islands, low-growing tropical hardwood flourishes. Two other natural resources found are salt and aragonite. Some soil is very fertile, but it is not very deep.[14]

Several islands contain large brackish lakes, and many islands contain tidal creeks. Grand Bahama and Andros have large tidal creeks, which are generally navigable by small boats.[15]

The geography of the islands makes them susceptible to flooding and wind damage by tropical storms and hurricanes.[16] Besides the effect that these natural disasters have on property and the life of residents and tourists, they also cause significant concern to the water resources.


**Figure 2. Vicinity Map**

## B. Population and Social Impacts

The total population for The Bahamas, according to the 2000 census, is 304,913. Most of the population of the entire country is concentrated in two cities: Nassau on New Providence Island and Freeport on Grand Bahama. Data vary from reference to reference, but only a small percentage of the 700-plus islands that make up the country are populated.[17] Table 1 shows the distribution of the population and land area by island. New Providence accounts for seventy percent of the total population, most concentrated in the capital of Nassau. The next most populated island is the Grand Bahama, which accounts for fifteen percent of the total population. The majority of these people live in Freeport. The Family Islands then accounts for the remaining fifteen percent.[18]

New Providence is the most densely populated island, with 2,655.4 people per square mile. No other island even comes close to this density. Of the other islands, only a few have population densities greater than 10 people per square mile. This low ratio of human resources versus land area for the majority of the country creates a challenge to manage the extensive coastline of The Bahamas.[19]

**Table 1. Population and Land Area Distribution by Island**

| Island | Population | Approximate Area ($mi^2$) |
|---|---|---|
| New Providence (Nassau, Capital) | 212,432 | 80 |
| Grand Bahama | 46,954 | 530 |
| Abaco | 13,174 | 649 |
| Acklins | 423 | 192 |
| Andros | 7,615 | 2,300 |
| Berry Islands | 707 | 12 |
| Bimini | 1,601 | 9 |
| Cat Island | 1,548 | 150 |
| Crooked Island | 341 | 93 |
| Eleuthera | 8,114 | 187 |
| Exuma & Cays | 3,575 | 112 |
| Harbour Island & Spanish Wells | 3,155 | 13 |
| Inagua | 970 | 599 |
| Long Island | 2,945 | 230 |
| Mayaguana | 262 | 110 |
| Ragged Island | 69 | 14 |
| San Salvador & Rum Cay | 1,028 | 93 |
| **Total** | **304,913** | ***5,382** |

Source: Central Statistical Office, National Census, 2000

*The total area figure is 5,373 if the column figures are totaled. However, the source document states 5,382.

The population growth is estimated at 1.8% per year. Tourism brings in about 4 million visitors a year.[20] These tourists use an estimated two to five times more potable water than the residents.[21]

In addition, the residents in the more central and southeastern islands are migrating to the urban centers of Freeport and Nassau due to the lack of water resources, job opportunities, healthcare, and education in these regions.[22]

The population growth, as well as the tourism industry, leads to large and increasing usage of water for food production and household (or hotel) use, which in turn may intensify water shortages, ultimately leading to economic and social crises. Naturally scarce water supplies, poor water quality, or uneven distribution of water resources may have adverse affects on the health and ultimately the growth and distribution of populations.

# C. Economy

The Bahamas is a stable, developing nation with an economy heavily dependent on tourism. Banking, fishing, agriculture, and manufacturing are other contributors to the economy. Tourism represents more than 60 percent of the gross domestic product (GDP) and employs about half of the work force. The tourism industry has increased from 45,000 visitors per year in 1950 to 4 million in 2000. Steady growth in tourism revenue and a large increase in new hotel construction, resorts and residences led to solid GDP growth in recent years until 2002. The slowdown in the U.S. economy and the attacks of September 11, 2001 reduced growth in these sectors from late 2001 to early 2002.[23, 24] By February 2002, tourist numbers returned to normal levels.[25]

Services performed in tourism are considered exports. The Bahamas leads Latin America and the Caribbean by far in the percentage of total exports attributable to tourism. Tourism accounts for about 75% of total exports. Without exception, the development of the tourism industry is dependent on the proper management of water resources. Pollution of the beaches, and associated health risks for tourists and the local population is a tremendous threat to the industry, and therefore the economy of the entire nation.[26] While being dependent on water availability and quality for the industry to develop and thrive, tourism also has devastating consequences on the freshwater resources. Tourists use 400 to 1,000 liters of water/visitor/day. Many elements are needed in the tourism industry, but water is the more critical of power, telecommunications, human resources and the environment.[27] As a result, water is a key economic resource.[28]

The overall growth prospects for the Bahamian economy are most dependent on the tourism industry, at least in the short run. The World Tourism Organization has forecast tourism, over the next ten years, to increase by more than 40%. For continuing the country's stronghold on the tourism industry, economic planning must include the protection and management of the natural and cultural resources of the country, including the water resources.[29]

The second most important sector of the economy is the banking and financial services, which accounts for about 15 percent of the GDP and contributes over $300 million per year to the economy through its services. The value of this sector is due largely to the country’s status as a tax haven and offshore banking center. The financial sector employs more than 4,000 people.[30,31]

The fishing industry generates another 4,000 jobs, and commercial fishing accounts for about $70 million per year of the economy.[32] The Exclusive Economic Zone of The Bahamas, the 200 nautical mile offshore zone within which the country has water-use rights, includes habitats such as sea grass beds, coral reefs, as well as deep oceanic waters. These habitats contribute to the country’s status as having the largest area of productive shallow water in the western North Atlantic. In fact, this environment supports one of the major fisheries for spiny lobster in the world and for conch and Nassau grouper in the western North Atlantic and Caribbean.[33]

Agriculture and manufacturing contribute a total of about 10 percent to the GDP. They show little growth despite the government’s efforts to stimulate these industries with incentives.[34] The agricultural sector produces $50 million per year supported by approximately 8,000 hectares of land concentrated on four of the northern islands.[35] The major agricultural products include citrus, vegetables and livestock (especially poultry).[36] The manufacturing industries that contribute to the GDP include; cement, oil refining and transshipment, salt, rum, aragonite, pharmaceuticals, and spiral-welded steel pipe. These two sectors each support 5% of the labor force.[37]

Water supply and sewerage are two critical concerns that present major constraints in achieving sustained economic growth in the country.[38] Ground water resources are vitally important to the economy, however a lack of control over the withdrawal and pollution of the ground water puts the resource at increased risk of degradation, overpumping, and pollution. Abstraction regulation and preventive measures in ground water pollution can have a dramatic and positive effect on the economy.[39] Specific issues related to water resources that warrant concern to the economy of The Bahamas (due to its island geography and geology and its strong dependence on tourism) are:

- Limited water reserves which leads to inconsistencies between distribution of freshwater reserves with distribution of development activity and population on some islands (over-pumping and salt water intrusion are commonly a direct result);

- Extreme weather events which are known to affect some water reserves, as well as transmission and distribution lines;

- Sea level rise which could affect the capacity of freshwater aquifers and the quality of groundwater in the future, and temperature increase which could result in an increase in evaporation and evapotranspiration (both predicted effects of global warming from greenhouse gas emissions);

- Disruption and loss of supplies which are expected to adversely affect small hotels and service providers more than large hotels, many of which have their own reverse osmosis (RO) plants,[40]; and

- Many sources of pollution, which are extremely difficult and costly to clean up in the ground water.[41]

The following sections provide a more thorough discussion of these water resources issues.

# D. Flooding, Flood Control and Storm Surge

A Disaster Preparedness Office has been established in the Cabinet Office to address the impact of natural disasters. The natural disaster profile consists of hurricanes and other tropical storms that cause extensive flood and wind damage.[42] Floods, in particular, become a national concern during the summer months when downbursts from thunderstorms are experienced, and predictions of climate change and global warming indicate a major increase in flooding conditions due to such storms, as well as due to a rise in sea level.[43, 44]

The Bahamas is located in the hurricane belt. More than fifty hurricanes have passed within 125 miles of Nassau between 1886 and 1999. In 1992, Hurricane Andrew caused severe saltwater intrusion on a major farming area. Hurricane Lili caused flooding in 1996, which resulted in leaching of fertilizer and delay in replanting.[45] In 1999, Hurricane Floyd caused a temporary rise in sea level and flooding in the Family Islands, resulting in water contamination, which required extensive pumping to restore water quality in some areas. Interruption of services was also experienced from a disruption of electricity at pumping stations and filtration system pumps, which lacked standby generators. Also, broken pipelines and wind-damaged storage tanks caused some storage tanks to empty. The cost of repairs from Hurricane Floyd to the water supply and distribution system was in excess of US$2 million.[46,47] Hurricanes Frances and Jeanne in 2004 caused similar type damage. Hurricane Frances passed directly over Grand Bahama, causing extensive saltwater coverage in the west.[48] It also created significant storm surges in Grand Bahama and Andros. About half of the Water and Sewerage Corporation (W&SC) water resources in Andros were affected, which impacted the import of water from North Andros to New Providence.[49]

For North Andros, the storm surge associated with Hurricane Frances increased chlorides in their trenches dramatically, from less than 400 mg/L about 3 months before Frances, to as much as 15,000 mg/L in some wellfields. However, the storm surge did not compromise the ground water lens beyond repair, according to strategically located monitoring wells that were sampled and analyzed. The 'trenching' system of North Andros contributed to saltwater intrusion of the entire system. One solution is to isolate the system, by separating the trenches from each other. A long-term, but expensive, solution is to run perforated piping along the bottom of the entire trench length and backfill all trench areas. To correct the saltwater inundation from Hurricane Frances, the trench and conduit systems were pumped down, to encourage rapid recharge from the underlying resources.[50]

Hurricane Jeanne passed directly over Marsh Harbour in Abaco and did considerable damage. W&SC operations were impacted by loss of power, fresh and salt water flooding, and infrastructure damage, such as storage tanks. In Grand Bahama, a storm surge from the northwest put 6 feet (ft) of seawater over the main wellfields. To correct, it took about a week or two pumping as much as possible to reduce salinities. Actual salinity data was not available at time of press. Hurricane Jeanne also caused a lot of damage to other small islands in the Little Bahama Bank.[51]

Both hurricanes and waves from the Atlantic Ocean, generally during high tide combined with storm surge, generate extreme wave conditions. Flooding and erosion typically occur during these wave conditions. The waves erode protective beaches and dunes and cause surge and flood damage to the adjacent lands, buildings, infrastructure, and groundwater resources.[52] This is especially significant since eighty percent of the country's land mass is only five feet above mean sea level and more than 90% of the freshwater resources are within five feet of the surface.[53,54]

Storm surges can cause coastal inundation of sea water, and heavy precipitation can cause localized flooding. This flooding contaminates the soil and groundwater with seawater, sewage, petroleum products, pesticides, as well as any other objectionable substances that are not adequately secured or stored. In addition, the winds and wind driven surges are capable of demolishing storage facilities.[55] Also, flooding causes infiltration into the wastewater system. It is estimated that 2/3 of Nassau’s 3 million imperial gallons per day (MIGD) of flow into the sewage system during the rainy season is due to infiltration from storm water.[56]

Flood plain mapping is also needed, to show vulnerable areas, including technical assistance and funding. The current storm surge atlas needs to be extended to the southeast. Currently, the storm surge atlas includes the northwest and central Bahamas.[57]

Flooding from heavy precipitation is a far more common problem than storm surges, per Dr. Cant of W&SC. Locally, it has the same potential for both soil and ground water contamination by salt and other pollutants.[58] The Department of Meteorology in Nassau indicated that 1 ½ inches of rainfall in six hours or less, typical of summertime, can cause flooding in New Providence. Once the ground becomes totally saturated, flooding can occur quickly since seepage to the sea is a slow process and is the only natural way to deal with the problem.[59]

One storm in North Eleuthera caused 8 inches of rainfall in just over a few hours in the Harbor Island area, and reports of as much as 20 inches in the Spanish Wells area. This rainfall soon saturated the land and the floodwater filled every topographic low, even in Spanish Wells, that is just a thin strip of land. The main road in North Eleuthera had 8 ft of standing water. The floodwaters took about 2 weeks to recede.

To further exacerbate these flooding problems, low-lying areas are being developed without building up the surface of the land, due to the high cost of building up. In New Providence, land is expensive, and wetlands and seasonal ponding areas are being developed without concern of floods, until the rainy season hits. Building on low-lying areas, as well as urbanization, which limits space for storm water drainage and decreases natural infiltration areas, intensifies flooding issues. Major outcries occur during the rainy season, as these low-lying areas are flooded.[60, 61]

Generally, wetland areas naturally have a beneficial role in pollution control, the attenuation of flood peaks, and erosion and sediment control. A sustainable approach to the functional roles of wetlands can assist in the reduction of costs associated with both storm water management and ground water recharge structures. Wetland retention and their creation offer a more sustainable approach to flood management. Additionally, the requirement of flood defenses such as walls, culverts, canals, and man-made ponds can be condensed in controlling the impacts of flooding.[62]

Climate change and global warming, from greenhouse gas emissions, are also expected to worsen the flooding issues related to the water resources of the country. Rising sea level from thermal expansion and melting glaciers, changes in rainfall amounts, and distribution and frequency of extreme weather events are all processes associated with climate change from global warming, which all affect flooding. Rising sea levels are expected to erode the land, expand wetlands, and cause migration and loss of mangroves. Flooding from extreme rainfall events and movement of seawater inland, due to rising sea level and eroding coastal defenses, will be experienced.[63]

W&SC believes the total elimination of flooding could probably only be overcome by the development of surface water drainage systems and/or the raising of road and plot levels. Dating back to the 1940’s, storm water drainage has been in existence. A system of gullies and channels leading to soakage wells in areas remote from the sea have been developed north of the Nassau ridge. It is not comprehensive, though, and localized flooding occurs.

The Ministry of Public Works roads and drainage program primarily focuses on drainage wells. These disposal wells, which are used for treated and untreated wastewater effluent as well, discharge the large volumes of storm water and effluent to the subsurface. It is estimated that 300 to 400 disposal wells are in operation in the country, with the vast majority used for injecting storm water runoff. Most of the wells are in Freeport, Grand Bahama, and New Providence. They are typically drilled to between 100 and 150 ft in total depth, with few exceeding 300 ft, and are cased to approximately 20 ft below ground level. This allows recharge to the groundwater, which is recommended by W&SC for all storm water. These wells work well due to the high permeability of the limestone substratum, but fail once the floodwaters reach the head of the wells.

Some of the Grand Bahama Utility Company's (GBUC) freshwater wells were completely inundated with seawater during Hurricane Floyd, and have not fully recovered yet. A French hydrologist calculated full recovery would take 72 years. The surge created by Floyd probably happens once every 100 years. The Utility Company added more wells to offset the loss and located them further inland.

Also, on Grand Bahama, canals have been dug in the low areas to bring the building site elevations up to a minimum of 7 ft above mean low water (MLW). The Building Code has not been amended, but builders have been advised to keep floor levels at 10 ft above MLW on waterfront property.[64]

Alternative analysis and design are required to effectively transport storm water to groundwater for recharge, and guidelines need to be developed to address disposal issues to prevent contamination of the freshwater resources. There are currently no established guidelines on disposal practices, no defined waste disposal zones, no agreed grouting procedures in place, and no established procedure for the abandonment of wells taken out of service.[65]

Based on experience and impacts from recent hurricanes, W&SC has started changing its policy and practices to reduce vulnerability of the water supply. A major policy change has been to increase the desalination or RO capacity. The number of RO plants in the next few years is expected to increase from seven to twelve.

Other measures to be taken include:

- Increasing water storage and ensuring storage facilities are filled prior to storms and hurricanes;
- Using standby generators at pumping stations to limit disruption in electricity supply; and
- Improving protection of transmission or distribution lines in areas subject to storm surge or flood damage.[66]

In planning for impacts of floods and wind damage, especially from hurricanes and tropical storms, planners must take into account the track and sector of the natural hazard, the location of facilities relative to the open ocean, the building materials used for structures and infrastructures, and settlement patterns. These issues, when used in hazard prediction and response models, can help to accurately predict damage. This in turn can help policy makers, field agencies, and donor agencies implement response and evacuation measures, as well as necessary changes to be made to limit damage.[67, 68]

## E. Legislative Framework

In The Bahamas, there are a number of Government agencies responsible for the management and conservation of the nation's water resources.

W&SC is a legislative agency, under the Deputy Prime Minister, responsible for the control and administration of the water resources. In 1976, the Government established W&SC to replace the Water and Sewerage Department of the Ministry of Works and Utilities. A government appointed Board of Directors and the Chief Executive Officer (the General Manager) govern the W&SC. The main functions of the W&SC, as defined in the Water and Sewerage Corporation Act (1976), are to:

- Control and ensure the optimum development, use and protection of national water resources;
- Coordinate activities influencing quality, quantity, distribution and use of water;
- Apply appropriate standards and techniques for investigation, use, control, protection, management and administration of water;

- Provide sufficient water for domestic, agricultural, urban and industrial uses; and
- Provide adequate facilities for drainage and safe disposal of sewage.[69,70]

The first three functions of the W&SC are control and regulatory duties on behalf of the Government. The last two define the service corporation duties of the W&SC. In practice, the implementation of the rules and regulatory duties are not fully developed. This is due to legal and institutional overlaps between water related laws and agencies, as well as the lack of a water resources development policy and a central institutional framework for its administration.[71]

This lack of regulatory function of the W&SC can be seen in the water and sewerage service industry. In addition to the W&SC, there are three other major water utility entities operating. These are: the Paradise Utilities (PU), the GBUC, and New Providence Development Company (NPDC). The PU and GBUC are the sole providers of water for the Paradise Islands (PU supplies sewerage services as well) and Grand Bahama, respectively. The NPDC, on the other hand, supplies water on demand for the W&SC and operates a distribution system at the southwestern end of New Providence. These private services are not approved and monitored by the W&SC.

The private water systems (17% of the country's water systems in 2000) confirm a move toward decentralization and towards increased privatization that the Government is committed to while improving the efficiency of public utilities. Increased privatization is expected to be opposed due to higher fees for consumers and labor layoffs. It is hoped that better service and access will bring political gains by a decrease in employee to customer ratio, reduction in water losses, and improvement of meter reading and water fee collection.[72]

Other regulatory agencies, which overlap with W&SC on the water resource management issues, include:

- Ministry of Health (MOH), which is entrusted with the administration of the Environmental Health Act (EHA) and the Health Services Act that regulates and monitors among other things, the supply of water to ensure that public health and well-being are preserved;[73]

- The Department of Environmental Health Services (DEHS), part of the MOH, which is the primary regulatory agency for environmental matters affecting human health and assists in carrying out the requirements of the EHA;[74] and more specifically, the Environmental Monitoring and Risk Assessment Laboratory, formerly the Public Analyst Laboratory, attached to DEHS, which has joint responsibility for monitoring water quality (to meet World Health Organization drinking water health standards) along with W&SC through its Drinking Water Quality Unit;[75]

- Ministry of Works and Utilities, which is entrusted with the administration of the Building Control Act and Regulations, thereby sharing responsibility with the MOH, and also entrusted with the preparation of land use plans and physical planning activities (including supplying water supply franchises to developers in areas that are impractical for the government to undertake);[76]

- Ministry of Agriculture, Fisheries, and Local Government, which is responsible for the agricultural land, development, and its impact on the environment, including pollution from use of chemical pesticides and overuse of the water supply from irrigation, through the Department of Agriculture; as well as for the conservation and management of the fishing industry and fisheries, through the Department of Fisheries, which requires coordination with the Ministry of Public Works through the environmental impacts;

- Local Government, which has shifted much of the authority of Central Government to elected District Councils and Town Committees, thereby giving Local Government responsibilities for providing community services, such as water, sanitation, and waste collection and disposal, and ensuring effective use of the community's resources;[77] and

- The Public Utilities Commission (PUC), which determines standards for the provision of public services and regulates the rates to be charged.[78]

The W&SC also works with the MOH and the Ministry of Works and Utilities in developing the sewage infrastructure, as reflected in the Building Code. A policy has been developed requiring new subdivision having a minimum size of 24 lots to install a sewage collection and treatment plant system. It is hoped that, as the number of systems increase, they may be linked as part of an island wide network in the future.[79]

The Government has begun to address the overlap by creating a Joint Water Quality and Pollution Control Unit (JWQPCU) in the mid-1980's from W&SC, DEHS and the Pan American Health Organization (PAHO). The JWQPCU holds meetings for information exchange and collaboration on health and environmental issues pertaining to the water and sanitation sector. Because water quantity and quality are strongly related, this unit fulfils a necessary and important task in water management.

The Bahamas Environment, Science and Technology (BEST) Commission was created in 1992 to facilitate better planning and communications between government agencies that are responsible for the natural resources and environment. BEST consists of representatives from all Ministries, Departments, Corporations, non-government organizations (NGO) and individuals responsible or involved in matters related to environment, science or technology. It is very influential in creating and changing the country's policies.[80]

BEST has appointed four subcommittees to deal with specific environmentally related matters and/or international agreements involving the country. These sub-committees consist of: Biodiversity Committee, Science and Technology Committee, National Climate Change Committee, and National Ramsar Committee (for management of wetlands).[81]

Many legislative acts and regulations exist to control all aspects of the water resources. The central acts that contribute to the legal framework of the water and sanitation sector include:

- The Bahamas Water and Sewerage Corporation Act, 1976, placing water resource use under the control of the government and creating an authority to oversee water management and protection;
- The Out Islands Utility Act, regulating water management in the Family Islands;
- The EHA, 1987, promoting environmental protection to ensure human health;[82,83]
- The Building Regulations Act, 1971;[84]
- And the Public Utilities Commission Act, responsible for the creation of the PUC and regulation of rates and the standards for public utilities.[85]

Current legislation, however, lacks clarity, does not fully protect the groundwater resources from over-abstraction and pollution, and is not adequate in achieving proper sewage treatment standards. This lack of legislation, in addition to the overlap of government entities and lack of a water resources development policy and central institution for administration discussed earlier, has led government agencies involved with economic development programs to recognize and accept that the allocation of the water resources, and their protection and control, are the primary responsibility of the W&SC under the Ministry of Consumer Affairs.[86,87]

Pending draft legislation covers most areas of concern by amending the existing legislation. Conservation of the water resources should come from enforcement of the existing legislation and from the pending passage of legislation on pesticide use, as well as land use. The development of a comprehensive land use policy that compliments legislation would be the most effective way to control activities that affect the resources. (Land use planning regulations are included in the 15 proposed regulatory instruments discussed below.)[88]

W&SC has recommended that a position be created for an environmental regulator to enforce certain legal issues (e.g. abstraction licensing, well drilling, solid waste disposal, environmental impact assessments, etc.). The MOH, as well as W&SC, support the formation of a Department of Environmental Planning and Protection (DEPP) under the MOH that could lead to the framework for this environmental regulator position. The other environmental enforcement issues (e.g., land use planning and the building regulations) could continue to fall under the Ministry of Works and Utilities (Physical Planning and Building Control Divisions).[89]

In a recent study by Water Management Consultants, November 2003, 15 existing and proposed regulatory instruments addressing ground water resources protection need to be enacted by an Act of Parliament, at the earliest possible opportunity. In this study, a strategic regulatory framework for ground water management and pollution control is outlined. The recommendations outlined therein are endorsed by the W&SC, and should be considered for implementation. The 15 instruments address land use, septic tank problems, management of ground water withdrawals, prosecution, building regulations, public education, use of agricultural chemicals, well drilling permitting and licensing, among others.[90]

There is currently no single environmental regulatory body. As a result, a lack of regulations controlling the use and abuse of ground water exists. The regulation of ground water, including abstraction and pollution, is necessary to avoid disaster to the country's water resources.[91]

## F. Hydrological Monitoring and Climate Change

The Caribbean Planning for Adaptation to Global Climate Change (CPACC) project is designed to support the participating Caribbean countries in preparing to cope with the adverse effects of global climate change, particularly sea level rise in coastal and marine areas through the following: vulnerability assessment, adaptation planning and capacity building linked to adaptation planning.

The following comments resulted from a CPACC project meeting in October 2000:

- Systematic hydrological data has been collected since 1971, but a systematic water monitoring program has not been established which precludes a vulnerability assessment. The establishment of a comprehensive water resources management regime is a critical requirement, together with the stringent control of water extraction.

- In The Bahamas, recording stations have been established on eight islands to monitor climatic conditions under the CPACC project, but these are insufficient to adequately monitor weather patterns. It is estimated that up to 60 stations may be required.

- Three sea-level rise monitoring stations have been established but these are insufficient to adequately monitor sea-level patterns. Additionally, no wave recorders are present in The Bahamas to measure sea swells, or wave height/length or wave energy. Storm surge modeling needs to be undertaken throughout the Archipelago.[92]

In lieu of systematic and continuous record keeping, a number of short-term sporadic monitoring programs have been funded over the last 50 years. These programs tend to address a specific issue such as hydroelectric projects or environmental concerns like deforestation. A typical example 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. Initiated in the late 1990s by the Global Environment Facility through The World Bank as implementing agency and executed by the Organization of American States. Stations were installed along the coastlines of The Bahamas, as well as several other countries. See Figure 3. The stations record sea level, air and sea surface temperature, wind speed, barometric pressure, relative humidity and precipitation. Due to problems with equipment, training, and damage from annual surge activity minimal information was collected.[93]

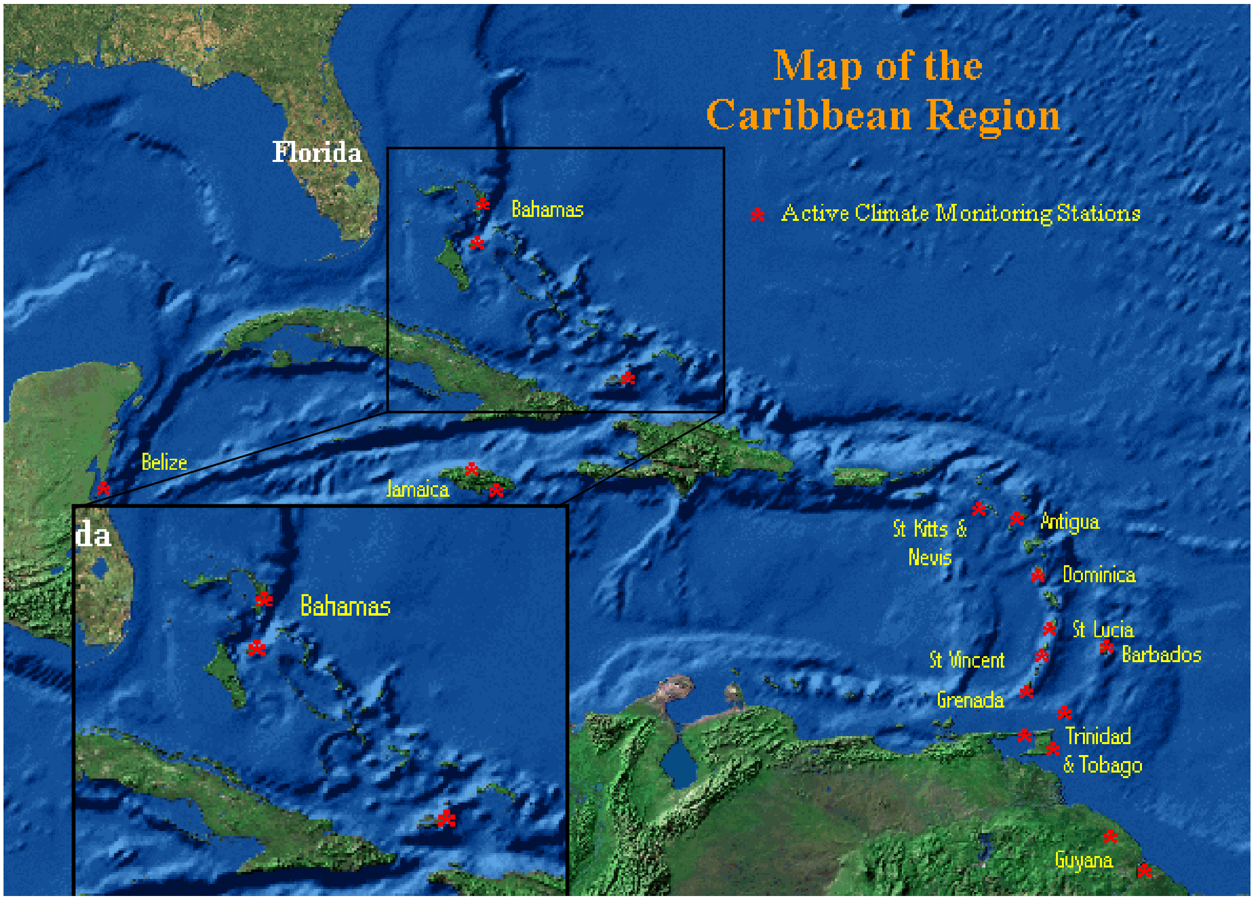


**Figure 3. Coastal Stations for Monitoring Climate Change Impacts**

# III. Current Uses of Water Resources

The current uses of water resources that are addressed here include: water supply and distribution (domestic uses – urban, rural, industrial/commercial, and agriculture); waterway transportation; and recreation. Information is also provided on hydropower, and water supply quality.

# A. Water Supply and Distribution

The Bahamas obtains its water supply from ground water and RO and distillation. Much water must be barged from one island to another. New Providence barges over 50% of its water supply from Andros. The only source of freshwater in the country is rainfall. The rainfall forms freshwater lenses in the ground as well as wetlands, small pools at the surface, and seasonal ponds. Freshwater wetlands tend to be small, seasonal, and widely scattered.

The total freshwater reserve is estimated at $7.7 \times 10^9$ cubic meters ($m^3$) and is scattered throughout the country in localized lenses of various sizes and quality. Exploitable freshwater is a small amount of the total reserves because the bulk of the reserves is used as a container which maintains the geometry of the freshwater body. (See Chapter IV for more information on the hydrogeology.) In fact, over-exploitation will result in long-term change in the shape and dimensions of the fresh groundwater structure.[94] The possibility of rain or storm water run-off collection/harvesting for possible ground water recharge has not been adequately explored.

The freshwater lens aquifers throughout most of the country are vulnerable to storm surges, causing saltwater inundation of the aquifers in many cases. These damaging storm surges occur during hurricanes, and other severe weather. Hurricanes Frances and Jeanne in 2004 caused significant damage in parts of the country.

Several options and scenarios for water supply source and distribution exist, including:

1. Private water wells;
2. Ground water distributed to the masses via water authority;
3. Ground water piped from one island to another via underwater lines;
4. Ground water barged from one island to another;
5. Desalination;
6. Rainwater catchment;
7. Water trucking from one part of island to another;
8. Reuse of treated effluent;[95]
9. Bottled water for drinking and cooking;[96]
10. Saltwater for salt-resistant grasses on golf courses;
11. Saltwater for cooling heating, ventilation, and air conditioning (HVAC) and other equipment.

The primary source of drinking water is fresh ground water. RO is increasing in usage, and will most likely continue to increase, as fresh (ground) water availability continues to decline, and water demands grow. Rainwater catchment is rarely used, supplying possibly 3% or less of the water consumed.[97,98]

Due to quality issues and brackish water, a huge bottled water industry has developed. The estimated number of bottled water companies varies from eight on New Providence, up to a total of 27 for the entire country. According to the Central Statistical Office, approximately 85% of the population on New Providence buys bottled water for drinking and cooking. The bottled water industry is strictly regulated. The second draft of the proposed Bottled Water Regulations was published in April 2003. A very successful training workshop was held that same month, with all the reputable bottling companies supportive of regulation.[99,100]

The availability and distribution of water is a concern.[101] The amount of rainfall, as well as the size of the island, determines the volume of its freshwater resources. The rainfall is, however, unevenly distributed across the country, and the southeastern islands receive as much as 40% less annual precipitation than the north and northcentral islands.[102] Therefore, on some islands, there are insufficient sources of freshwater, and others who had adequate water supplies are experiencing shortages due to growth of population, development and tourism. Andros has the largest freshwater reserve, but Grand Bahama and Abaco have large reserves also. In New Providence, thousands of gallons of water are barged, predominantly from Andros, because of insufficient freshwater available on the island.[103]

The W&SC claims 60 extraction and distribution systems on 26 separate islands. Daily delivery by the corporation exceeds 45,424 $m^3$. However, this represents only a part of the total consumption; thousands of private abstraction schemes as well as mass distribution schemes are also attributed to the total.[104]

Table 2 summarizes the current data on the occurrence of freshwater throughout the country. The information suggests that there is sufficient freshwater available for the total population. However, per capita shortages can be seen based on the distribution of freshwater. This analysis ignores the tourism sector, which is the largest demand sector of freshwater. Conflicts between land use and water quality are not apparent in this data, either.

With the depth to water table up to 1.5 m for most areas, groundwater access is simple. Abstraction methods include: hand-dug wells, drilled wells, trenches, pits, and direct use or water from freshwater marshes.[105] However, for areas with insufficient freshwater, distillation and RO are used to produce potable water. In distillation, freshwater is obtained from condensing pure steam from boiled and evaporated seawater. RO removes salts and dissolved solids by passing water molecules through a membrane at high pressure. The cost of RO is considerably higher than traditional methods, but it is cheaper and faster than distillation.[106]

Water rates can affect the daily consumption. Rates vary from place to place and in some of the remote locations the water is provided free of cost to the local residents. Generally, water rates are lower where local ground water provides the sole water supply. However, the cost increases where ground water is blended with barged water or water that is produced by RO. The cost is the greatest where RO provides the only source of water.[107]

Water supplies obtained from the RO of seawater cost from six to eight times that obtained directly from fresh groundwater. Freshwater obtained from the RO of brackish water, as well as freshwater blended with barged water, costs approximately four times that of fresh groundwater.[108] Few residential communities and small hotels and service providers can afford the full cost of water obtained from RO.[109,110] Over time, the technology for RO has improved, and the cost of RO has decreased. Assuming this trend continues, RO will be a viable alternative as a source of potable water supply.

In addition to the high costs, RO plants produce substantial brine wastes (typically in excess of 35,000 mg/L dissolved solids), which could cause significant environmental problems as the need for these plants increase. These wastes are generally discharged into deep saline aquifers or surface waters with a higher salt content. Brine can, however, also be diluted with treated effluent and disposed of by spraying on golf courses and/or other open space areas.

**Table 2. Freshwater Resources in The Bahamas***

| Island | Maximum Volume Available Daily (million imperial gallons) | Water Available Daily per Person (imperial gallons) 2000 Census | Calculated Water Demand** (million gallons†) | Total Population 2000 Census |
|---|---|---|---|---|
| Abaco | 79.1 | 6,004 | 0.66 | 13,174 |
| Acklins | 4.36 | 10,307 | 0.02 | 423 |
| Andros | 209.92 | 27,567 | 0.38 | 7,615 |
| Bimini and The Berry Island | 0.17 | 74 | 0.12 | 2,308 |
| Cat Island | 6.8 | 4,393 | 0.08 | 1,548 |
| Crooked Island | 1.74 | 5,103 | 0.02 | 341 |
| Eleuthera, Harbour Island & Spanish Wells | 8.13 | 721 | 0.56 | 11,269 |
| Exuma & Cays | 2.9 | 811 | 0.18 | 3,575 |
| Grand Bahama | 93.17 | 1,984 | 2.35 | 46,954 |
| Great Inagua | 0.86 | 822 | 0.05 | ***1,046 |
| Long Island | 2.88 | 978 | 0.15 | 2,945 |
| Mayaguana | 0.65 | 2,481 | 0.01 | 262 |
| New Providence | 9.63 | 45 | 10.62 | 212,432 |
| Ragged Island | 0.01 | 145 | 0.00 | 69 |
| San Salvador & Rum Cay | 0.1 | 97 | 0.05 | 1,028 |
| **All Bahamas** | **420** | | | *****304,989** |

Source: Table adapted from The Government of the Bahamas, "The Bahamas National Report," March 2001, p.13.
Notes:
† Assume imperial gallons, although source document states 'million gallons' as stated here.
* Freshwater resources occur as concave lens-shaped bodies that overlie brackish or saline waters at depths (ground water).
** Based on standard water usage of 50 gallons per person per day.
*** Population figure differs slightly from Table 1 due to reference used.

Other disadvantages of RO plants include membrane fouling and the need for a reliable energy source, both of which are costly and adversely affected by severe weather conditions.[111] Another disadvantage is the large amount of energy required, which can be up to 25% of the total cost of the water. However, due to increasing tourism and population demands, as well as the scattered nature of the water resources (often far from population centers) and global warming impacts (see Hydrological Monitoring section), water supplementing the freshwater lens resources with desalinated water is the future in water supply for The Bahamas.[112,113,114]

W&SC is gradually introducing more RO plants to supplement or replace ground water sources in many of the islands, particularly in the smaller and drier southeastern islands, where inadequate freshwater supplies exist and seasonal drought occurs. These plants are being introduced despite the poor economic returns associated with serving these small, scattered communities.[115]

To reduce the need for RO plants and other alternate methods of obtaining freshwater, solutions such as conservation and responsible use of freshwater resources, as well as reducing (or eliminating) unaccounted-for-water (UFW) are necessary. Conservation will come from increased regulation of waste from industry, agriculture, and domestic sewage; increased regulation of land use for fuel storage and dispensing, solid waste, agriculture, tourism, residential, and recreation sites; and finally the regulation of water abstraction methods, sites of abstraction, and rates of abstraction.[116] See Water Supply Quality and Sanitation for further discussion on pollution issues, and Legislative Framework Section for regulation issues.

Faulty mains, leaking distribution pipes, broken valves, illegal water connections and outdated customer listings are the causes of UFW. In New Providence, the UFW was approximately 49% in 1999. If water losses could be controlled or lowered, the water supply would be sufficient to satisfy the demand over the next several years, in particular, for New Providence.[117] The water losses are roughly equivalent to the amount of water that is barged to New Providence from Andros.

## 1. Domestic Uses and Needs

In 1996, about eighty-eight percent of the population had access to a piped water supply. This high coverage indicates that the more densely populated areas of the country (the northern and north central islands) have access to piped water. Many smaller communities, especially in the drier southeast islands, do not have adequate water supplies. Piped supplies are not available in some islands because freshwater is not available. However, in some areas, the piped water is brackish because that is all that is available.[118] In addition, the number of residents and the (low) population density economically preclude adequate water system development.

### a. Urban Areas (predominantly New Providence and Freeport)

In the urban areas, 98% of the population had access to safe water from improved drinking water sources, as of 2000.[119] W&SC provides water (50% of the total consumed) and sewer services in New Providence where a large part of the economic activities of the country are concentrated. Of the water supplied by W&SC, 50 to 55% is barged from Andros, about 22% is obtained from Water Fields Company RO plant, and the rest is from freshwater sources on the island. The other 50% of the total consumed in New Providence is attributed to a proliferation of private wells, which often have poor quality water. These private wells are unregulated, and the exact number of wells are unknown. A rough order of magnitude estimate for the total number of these wells on New Providence is 30,000.[120,121,122,123]

Much of the population on New Providence purchases bottled water for drinking and cooking. It's popularity has grown tremendously in recent years. Eight bottled water companies exist on New Providence. Most companies use brackish groundwater, and use RO to reduce the chlorides to less than 250 parts per million (ppm), and employ ultraviolet radiation or ozonation for disinfection. The quality of the water is monitoried by DEHS. Due to the popularity and widespread use, for health and safety reasons, it became necessary to regulate bottled water production. DEHS produced the bottled water regulations in collaboration with PAHO and JWQPCU.[124]

Barged volumes of water for New Providence were over 4 MIGD in 2000. Water obtained for shipment to New Providence is pumped into temporary storage in North Andros before barging to the island where it is chlorinated and discharged into the distribution system. Of W&SC's total water supply to New Providence, W&SC-owned wellfields supplied 1.92 MIGD, purchased freshwater supplied 0.061 MIGD, and purchased RO water supplied 1.786 MIGD (2000 latest estimates). Therefore, the total volume of water provided to New Providence residents by the W&SC is 8.1 MIGD.[125]

The approximately 2 million gallons per day (MGD) of water produced currently by wellfields on New Providence is not sustainable in the long-term at that rate. Better management of the wellfield abstractions and well layouts is necessary to sustain the fresh ground water reserves on New Providence.[126]

NPDC supplies about 1,000 customers on the western end of New Providence, with a potential for 1,000 more. The water is abstracted from wells, and is usually brackish, with other quality issues, such as excessive sulfur and undesirable color. Sand filtration is needed to adequately treat the well water. Total production is 260 million gallons/year, with 160 million gallons/year sold to W&SC. The wellfield is about 2,000 acres. Sustainable pumping is estimated to be 500 to 750 gallons/day/acre. However, during peak times, pumping has reached over 2 MGD per acre.[127] UFW for NPDC is estimated at 25%.[128]

Waterfields Company Limited was awarded the contract for the RO plant on New Providence under a 15 year Build, Own, and Operate (BOO) Agreement with W&SC. This has proven to be a successful venture. In fact, from 1998 to 2003, the plant produced over 3.5 billion gallons of water.[129]

The GBUC, a private company, supplies Freeport/Lucaya City with unlimited freshwater from an extensive water table.[130] Freeport is the second most populous town in the nation. Piped water has been available to residents in Freeport since 1920.[131]

**b. <u>Rural Areas and the Family Islands</u>**

In rural areas, 86% of the population had access to improved drinking water sources, as of 2000.[132] W&SC provides service to the Family Islands where they operate numerous small systems in difficult conditions providing service to mostly low income areas of the country. On Grand Bahama Island, the Ministry of Works and Utilities provides water to the rural areas. Water supply for these rural areas is also purchased from GBUC.[133]

In the most rural areas, water is still privately obtained by bucket from shallow hand-dug wells. These wells usually contain less than one meter of water and are practical where the freshwater lens is very thin. Other methods such as hand or electric pumping systems may lift water to overhead storage, thereby supplying water for domestic usage. Besides dug and drilled wells, public supply of ground water is obtained from mechanically cut trenches, pits and seasonal freshwater marshes. Where fresh ground water is not available, rainwater catchments are typically utilized. Alternatively, where costs allow, water is obtained by desalination (typically RO), and marine transport of ground water from other islands.[134] Underwater transmission lines for water from island to island also exist.[135]

Daily consumption by households in the Family Islands varies. In Exuma and Eleuthera, daily averages were 65 imperial gallons per day (IGD) and 116 IGD, respectively. While in Abaco, the average was 109 IGD, just over the 97 IGD for residential piped water in New Providence. Most rural areas tend to have low averages similar to Exuma. This trend is due to lower quality of service, typically lower incomes, and the ground water resources available to many settlements, although water quality is generally a problem. On the other hand, Eleuthera, Abaco, and also Andros have higher water usages per person, due to better quality of service (pressure, salinity, and reliability) than most rural areas.[136] Water rates also have an impact on consumption rates, as previously discussed.[137]

The Family Islands obtain most of their water from ground water resources and RO. Traditionally, fresh ground water was used for water supply, but in more recent years, the use of RO to supply water is becoming widespread. The use of RO for water supply on the Family Islands is increasing. W&SC operates and maintains over 50 water supply systems on 24 Family Islands. The W&SC water systems serves about 70% of the Family Islands population. Some of the water provided is brackish.[138] According to a consumer survey, which is a little dated, the quality of the service (and the water supplied) by W&SC is highly variable from acceptable to extremely poor.[139] However, the water services on the Family Islands are being upgraded. A $13 million contract was let to an Italian contractor for installing water systems in three Family Islands. Also recently, W&SC received a $14 million loan from Inter-American Development Bank to improve water supply in Exuma, south Eleuthera and Abaco.[140] The southernmost islands have inadequate freshwater resources, as they have much lower rainfall.

Discussion of water supply on some of the Family Islands follows:

- Inagua has been supplied with desalinated water by RO, provided by Morton Salt Company. A new RO plant to be operated and maintained by W&SC is being planned to supply water to the population.[141] In the past, water was barged to Inagua from Florida, but this is no longer occurring.[142]

- In addition to a new RO plant for Inagua, Exuma, South Eleuthera, Bimini, and Long Island, new plants are planned or are anticipated for Mayaguana, Rum Cay, San Salvador, Ragged Island, Grand Cay (off Great Abaco) and in the Exuma Cays.[143,144]

- Bimini's water supply was from a wellfield, but it is no longer operational due to saltwater intrusion. The water demand now is met by private wells, rainwater harvesting, bottled water (imported), and RO.[145] The BOO RO facility on North Bimini is operated by Bimini Bay Water, and provides 50,000 gallons per day (gpd) (minimum contract supply @ $6.00/thousand imperial gallons (Kig) Selling Price).[146]

- Water supply for the population on Grand Cay, Moores Island, Black Point and Farmers Cay is from RO, at a cost ranging from $12.00 to $25.00 /Kig.

- Most of the other Family Islands use fresh ground water as their water supply. Andros has extensive fresh ground water resources, enough to supply 1/2 the needs for New Providence. Very little rainwater catchment is used since many of the newer structures built are not equipped with rainwater catchments or storage tanks.

- Distribution systems are not found on all the islands. However, more distribution systems are being planned and constructed by W&SC for many islands for better piped coverage. Water trucking is a common means of household water distribution for various communities and areas of the islands.[147] Water is delivered via trucking on the islands of Long Island, Acklins, Rum Cay and Cat Island. On Long Island, many of the homes have been built with rainwater storage tanks, and the tanker is utilized to top-off supplies during the dry season.[148]

- According to the Global Assessment of Drinking Water Supply and Sanitation Services

2000, a consumer survey revealed that the quality of the water service on the Family Islands was highly variable, from acceptable to extremely poor. The service was scored in terms of water quality and pressure.[149]

- As part of the new project mentioned earlier, the upgrades planned for Abaco consist of installing 33 new wells, and laying 13 miles of water mains. The upgrades planned for Eleuthera consist of installing 168 new wells and laying 16 miles of water mains. Upgrades planned for Exuma include installing over 300 new wells. To date, only the planned upgrades for Abaco have been completed. Alternatives for both Exuma and Eleuthera consist of BOO RO contracts, which were seen as being a more sustainable approach for supplying both areas. In 2004, a 140,000-gpd (minimum contract supply @ $6.00/Kig Selling Price) RO facility was commissioned in Georgetown, Exuma, and a 75,000 gpd RO facility in Waterford, South Eleuthera. Additional RO supplies on Great Exuma are provided by Emerald Bay Resort Holding Ltd (EBR). as compensation for the loss of the water resources from the Ocean Bight Aquifer (up to 50,000 gpd). The basic selling price for water over 50,000 gpd from EBR is $6.00/Kig, with a purchase cost of $4.00/Kig.

- An underground water transmission main from Eleuthera to Harbour Island and Eleuthera to Spanish Wells provides both islands with fresh ground water supplies.[150] Additional underwater mains are located between Great Harbour and Bullocks Harbour Cays in the Berry Islands, and between North and South Bimini.[151]

Table 3 below outlines the reverse osmosis water supply costs for the Family Islands and Windsor, New Providence, as provided by the Water and Sewerage Corporation, November 2004.

**Table 3. Reverse Osmosis Water Supply Costs, November 2004**

| Location | Capacity (Imperial gallons per day) | Purchase Rate per 1000 Imperial Gallons (IG) | Estimated Annual Cost | Shorfall in Tariff Compared to Cost/1000 IG |
|---|---|---|---|---|
| REVERSE OSMOSIS OPERATORS PRESENTLY UNDER CONTRACT | | | | |
| Grand Cay, Abaco | 12,600 | $25.00 | $115,000 | $19.00 |
| Black Point, Exuma | 10,000 | $25.00 | $91,000 | $19.00 |
| Farmers Cay, Exuma* | 3,000 | $25.00 | $280,000 | $19.00 |
| Staniel Cay, Exuma* | 12,000 | $25.00 | $109,000 | $19.00 |
| Moores Island, Abaco | 30,000 | $12.60 | $138,000 | $6.60 |
| North Bimini | 100,000 | $9.91 | $360,000 | $6.46 |
| Inagua | 50,000 | $14.50 | $270,000 | $11.05 |
| Deadmans Cay, Long Is. | 50,000 | $12.00 | $220,000 | $8.55 |
| Georgetown, Exuma* | 180,000 | $10.20 | $670,000 | $4.20 |
| Waterford, S. Eleuthera* | 75,000 | $14.30 | $392,000 | $8.30 |
| Windsor, New Providence (for blending with ground water) | 2,000,000 | $6.60 | $2,200,000 | ---- |
| REPLACEMENT WATER FOR PREVIOUS WELLFIELD AREA (OCEAN BIGHT AQUIFER) | | | | |
| Ocean Bight, Exuma (EBR) | 50,000 (max) | $4.00 | ---- | ---- |
| PROPOSED CONTRACTS, PRESENTLY UNDER NEGOTIATIONS | | | | |
| San Salvador | 60,000 | $10.95 | $240,000 | $4.95 |
| Ragged Island* | 2,500 | $30.00 | $27,000 | $30.00 |

Source: John A. Bowleg, Water and Sewerage Corporation, personal communication, November 17 and 18, 2004.

Notes:

*This water is sold by W&SC at a lower cost than the purchase price.

---- not available

Windsor, NP has a water quality criteria for TDS of 50 mg/L or less; all other RO water has an acceptable TDS range between 450 to 700 mg/L. As a result of the requirement for lower TDS RO water for Windsor, the cost of the water is higher. This RO water is for blending with ground water.

Black Point, Farmers Cay, Moores Island, Bimini, Inaqua, Long Island, Georgetown, and Eleuthera include storage and distribution.

## 2. Industrial/Commercial Uses, Needs, and Impacts

Tourism, the major industry for the country, has serious impacts on the freshwater resources. The total number of visitors has been greater than 3 million annually for a number of years. Tourists consume an estimated 400 to 1,000 liters of water per person per day. This is in contrast to residential consumption of 150 to 200 liters per person. Increasing water demands from visitors will place increasing demands on the limited water source.[152] For the industry to continue to develop, additional high quality water will be in demand.

Bacardi, some hotels (for laundry use), the electric company (for cooling purposes), and other private companies (including bottled water companies) use RO to produce millions of gallons of potable water a day for the commercial market.[153,154] Bottled water is also considered as 'domestic use' water, and is discussed in that section.

Most of the large-scale manufacturing and industrial operations are located in and around Freeport Harbour on Grand Bahama Island.[155] Service and light industry account for significant contamination of the aquifer. These industries are responsible for a large portion of the non-aqueous phase liquids (NAPLs), heavy metals and other water soluble pollutants in the ground water. Bulk fuel storage and dispensing sites are major sources of many NAPLs in the form of fuels, lubricants, hydraulic fluids and cleaning solvent. Such sites are also sources of heavy metal contamination including copper and lead compounds. Other products contributed at these points include detergents and anti-freeze liquids.[156]

New golf course construction, as part of new large resorts on many islands, will create increased water demands. Salt-free grasses are planned for some new courses. On New Providence, a new golf course is planned that will use 1 MGD.

Large volumes of nonpotable water (seawater or saline ground water) are used on New Providence and Paradise Island in HVAC and for cooling plants. Seawater for aquariums also use a large volume of seawater.[157]

## 3. Agricultural Uses, Needs, and Impacts

Agriculture does not have a significant impact on New Providence, due to urbanization. However, many of the Family Islands, as well as Grand Bahama, do support agricultural development. Agricultural water demand on New Providence is negligible.

A national land use policy is being formulated, which will have objectives for planned agricultural expansion to increase export earnings, increase employment opportunities, and achieve greater self-sufficiency in food supplies. The Bahamas recognizes that with this expansion, creation of buffer zones and limitations on the use of pesticides will be required. The protection of the freshwater resources from contamination by fertilizer nutrients, pesticides, and animal wastes will be particularly important.

Given the permeability of the soils and parent rock and the close proximity of the freshwater aquifer to the land surface, these agrochemicals are readily leached into the freshwater lenses. It is a matter of self-interest for the agricultural sector to protect the water resources, since future expansion of agricultural land will depend on good quality water for irrigation.[158]

In addition to its impact on the quality of the water resources, agriculture can also have a major impact on the supply and availability of the water resources. In a study done for the Caribbean, it was noted that most of the water used for irrigation of agricultural products doesn’t reach the roots of that product. According to the Worldwatch Institute, usage of a drip irrigation system can deliver water directly to the roots, as well as cut water use by 30 to 70 percent. In return, it can raise crop yields by 20 to 90 percent. Practice of this irrigation could significantly reduce the drain of the freshwater resources.[159]

## 4. Water Supply Quality and Sanitation

Of the many water systems throughout the country, only about 8.5% reported a violation of one or more drinking health standards in 1998.[160] However, in 2003, as part of the Environmental Study conducted by Water Management Consultants, about 65% of the ground water samples collected and analyzed showed signs of microbiological contamination.[161] A major concern of the water supply quality is the proliferation of private shallow water wells, including domestic wells (as many as 30,000 in New Providence alone), hotel wells (which obtain about 90% of their supply from these), and industrial wells. Nitrates, pathogens and other substances compromise the groundwater quality when these shallow wells are developed near on-site sanitation.[162]

Those who are at greatest risk from polluted groundwater are those who drink and cook with private well water out of choice or necessity. This group principally includes the poor Bahamians and poor illegal immigrants. Public education on the benefits of using standpipe supplies for drinking supplies (for those who have a choice) and how to minimize risk of water-borne diseases by boiling and disinfecting well water could decrease these risks, at least in the short term. Long-term solutions include Government control and engineering measures (e.g., extending service to unserved areas).[163]

In addition to contamination, salinity affects the water quality in many areas. Most of the water systems on Abaco have good quality (salinity below 400 mg/L). However, the existing water system in the resort of Treasure Cay, Abaco has significant salinity and odor problems. Individual well fields supply water for four systems in southern Eleuthera and most of the systems in Exuma, where some of the well fields are being over-pumped, are yielding water with salinity levels above 1,200 mg/L and some above 2,000 mg/L. Salinity levels above 1,000 mg/L are generally considered unacceptable for domestic use.

In terms of sanitation, 100 percent of the population utilizes some type of wastewater treatment with the majority of the population using on-site systems, as evaluated in 1995. The lack of sewage treatment facilities in the main population centers remains one of the critical sanitary problems in the country, as sewage contamination of the ground water resource in the urbanized areas is widespread. Wastewater treatment plants provide service to 16 percent of the population in the capital city of Nassau, and an estimated 90 percent of the wastewater collected through public sewers is effectively treated through use of primary or secondary extended aeration systems.[164]

During our meetings, it became overwhelming clear that well field squatting is a serious problem, particularly for New Providence. Numerous villages, possibly more than 30, of squatters, primarily Haitian, are on New Providence Island. Health Inspectors have to handle dispersal and clean up. After an 'eviction', the squatters move elsewhere, and the cycle repeats. Many of these squatters live in the well fields, creating a disastrous situation.

The main source of ground water contamination is from septic tanks, soakaways, pit latrines and cess pits. Less than 10% of the population is connected to conventional sewage collection and treatment. Many of the private schemes are improperly constructed and maintained, posing serious threats to the environment and health risks. Due to the low land elevations, and high water table, the septic tank effluent discharges directly into the subsurface, draining into the ground water below the septic tank. Many septic tanks are located close to private wells, thereby easily contaminating the private wells, at great risk to the well users.[165]

The water quality on the Family Islands is highly variable, according to a consumer survey discussed in the "Global Assessment of Drinking Water Supply and Sanitation Services 2000". The rankings range from acceptable to extremely poor.[166]

The W&SC has identified eight specific threats to the water supply quality from water users. Practical solutions have also been offered. These threats are:

1) *Over-abstraction:* Over-abstraction is caused by pumping groundwater at too high a rate, or from too concentrated an area, usually from individual wells or sections of wellfields, causing a localized increase in salinity.[167] This over-pumping is possible because the distribution of population and development does not match the distribution of freshwater reserves.[168] The practical solution consists of careful management of wellfields and monitoring output and salinity of individual wells or trenches. Given enough time, the effects of over-abstraction can be reversed.

2) *Physical disturbance:* This threat is caused by salt water invading areas, which were previously fresh through the construction of marinas, canals, and waterways which are connected to the sea. The main example is the Grand Lucayan Waterway on Grand Bahama which consists of canals cut through the island (and through the freshwater lens). The damage to the fresh ground water is usually permanent. Also included in this category is any excavation below the water table, such as borrow pits for road construction, which expose open water, and lead to salinization through evaporation. The practical solution includes impact assessment studies of plans for new marina or waterfront developments, approving designs, and inspecting construction. Another solution is avoiding excavation below the water table if possible.

3) *Point-source pollution:* This category includes specific incidents or local sources of pollution, such as oil spills, leaks from underground storage tanks at gas stations, engineering workshops, chemical spills, etc. The practical solution is establishing good working practices, approving designs for fuel and chemical storage and handling facilities, inspecting construction, and then enforcing standards. Illegal squatters living in the well fields also pose a contamination threat to the ground water.

4) *Solid waste disposal:* Solid waste disposal pollution is caused from leachates from landfills, sludge disposal, and illegal dumping. This is another form of point-source pollution.[169] Disposal of garbage and sewage is difficult for small islands. Urbanization and growing consumption leads to increasing amounts of waste, which then leads to pollution of lagoons and oceans, and contamination of groundwater. Isolation and dependence on marine and land resources makes small islands highly vulnerable to such contamination.[170]

The practical solution is establishing good working practices, ensuring landfills are correctly designed and constructed, and educating the public on illegal dumping.

5) *Disposal wells:* This category includes pollution from disposal or drainage wells which have been badly constructed, wrongly sited, or drilled to the wrong depth. Inadequate treatment of waste before disposal down wells is another type of pollution in this category. The problem is not with the concept of using disposal wells, which can be a safe, effective and low-impact method of disposal for liquid waste. The threat is caused from bad design, bad construction, or bad operation. The practical solution is approving designs, inspecting construction, and monitoring operation.

6) *Septic tanks:* This category includes pollution from septic tanks, cesspits and latrines which have been improperly constructed, built in the wrong place (e.g., below the water table), not

emptied often enough, or not equipped with an accompanying disposal well.[171] On the islands, sewer collection and treatment systems are limited to a few small subdivisions, private developments, and hotels. Septic tanks are commonly utilized on the major islands. The septic tanks do not always conform to the building code and may not function properly. Septic tanks are usually combined with a drain field or disposal well, but not always. In less developed areas, pit latrines or cesspits are being used.[172]

This pollution frequently causes contamination in private wells via cross-connections. This risk was highlighted during an outbreak of Hepatitis A following a period of severe flooding. Most of the private wells tested during the Hepatitis A surveillance and monitoring were contaminated with sewage, thus reinforcing results of previous field surveys.[173]

The practical solution is to require approval of designs, inspection of the construction, and education of the public.[174] It is also considered important to keep customers on the public potable water system for these environmental and sanitary reasons.

7) *Abstraction wells:* Abstraction wells (mostly private wells) can cause a threat as well, when badly constructed, incorrectly sited, or drilled to the wrong depth. The approval of designs, inspection of the construction, and education of the public is again the practical solution.

8) *Diffuse pollution:* Pollution over wide areas from poor use of fertilizers, chemicals and manures in agriculture and on golf courses. Also poor use of treated effluent for irrigation. This subject is discussed further in the Industrial/Commercial and Agricultural Uses, Needs, and Impacts sections. The practical solution is to establish good working practices, have control of products, and education of the public.[175]

In addition, freshwater can be recycled in the same home or factory, or collected from one or more sites, treated, and redistributed and used in another location (known as wastewater reuse). Wastewater treatment technologies can produce reuse water suitable for irrigation or industrial purposes.[176]

All of these threats have practical solutions, as can be seen here. Good working practice, good design, construction, enforcement of standards, careful operation, and public education are required to make a positive impact on the water resources. Legal and administrative enforcement is, however, typically necessary to make a significant impact.

## B. Hydropower

The Bahamas generates 100 percent of its electricity from fossil fuels. Hydroelectric plants in The Bahamas do not exist.[177]

## C. Waterway Transportation

Waterways, except for the Grand Lucayan, are non existent throughout the islands, but several islands have large brackish lakes and many other islands are penetrated by tidal creeks, notably Andros and Grand Bahama. These creeks are generally navigable by small boats.[178]

The Grand Lucayan Waterway, about 8 miles long and navigable, on Grand Bahama Island was the largest engineering project in The Bahamas. This canal cuts the island in two, running north-south, just east of Freeport. The waterway is open to the sea on both ends, and is unlined, allowing seawater intrusion. As a result, the construction of this waterway destroyed a significant portion of the fresh ground water resources.[179]

As a result of the natural porosity of the limestone rock and relatively flat terrain, no rivers or other forms of surface flow are present, except where concrete and asphalt have been placed.[180] Ports and harbors are Freeport, Matthew Town, and Nassau.[181]

## D. Recreation

The economy is heavily dependent on tourism. Much of this tourism relates to water and water activities. Tourism became a major industry following the Second World War. The number of yearly visitors grew from 45,000 in 1950 to about 4 million in 2000. Among the attractions are the scenery, particularly the water, the appealing climate and culture, and the pristine appearance.[182] Numerous cruise ships travel to Nassau and Freeport. In 2001, 13.3 million passengers arrived on cruise ships.[183]

Marine biodiversity has been an important aspect in the tourist industry for wealthy visitors interested in recreational fishing, scuba diving, other water sports and fresh seafood.[184] The Bahamas are known for superior scuba diving, game fishing, and sailing. Snorkeling, water-skiing, angling, and swimming are other popular water-related activities.[185] One of the largest and best established scuba diving businesses is in The Bahamas.[186]

Clean water and coastlines are crucial to the country's economy. The dumping of sewage from cruise ships is a continuing problem. Heavy fees are levied on the abusers, but overseeing 100,000 $mi^2$ of ocean waters for infractions is impossible.[187] Excellent environmental health conditions are required for tourism to thrive. Visible signs of garbage and waste in the waters and on the beaches, as well as tourists' diarrhea and swimmers diseases associated with improper sewage disposal and water treatment (poor water quality) can have devastating effects on the tourism industry.[188]

Ecotourism is relatively young, but it is increasing in popularity, particularly on the islands of Andros, Abaco, Eleuthera, Inagua, and Bimini.[189]

The Bahamas National Trust is a legislatively mandated non-Governmental organization dedicated to the conservation of the natural and historic resources. Its main areas of focus are national park management, wildlife and habitat protection, historic preservation, conservation education, strategic development for the national parks system, and research.[190] The Bahamas National Trust has created a national parks system for the protection of hundreds of thousands of acres of wetlands, forests and islands.[191] There are 25 national parks and protected areas throughout the country, totaling more than 700,000 acres. Additional discussion is in the Forestry and Deforestation section. The Exuma Cays Land and Sea Park is a great success story of The Bahamas National Trust. This park is 176 $mi^2$ of land and sea, created in 1958 as a marine fishery reserve, the first of its kind.[192] It was also the first national park of The Bahamas. In 1986 the by-laws for the park were rewritten, making the entire park a 'no-take' fisheries replenishment area. It has been extremely successful. Fish replenishment occurs as much as 150 miles away. This national park draws a large number of tourists as well. Based on the success of this park, the establishment of such reserves is promoted worldwide to sustain fisheries resources.[193] The Bahamas National Park System successes were highlighted at the World Parks Congress, held in September 2003. The Exuma Park model was presented, receiving an increased level of interest and recognition from the international conservation/protected area community. This model may play a significant role in increasing marine protected areas internationally in the years ahead.[194]

New resort construction on the islands is increasing. Golf course construction and marina developments are part of most of the new resorts springing up on the various islands, such as Exuma, Eleuthera and Abaco. For most, the new resort golf courses being constructed or planned will have grasses that are salt-resistant. On the west end of New Providence, there are plans to build a new golf course that will use 1MGD. All new developments must be monitored for environmental impacts. Artificial liner systems are used to protect the underlying water resources from potential contaminants and for the sustainability of the Ghyben-Hertzberg Lens. Inland marinas and canals are required to be bulkheaded to minimize the ingress of saltwater.

# IV. Existing Water Resources

Water in The Bahamas is considered 'scarce' according to United Nations criteria. The criteria is based on annual internal renewable water resources per person. If the amount of water in a country is less than 1,000 $m^3$/capita/year, water is 'scarce'. The United Nations Food and Agricultural Organization (FAO) produced a table in 2002, entitled 'AQUASTAT 2002' ranking 180 countries in the world. The Bahamas ranks 177 out of 180 for water availability per capita/year, at 66 $m^3$/capita/year. This level of water availability poses serious limitations on the social and economic development of a nation.[195] This also means that protection of the available water should be considered top priority.

## A. Surface Water Resources

### 1. Precipitation and Climate

The Bahamas is classified as a marine tropical climate dominated by Atlantic Southeast Trade Winds in the summer and cool dry North American high-pressure systems in winter.[196] Average rainfall totals range from 600 millimeters (mm) (24 inches) in the dry southeastern islands to more than 1,600 mm (63 inches) in the northwestern islands (See Figure 4).[197] Most rainfall occurs during the warm summer months from May to October.[198] Limited rainfall is contributed in the cooler months from November to April, due to the passage of North American winter frontal systems.[199]

Annual rainfall totals vary significantly from the average due to tropical storms and hurricanes, both of which exert a great deal of influence on precipitation even when their tracts of passage are several hundred kilometers away from The Bahamas.[200] The hurricane season officially extends from June to November. More than 50 tropical cyclones of hurricane intensity passed within 200 km (125 miles) of Nassau between 1886 and 1999. During this period three major hurricanes wreaked havoc on the islands including: the destructive 1929 hurricane, which affected the islands of Eleuthera, New Providence and Andros; Hurricane Andrew of 1992; and Hurricane Floyd of 1999.[201]

Within more recent years in the historical record, however, rainfall amounts over the islands have changed. Rainfall per year in Nassau in the last 95 years decreased about 4.2 inches per 100 years. But since 1959, there has been an increase in rainfall of 21.8 inches per 100 years. For other islands, decreases in precipitation have occurred. For Long Island and Inagua, both south of New Providence, the rainfall has been decreasing 10.2 and 16.8 inches per 100 years, respectively, since 1959.[202]

Maximum temperatures for the islands range from 25 to 30 degrees Celsius (77 to 86 degrees Fahrenheit) and minimum temperatures range from 17 to 24 degrees Celsius (63 to 75 degrees

Fahrenheit) from north to south.[203] The Southeast Trade Winds dominate the weather for much of the year providing a cooling effect.[204]

Maximum temperatures for the islands range from 25 to 30 degrees Celsius (77 to 86 degrees Fahrenheit) and minimum temperatures range from 17 to 24 degrees Celsius (63 to 75 degrees Fahrenheit) from north to south.[205] The Southeast Trade Winds dominate the weather for much of the year providing a cooling effect.[206]

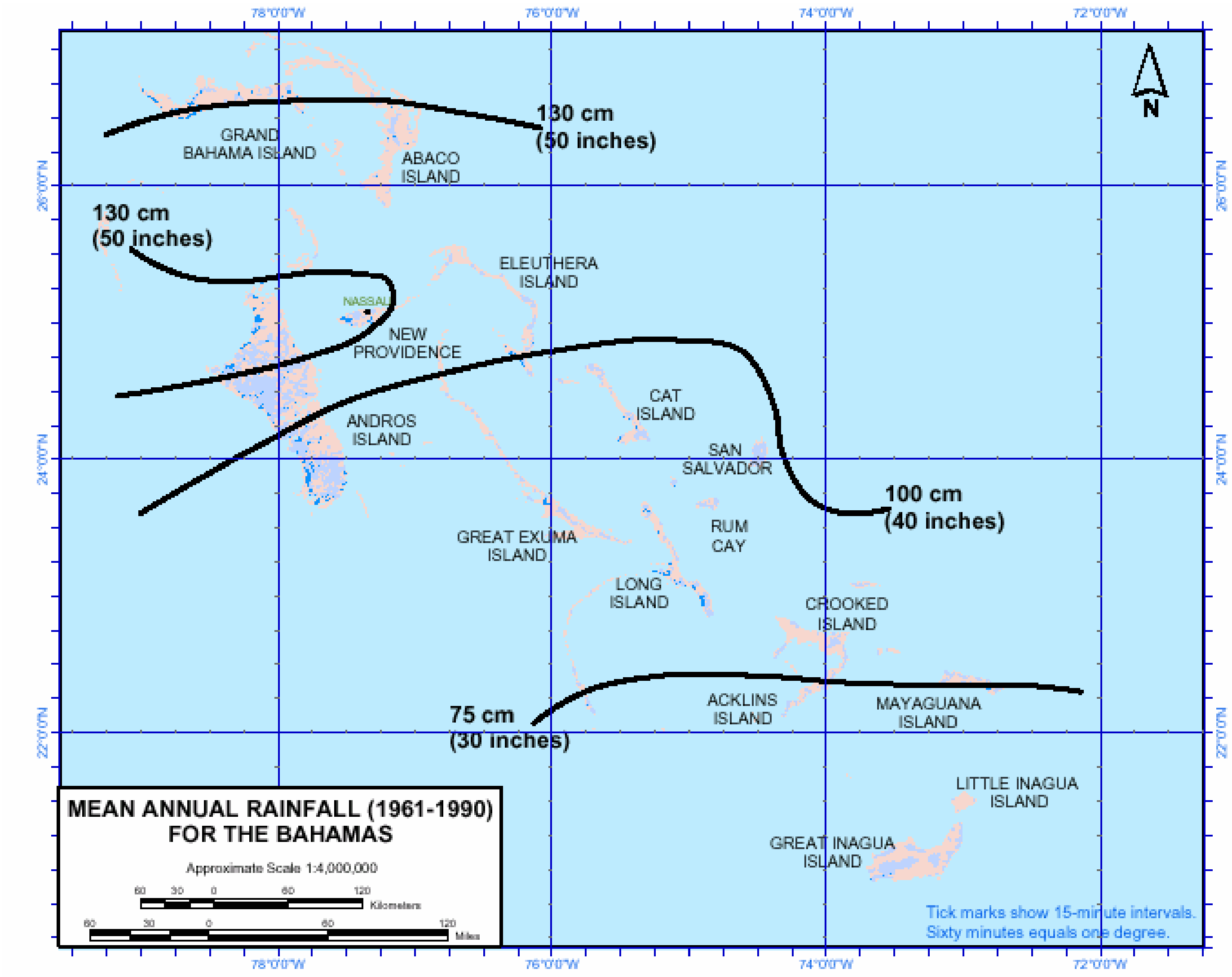


**Figure 4. Precipitation Map**

Source: Bahamas Department of Meteorology, Jeffrey Simmons, July 2003

Humidity is fairly high, especially in the summer months. Winds are predominantly easterly throughout the year, but with a tendency to become northeasterly from October to April and southeasterly from May to September.

## 2. River Systems and Inland Water Bodies

There are no true rivers or streams on the islands due to two factors; 1) the high permeability of the limestone surface permits the rainwater to percolate quickly to the water table and 2) the low relief of the land.

Inland water bodies are, in most instances, places where the water table is at or near the same level as the land surface. These bodies are usually saline or brackish nature. In other cases, ponding of water can occur after a heavy rainfall where the surface rock is impervious enough to retard infiltration. These intermittent freshwater pools may persist for a few hours or for the full length of the wet season. The two most prominent types of surface water bodies are blue holes and salt ponds.

Blue holes are found on all the larger islands of The Bahamas; however, the blue holes of Andros are the best known. Blue holes are subsurface voids resulting from the dissolution of the carbonate bedrock during periods of low sea-level. They are open to the earth's surface, with depths ranging from 6 m to more than 100 m (20 to 350 ft).[207] Many blue holes are connected to submerged cave passages. Blue holes may contain freshwater, however, due to tidal influences and high surface evaporation, mixing between freshwater and salt water often occurs at the boundary within an aquifer.[208] Therefore, blue holes may be saltier than the surrounding groundwater. Some of the well known Bahamian blue holes include James Cistern (Eleuthera), Near Treasure Cay (Abaco), Rock Sound (Eleuthera), Mermaids Pool (New Providence), Church's (North Andros), Stargate (South Andros) and Dean's (Long Island).[209]

A salt pond occurs when evaporation exceeds precipitation and a standing body of brackish water may become hypersaline.[210] At certain salinities, algal growth is encouraged. As the salinity increases, algal growth is unfavorable and bacteria will feed on the dead algae. The pond will vary in color as the concentration of these pigmented-bacteria increase. Hypersaline ponds may be green, yellow, brown, red, or purple.[211] Some ponds develop thick algal mats, which can act as a barrier (aquiclude) between and underlying freshwater lens and the overlying hypersaline pond, preventing mixing between groundwater and hypersaline water.[212] Salt ponds are common on most of the southeastern islands such as the Inaguas, Mayaguana, Crooked and Acklins, where rainfall is less than 80 centimeters (cm) per year.

Due to the low relief, large areas of New Providence, Grand Bahama, Abaco and Andros Islands are inundated with water. These wetland areas are covered by shallow water, at least part of the year and are heavily influenced by the changing tides. Some of the dominant water features of the coastal wetlands include tidal flats, tidal creeks, lagoons, marshes, and swamps. These wetland features are not freshwater sources, as much of the water is brackish.[213]

For The Bahamas, the relationship between ground water and wetlands is still not fully understood, or at least adequately documented. Aside from their support of biodiversity, the importance of their point of exchange between ground water and the atmosphere through precipitation, infiltration, ex-filtration, and evapotranspiration has not successfully been documented.

Wetlands play a beneficial role in pollution control, the retention of peak run-off flows, and erosion and sediment control. On Andros, Abaco, and Grand Bahama, the coastal wetlands (mangroves) are believed to protect inland areas (including the freshwater resources) from the inundation of salt water. The National Wetlands Committee is presently evaluating guidelines to promote the conservation and wise use of wetlands, provide a framework for wetland inventory, and produce guidelines to encourage local participation in the management of wetlands.

Wetlands are nursery areas for bonefish, crawfish, shrimp, crabs, and numerous export fish species. Increasing development over the years has resulted in a decline of healthy wetland ecosystems. The absence of wetlands policy causes a lack of protection and conservation. The National Wetlands Committee undertook public consultation in August and September 2004 for a National Wetlands Policy. As of January 2004, The Bahamas has responsibility for the Caribbean position on wetlands. Lake Rosa in Inagua National Park is a Ramsar Wetland of International Importance.

# B. Ground Water Resources

The major source of freshwater is from wells. However, the availability of ground water is highly variable. Freshwater is often barged from islands with ample ground water supplies, such as Andros, to islands with inadequate fresh ground water resources. As a Caribbean nation, The Bahamas is susceptible to storm damage from tidal surges and flooding from hurricanes, which can have dramatic effects on the ground water supply. Hurricane Frances in 2004 did considerable damage to the ground water lens aquifers on North Andros, impacting about half of the fresh water supplies for New Providence. At time of press, it is expected that the lens will recover over time. Hurricane Frances and Jeanne in 2004 impacted the well fields on Grand Bahama Island. It is expected that the wells will recover, over time. Hurricane Jeanne passed directly over Abaco and did considerable damage. At time of press, the extent of the damage was not known. The islands in the southeastern Bahamas are also prone to seasonal drought. On New Providence, which is home to over two thirds of the country's population, ground water resources are threatened by pollution from anthropogenic activities. In an effort to combat these vulnerabilities, the Government of The Bahamas utilizes RO (a method of desalination) systems on many islands to supplement or replace ground water sources.

Ground water resources are considered easy to extract. Water is primarily obtained using the following methods: (a) shallow hand-dug wells, (b) hand or electric pumps in uncased wells, and (c) trenches and pits. It is extremely important to note that all ground water extraction rates included in this report refer to the capacity of one borehole and that in order to obtain large quantities of water, a network of boreholes and/or trenches should be used. Also, close attention should be given to recommended drawdown heights for each island and salinities should be monitored frequently to make sure freshwater lenses are not contaminated from upconing of seawater. Proper management of pumping wells is crucial for protection against saltwater intrusion, which ruins the wells and the aquifer.

During hurricanes, particularly Hurricane Frances, the trenching network on North Andros caused the entire system to become inundated with saltwater. The trenches served as conduits for seawater passage during the hurricane, from the western trenches throughout the entire system. To prevent this occurrence in the future, the system should be isolated, with the trenches separated from each other. Installed valves in each cruciform/chamber should be used to cut off the system.

## 1. Aquifer Definition and Characteristics

To understand the concepts of ground water hydrogeology and where the most likely sources of water may be located, short aquifer definitions and aquifer characteristics are presented followed by specific country attributes.

Ground water supplies are developed from aquifers, which are saturated beds or formations (individual or group), which yield water in sufficient quantities to be economically useful. To be 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 a borehole, at any one location. Ground water exists in many types of geologic environments, such as intergrain pores in unconsolidated sand and gravel, cooling fractures in basalts and other volcanic rocks, 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 limestone and volcanic rock, water cannot flow, for the most part, through the mass; the only water sufficient to produce usable quantities of water may be through the 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 permeability) 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 with water flowing through the fractures, then the borehole could yield sufficient water to be economically useful.

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, or, as is the case in The Bahamas, the mean sea level. The water table fluctuates in response to seasonal and daily factors. As expected, the water table rises during the rainy season and falls during the drier seasons. The depth of the water table is also affected by evaporation, barometric pressure changes, and ocean tides. Since rainwater is the sole source of freshwater in The Bahamas, aquifer recharge is controlled primarily by the quantity and distribution of rainfall, as well as vegetation, topography, and the permeability of surface materials.

## 2. Hydrogeology

The islands are part of an extensive archipelago of carbonate islands and shallow banks, generally less than 10 m thick.[214] Although the islands are predominantly low-lying, eolianite ridges, or dunes formed over time by wind action, with heights of up to 30 m (98 ft) are found on most major islands. The infiltration of rainwater through the porous bedrock resulted in the dissolution of the carbonates underlying the islands and the creation of a karst landscape. Karstic features commonly found include sinkholes, caves or solution cavities known as banana holes, and stalactites (or other dripstone features).

Freshwater is extracted from lenses that occur in the Pleistocene and Holocene limestone and limesand aquifers. Freshwater lenses form when rainwater seeps through the porous surface material and upon reaching the water table, it slowly spreads outwards toward the sea, or, downwards to mix with saline water.[215] Freshwater is less dense than the saline seawater and will float on top of it within the pores of the rock. The rock acts as a reservoir (aquifer) for the freshwater and impedes its movement and therefore mixing of freshwater with salt water. This layer of freshwater derived from rainfall is known as a lens, due to its lens-like shape. The lens will also include a zone of brackish water between the upper layer of freshwater and bottom layer of salt water.[216]

a. Holocene sands aquifers (unconsolidated, loose sands)

Holocene sands comprise many of the coastal areas of the country. These well-sorted sands are fine-grained, oolitic in some areas, and highly porous, however, the pores are very small and surface tension is high. These characteristics allow the sands to retain small quantities of freshwater, even in close proximity to the seawater. Freshwater yields, when available, are small in these aquifers. Although these aquifers are not a significant source of freshwater on large islands such as Grand Bahama and Andros, thick deposits of Holocene sands accumulate along the coasts of windward islands, such as Eleuthera, Cat Island and Exuma, and provide important sources of freshwater.[217]

b. Lucayan Limestone aquifers

The principal aquifer on most Bahamian islands is the Pleistocene-aged Lucayan Limestone. The aquifer is comprised of poorly-stratified, oolitic limestone. The freshwater bodies that occur in this unit are known as Ghyben-Hertzberg lenses after the two hydrologists who first described their occurrence in coastal areas (See Figure 5).[218] Ghyben-Hertzberg lenses in the country are composed of three lateral zones: (1) a fresh section (freshwater lens in Figure 5) where the chloride content ranges from 90 to 400 ppm; (2) a transition zone, approximately 1-2 m thick, in which chlorides increase rapidly from 400 to 1,200 ppm; (3) a saline portion (salt water zone in Figure 5) in which chlorides increase from 1,200 ppm to levels approaching seawater.[219] Rainwater is the only source of freshwater for this aquifer, therefore the amount of rainfall coupled with geological constraints, determines the size and extent of freshwater lenses. In the southern Bahamian islands, where annual rainfall is less than 900 mm, saline and brackish lenses form, in lieu of freshwaterlenses. The islands tend to be low-lying, and direct evaporation from the water table can occur. Much like the formation of salt ponds, evaporation exceeds precipitation, resulting in high chloride concentrations in the lenses. Saline or brackish lens development in lieu of freshwater lens development, is common on Mayaguana, Great Inagua, Long Island, Crooked Island, and Acklins Island.[220]

The base of the Lucayan Limestone is accepted as the maximum thickness to which a freshwater lens can develop. The aquifer has an average maximum thickness of 43 m (141 ft) on Andros Island and an average minimum thickness of 10.5 m (34 ft) on Mayaguana Island (See Table 4).[221]

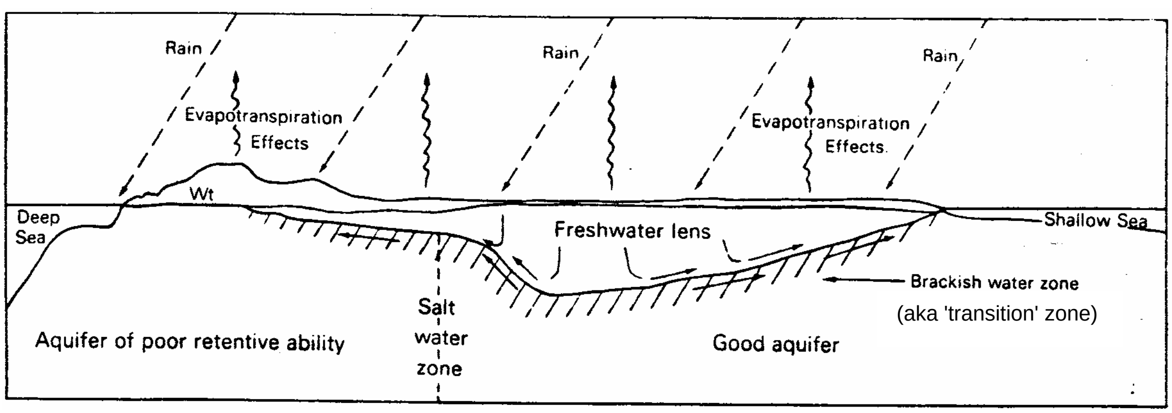


**Figure 5. Schematic of Ghyben-Hertzberg Lens**

Source: B. G. Little et al., *Land Resources of the Bahamas: A Summary*, Surrey, England: Land Resources Division, Ministry of Overseas Development, 1977, pp. 35.

**Table 4. Thickness and depth measurements of the Lucayan Limestone[222]**

| Location | Average thickness of Lucayan Limestone (m/ft) | Depth (below mean sea level) to base of Lucayan Limestone (m/ft) |
|---|---|---|
| Andros Island and Great Bahama Bank | 43 / 141 | 43 / 141 |
| Long Island | 40 / 131 | 38 / 125 |
| San Salvador | 35 / 115 | 32 / 105 |
| Hogsty Reef | >21 / >69 | >31 / >102 |
| Great Inagua | 29 / 95 | 28 / 92 |
| Crooked-Acklins Bank | 25 / 82 | 21 / 69 |
| Grand Bahama Island and Little Bahama Bank | 24 / 79 | 21 / 69 |
| Mayaguana | 10.5 / 34.4 | 3 / 10 |

## 3. Forestry and Deforestation, and Impacts on Ground Water Resources

Deforestation has been a problem in the past. Some tree species nearly became extinct. Hardwoods were exploited beginning in the 1600's. As a result of their extensive exploitation over the years, few mature hardwood trees exist today.[223,224] Exploitation of the pine forests began in 1906, ending in the 1970's. This indiscriminate type of clearing was not considered 'sustained yield practices', acceptable to current standards and practices. The forestry sector today practices environmental management and conservation. Public attitude changed in the 1980's towards more sustainable forest practices.[225] Threats to the forests now are fires, indiscriminate tree clearing for development (urbanization), severe weather, and competition from exotic species which reduces the native vegetation.[226] Long-term sustainability of the forests, however, is also threatened due to understaffing of the forestry department, and the absence of a Forestry Act.[227]

Today, there are four categories of forests in the country: 1) pine; 2) coppice; 3) dwarf drought-resistant woodlands; and 4) mangrove swamps.[228,229] The northern islands have large pine forests. The Central islands have broadleaf hardwood forests (coppice), and the southern islands have dwarf drought-resistant woodlands.[230] The mangrove forests occur mainly on the lee shores, with the major mangrove forests occurring on the North Coast of Grand Bahama, Western Andros Island, The Marls of Abaco Island, and the Bight of Acklins Island. The total area of mangroves and other wetlands is over 4,000 $km^2$ (1,600 $mi^2$).[231]

The absence of land use planning, particularly for long-range planning for sustainable development has created problems in the competing uses of the forest. Agriculture is the main competition. Urbanization and tourism are other major competing users. The rapid expansion of the economy has placed tremendous pressures on the land resources.

The forestry sector is comprised of several components, including commercial forestry, charcoal production and handicrafts, the reservation and protection of freshwater resources, soil conservation, biological diversity, bush medicine, microclimate regulation and climate change, recreation and eco-tourism and national park establishment.

The northern pine forests are above the majority of the freshwater reserves for the country.[232] Forest cover over the ground water lenses play an important role in absorption and storage of the rainwater, but the extent of the role is unknown. It is believed that loss of forest cover would create a loss of water resources. Deforestation due to urbanization over important freshwater lenses would lead to contamination of the water resources. This is a concern in North Andros where very important and substantial freshwater lenses exist. These lenses provide a substantial amount of water to New Providence. Incidences of encroachment have occurred in these wellfields. On Abaco, important wellfields need expanding, but nearby developments have precluded expansion.

Since forest exploitation of the pine forests ceased in the 1970's, there are no primary forest industries. The pine forests can support small local forest industries, such as sawmilling, fuel, utility poles, charcoal, etc.  High value products such as furniture, joinery, and constructional timber are also possible from the pine forests. The Bahamas imports a substantial quantity of timber and timber product imports, so forest industries could make a great contribution to socioeconomic development.[233] However, these industries, and encroachment by agriculture, tourism, and urbanization in general would probably be at the expense of the water resources, the environment, ecotourism, etc., having a counter-economic effect.

Extensive damage to forest cover occurred on some islands during Hurricane Floyd. As many as 5 out of 10 trees were destroyed. Forestry resources data has been collected since the early 1980's, but a critical need exists to monitor forest and mangrove changes from climatic events and changes.

The Bahamas National Trust was established in 1959.  It is a NGO devoted to the conservation and management of the country's natural and historic resources. One achievement of the Trust over the years has been the protection of hundreds of thousands of acres of wetlands, forests and islands.[234] The main objectives of the Trust are to expand the acreage in the National Park System and to focus on protecting ecosystems. This objective was achieved in April 2002 when the government recognized new parks, which doubled the size of the National Park System.[235] Ten new parks were created, protecting both marine and terrestrial land, The estimated total area of the Bahamanian National Parks is now 700,000 acres, including marine ecosystem areas.

Central Andros National Parks were created in April 2002.  Andros has the country's largest freshwater reserves. The area is now protected under the National Park System.  Among the areas protected are the blue holes, portions of the Andros Barrier Reef, and many mangrove areas.[236] Abaco also has a great reserve of freshwater. Abaco National Park encompasses 20,500 acres of the southeast portion Great Abaco Island, including 5,000 acres of forest land.[237]

# C. Water Quality

## 1. Surface Water Quality

Most of the surface water features contain brackish to saline water.  On Eleuthera and all the major islands south of Eleuthera, evaporation exceeds rainfall and ponds and lakes are hypersaline. The northern island ponds and lakes are usually brackish and often contain chloride concentrations less than 2,000 ppm.[238] Some lakes do contain chloride concentrations below 400 ppm, especially on the larger islands where many ponds are underlain by freshwater lenses.[239] These ponds should be considered surface “exposures” of groundwater lenses where evaporation has resulted in higher than normal chloride concentrations.[240] Pollution of surface water sources is not a major concern, as surface water is not used for water supply.

## 2. Ground Water Quality

Ground water quality is generally fresh, except on New Providence Island, where over sixty percent of the population reside. The capital city, Nassau, is located on New Providence, a small island with an area of only 207 sq km (80 sq miles). The water table is within a few feet of the surface, thus making the ground water vulnerable to contamination from untreated sewage, industrial wastes, and leaking fuels. This is especially dangerous for residents who obtain their water from hand-dug wells in their backyards. Only twenty percent of households in Nassau are connected to the central sewage system.[241] The remaining homes collect sewage in individual septic systems. Many of these systems do not meet building codes and consist of an open pit in the ground where contaminants are prone to infiltrate the groundwater. Ground water quality studies in residential areas of Nassau conducted by the Water and Sewage Corporation through the period of 1991 to 1994 reported elevated levels of nitrates, phosphates, fecal coliforms, and other bacteria.[242] Bulk fuel storage and dispensing sites are major sources of ground water contamination from industrial wastes such as solvents, hydraulic fluids, lubricants, fuels, and heavy metals.[243]

The biggest threat to ground water resources is contamination by saltwater intrusion due to two causes: (1) storm surges resulting from hurricanes and (2) over-pumping of freshwater aquifers. Since many of the islands are low-lying, storm surges, coupled with heavy rains, can cause widespread flooding. Ponding of seawater above freshwater aquifers results in increased and persistent levels of salinity until rainwater recharges and dilutes the ground water. Most recently, the well fields on Grand Bahama Island and North Andros were flooded with seawater and showed sharp increases in salinity after storm surges produced by Hurricane Floyd in 1999,[244] and Hurricane Frances in 2004.[245] Hurricane Jeanne in 2004 also caused significant damage to the aquifers on Grand Bahama and Abaco.[246]

The intrusion of seawater into an aquifer due to excessive pumping can cause significant damage to a freshwater lens because the amount of freshwater is reduced and replaced with seawater. Continued pumping will result in the upconing of saltwater and contamination of the lens (See Figure 6). Pumping stations are monitored to control the rate and amount of extraction, however, domestic or hand-dug wells are not controlled and saltwater intrusion is a concern in densely populated areas such as Nassau. A related problem is the construction of canals and docks for marinas. Canals connect to the ocean and allow seawater to penetrate inland at the surface.[247] Seepage of saltwater into the freshwater lenses occurs unless the canals are lined.

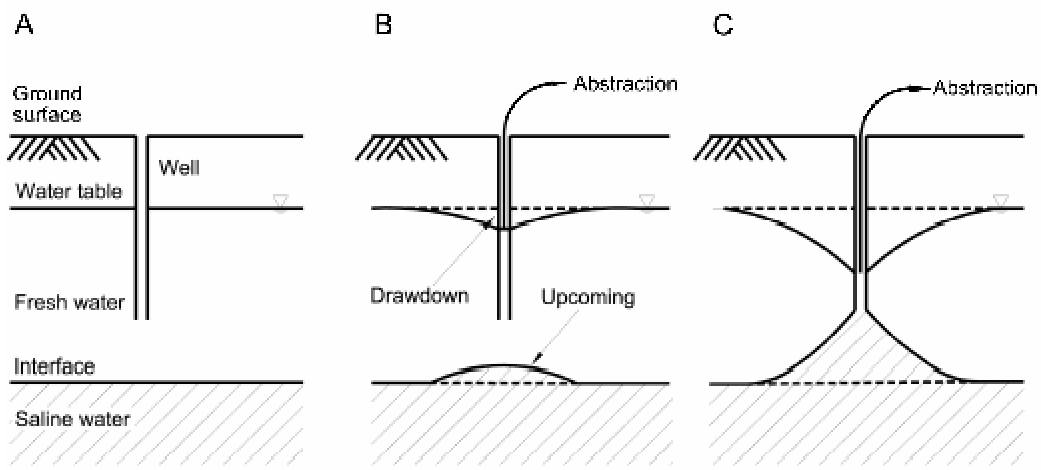


**Figure 6. Diagram Illustrating Upconing of Seawater[248]:** (A) A cross-section through limestone rock, with a layer of fresh ground water lying on top of saline water, with a well drilled into the freshwater section of the aquifer. (B) As water is pumped from the well, the water level in the well will be lowered. The distance between the pumped water level and the original rest water level is known as the drawdown. The lowering of the water table causes the boundary between the fresh and saline water to rise slightly, a phenomenon known as upconing. (C) The more the water table is lowered, the more upconing there will be. If the upconing becomes more than about a third of the distance from the base of the well to the original fresh-saline interface, the cone may become unstable, and rise abruptly to the base of the well, causing the underlying saline layer to "breakthrough" the interface.

The salinities in the North Andros wellfields increased from 330 mg/L in May 2004 to as much as 15,000 mg/L after the passage of Hurricane Frances in September 2004. However, the ground water lens did not become permanently compromised. The trenching system through the wellfields caused the entire system to be inundated with saltwater. A remedy would be to isolate the system, separating the trenches from each other using valves in each cruciform/chamber. A long-term solution would be to run perforated pipe along the length of the bottom of the trenches and backfill all trenches. This would prevent a direct exposure of the vulnerable lens to the elements. To correct this saltwater inundation, a tremendous increase in pumping was conducted to induce rapid recharge from the underlying resources.

It is desirable to use the freshwater lens aquifers for the water supply of the country in lieu of RO. As a result, priority is given to conserve and using the ground water over reserve osmosis.

# V. Water Resources by Island Summary

## A. Introduction

This chapter summarizes the water resources information for The Bahamas, which can be useful to water planners as a countrywide overview of the available water resources. Figures C-1 through C-3, Water Resources, divide the country into surface water and ground water categories identified as map units 1 through 6. Table C-1, which complements figures C-1 through C-3, details predominant surface water and ground water characteristics of each map unit including aquifer materials, aquifer thickness, yields, quality, and depth to water. A summary based on this information is provided for each of the major islands.

## B. Water Conditions by Map Unit

Figures C-1 through C-3 divide the country into six map unit categories based on water quantity, water quality, and aquifer characteristics. Map unit 1 depicts areas where fresh ground water is generally plentiful in moderate to enormous quantities. These areas appear, at a country scale, to be the most favorable areas for ground water exploration. Map units 2 and 3 depict areas where fresh ground water is locally plentiful, ranging from unsuitable to large quantities. At the local level, these areas might be suitable for ground water exploration but will require additional site-specific investigations. Unsuitable quantities of freshwater are available from map unit 4 areas, as freshwater is scarce or lacking. Map units 5 and 6 depict surface water features such as ponds and wetlands.

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

Quantitative Terms:

| | |
|---|---|
| Enormous | $\geq$ 6 liters per second (L/s) (100 gallons per minute (gal/min)) |
| Very large | $\geq$3 to 6 L/s (50 to 100 gal/min) |
| Large | $\geq$1.5 to 3 L/s (25 to 50 gal/min) |
| Moderate | $\geq$0.6 to 1.5 L/s (10 to 25 gal/min) |
| Small | $\geq$0.25 to 0.6 L/s (4 to 10 gal/min) |
| Very small | $\geq$0.06 to 0.25 L/s (1 to 4 gal/min) |
| Meager | $\geq$0.015 to 0.06 L/s (0.25 to 1 gal/min) |
| Unsuitable | < 0.015 L/s (0.25 gal/min) |

Qualitative Terms:

| | |
|---|---|
| Freshwater | = maximum TDS <1,000 mg/L; maximum chlorides $\leq$600 mg/L; maximum sulfates ($SO_4$) $\leq$300 mg/L |
| Brackish water | = maximum TDS $\geq$1,000 mg/L, but $\leq$15,000 mg/L |
| Saline water | = TDS >15,000 mg/L |

Ground water is primarily obtained using the following methods: (a) shallow hand-dug wells, (b) hand or electric pumps in uncased wells, and (c) trenches and pits. It is extremely important to note that all ground water extraction rates included in this report refer to the capacity of one borehole and that in order to obtain large quantities of water, a network of boreholes and/or trenches should be used. Also, close attention should be given to recommended drawdown heights for each island and salinities should be monitored frequently and properly managed to make sure freshwater lenses are not contaminated from upconing of seawater.

## C. Water Conditions by Island

The following section is compiled for each major island from figures C-1 through C-3 and table C-1. 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-3 and Table C-1. 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. Also large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities.

Freshwater lens thicknesses and pumping rates are based on a study conducted by B.G. Little et al. in 1977 titled, “Land Resources of the Bahamas”. Therefore, the data and information are from the mid 1970's and earlier. It is highly possible that lens thicknesses may have decreased since 1977 due to ground water exploitation.

The population and area data that are included at the beginning of the island write-ups that follow are from information provided by the Central Statistical Office in Nassau in July 2003.

All of the islands are not included in the following section. The uninhabited islands, and other islands, such as Bimini, Harbour Island, Spanish Wells, Ragged Island (Cay), Rum Day, Long Cay and the Berry Islands are excluded. The latter named islands each have total land area that is less than 15 $mi^2$. These same islands are not discussed in the Land Resources Study from 1976. Typically, Harbour Island and Spanish Wells are grouped with Eleuthera, Long Cay with Acklins & Crooked Island, Bimini and the Berry Islands, and Rum Cay with San Salvador.

# Abaco Island

**Area:** 649 $mi^2$ (12% of total area)

**Estimated Population (2000):** 13,174 (4.3% of the total population)

**Population Density:** 20.3 people per square mile

**Largest City:** Marsh Harbour

**Location:** One of the northernmost islands, Abaco is located approximately 1,617 km (1,005 miles) north of Nassau and 282 km (175 miles) east of Palm Beach, FL. Grand Bahama Island, the closest Bahamian island, is approximately 135 km (84 miles) east of Abaco.

## Surface Water

Nearly three quarters of the average annual rainfall occurs during the rainy season, which extends from May through October. Average annual precipitation is approximately 1,010 mm (40 inches).[249] The terrain of Abaco Island is largely flat and rocky. Surface water bodies cover less than 2% (Map Unit 5) of the island and include blue holes, man-made lakes, and ponds. Six blue holes were discovered on Abaco. A blue hole near Treasure Cay airport measured 57 m (186 ft) in depth and has a 15 m (50 ft) column of freshwater overlying saline water.[250] The depth of this blue hole is comparable to a large freshwater lens and may provide meager yields of water. It should not be considered a primary source of freshwater. The depths of the remaining blue holes on Abaco range from 10.4 to greater than 46 m (34 to greater than150 ft).[251]

In the mid-1970's, man-made ponds resulted from the removal of limestone to provide material for road construction. Many of the pools penetrate a couple meters below the water table and may be 30 m (100 ft) or so in diameter. These surface water bodies should not be used as primary water sources. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Abaco Island possesses good freshwater resources from the Lucayan Limestone aquifer lenses. Very large to large quantities of water are available from four relatively large freshwater lenses: (a) Normans Castle, (b) Marsh Harbour – Lake City, (c) Lake City – Crossing Rocks, and (d) Crossing Rocks – Hole in the Wall.[252] The lenses vary in thickness and the water table is between 0.6 and 6 m (2 to 20 ft) below the surface.[253] The lens at Norman's Castle reaches a maximum thickness of 16.8 m (55 ft) and one borehole can produce a maximum yield of 3.8 L/s (60 gpm).[254] The area between Marsh Harbour to Lake City Lake is well developed with regards to ground water resources, as this lens serves the population of Marsh Harbour and its surrounding communities. The lens also reaches a maximum thickness over 15 m (50 ft) and each borehole can produce yields between 2 – 3 L/s (30 – 45 gpm).[255] The lens extending from Lake City Lake to Crossing Rocks has a maximum thickness of 13.7 m (45 ft) and thins southward where the water becomes brackish near Guinea Schooner Bay.[256] Maximum yields in this area are 2 L/s (30 gpm). The area between Crossing Rocks and Hole in the Wall contains a thick (12 – 18 m) and extensive freshwater lens that may produce yields greater than 2.5 L/s (40 gpm).[257] This unit (Map Unit 1), which covers approximately 33% of the total island area, is suitable for hand pumps. Given the geological conditions, uncased boreholes should be used to abstract ground water from the limestone aquifer. Also, abstraction should be spread over many boreholes. A series of test boreholes should be drilled to confirm not only the presense and extent of the lens, but also the depth of the salt water/ freshwater interface.[258] Table 5 presents suggested borehole depths based on the original thickness of the lens and water column. Also, pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft) for lens greater than 9 m (30 ft) thick and 0.003 m (0.01 ft) for lens less than 9 m (30 ft) thick.[259]

**Table 5. Recommended borehole depths for Abaco Island**[260]

| Orginal lens thickness (m/ft) | Depth of water in borehole below the water table (m/ft) | Location |
|---|---|---|
| 18 - 22/ 60 - 70 | 5 - 6/ 17 - 20 | Crossing Rocks to Hole in the Wall |
| 15/ 50 | 4/ 13 | Normans Castle<br><br>Marsh Harbour to Lake City |
| 12/ 40 | 3/ 10 | Normans Castle<br><br>Lake City to Crossing Rocks |
| 9/ 30 | 2/ 7 | South of Cedar Harbour |
| 6/ 20 | 1.5/ 5 | Treasure Cay to Dundas Town |
| > 6/ 20 | 1/ 3 | Coastal sand aquifers, scattered throughout the island (see Figure C-5) |

Very small to meager quantities of water are also available from:

(a) smaller lenses on Little Abaco, south of Cedar Harbour (Map Unit 2),

(b) lenses in areas between between Treasure Cay and Dundas Town (Map Unit 2), and

(c) coastal Holocene Sand aquifers (Map Unit 3).

Water quality is saline to brackish, however freshwater may occur is certain places. These sources may not be suitable for tactical purposes. Map Units 2 and 3 comprise approximately 4% and just less than 2% of the total island area, respectively. Approximately 60% of Abaco island is unsuitable for ground water development (Map Unit 4). Chemical or biological contamination of the aquifers has not been reported for Abaco Island.

In 2004 Hurricane Jeanne passed directly over Marsh Harbour, causing considerable damage to the freshwater lens aquifer. At time of press, the extent of the damage was not known.

# Acklins Island

| | |
|---|---|
| **Area:** | 192 mi$^2$ (3.5% of total area) |
| **Estimated Population (2000):** | 423 (0.1% of the total population) |
| **Population Density:** | 2.2 people per square mile |
| **Largest City:** | Snug Corner |
| **Location:** | Acklins Island is one of the southern most Bahamian islands. It is located 600 km southeast of New Providence and its closest neighbors are Crooked Island, located just a few kilometers to the north, Long Island to the northwest and Mayaguana Island to the southeast. |

## Surface Water

Acklins Island is long, narrow and hilly and has numerous caves and bays along its western shores.[261] Both Acklins and Crooked Islands are enclosed in a shallow lagoon known as the Bight of Acklins. Surface exposures of ground water (Map Unit 5) are common on Acklins, normally in the form of shallow reddish-colored hypersaline ponds.[262] Some ponds contain cavern systems and blue holes. Two blue holes sampled south of Morant Bay contained brackish water. Acklins Island received significantly less rainfall than the Bahamian islands to the north. Annual rainfall averages 76 cm (30 inches). Nearly all surface water bodies remain brackish, saline, or hypersaline due to low rainfall and high evaporation. Surface water features (Map Unit 5) and northweastern wetland areas (Map Unit 6) comprise 4% and 17% of the total area of the island, respectively. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Very small to moderate quantities of freshwater are available from the Lucayan Limestone lenses located (a) west of Hardhill and Andersons, (b) between Spring Point and Delectable Bay, and (c) south of Pompey Bay and Morant Bay. The Spring Point-Delectable Bay and Pompey Bay lenses have maximum thicknesses of 9 m (30 ft), however, the thickness of the Hardhill-Andersons lens could not be found. The depth to the water table is approximately one or two meters from the surface. A conservative estimate of the maximum pumping rate for these lenses is 1 L/s (15 gpm). Also, pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft) for lenses greater than 9 m (30 ft) thick and 0.003 (0.01 ft) for lenses less than 9 m (30 ft) thick.[263] This unit (Map Unit 2) is suitable for hand pumps and uncased boreholes and abstraction should be spread over many boreholes. Very small to meager quantities are available from a small lens (Map Unit 2) just south of Pinefield Point. This lens is 5 m (16.5 ft) thick and the water table is within 3 m (10 ft) of the surface. Specific capacties are relatively high and this lens could be a limited source of potable water.[264] Map Unit 2 comprises 13% of the total island area. Note that large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities.

Holocene sand aquifers (Map Unit 3) are present at Chesters and along the western coast of Cold Rock. The lens at Chesters is slightly less than 3 m (10 ft ) thick and the water table is within a meter or two of the surface. Only meager quantities of freshwater are available at

Chesters. Large diameter, shallow hand dug wells should be used to extract the ground water in this sandy area.[265] The lens at Cold Rock is thought to be more than 2 m (6.5 ft) thick, however, sources suggest it is unsuitable for exploration.[266] These lenses are unsuitable for hand pump or bucket wells.[267] The sandy aquifers of Map Unit 3 comprise 2% of the total island area. Nearly two-thirds of the island (64%) is unsuitable for ground water exploration (Map Unit 4). Chemical or biological contamination of the aquifers has not been reported for Acklins Island.

# Andros Island

**Area:** 2,300 mi$^2$ (43% of the total area)

**Estimated Population (2000):** 7,615 (2.5% of the total population)

**Population Density:** 3.3 people per square mile

**Largest City:** Andros Town

**Location:** Andros is the largest of the Bahamian islands, nearly ten times larger than New Providence. The island is located approximately 65 km (40 miles) west of Nassau and 320 km (200 miles) off the southern coast of Florida.

## Surface Water

Andros is the largest Bahamian island, however, it comprises a number of separate islands and is often classified as North and South Andros, separated by North Bight. North Andros has a well-defined coastal ridge, which reaches just over 30.5 m (100 ft), and exceeds 18.3 m (60 ft) at many locations north of Fresh Creek. Apart from the east coast, little of North Andros exceeds 6 m (20 ft) in altitude. The interior is flat and heavily forested with pine trees. North Andros receives about 150 cm (60 inches) of rain a year, which helps to recharge the large ground water lens on the island. Similar to North Andros, the islands of South Andros have a coastal ridge reaching 27.4 m (90 ft) in height and the interior of the islands is flat and forested.[268] South Andros is much drier than North Andros, receiving just fewer than 100 cm (40 inches) of rain annually.

Surface water bodies most prevalent on Andros are (a) ponds or lakes occupying topographic lows, (b) marsh areas and creeks, (c) blue holes, (d) lagoons, and (e) man-made features. Conversely to other Bahamian islands, many of the ponds and lakes of Andros may contain freshwater during the months of May through October, where precipitation is it's highest. The ponds and lakes (Map Unit 5) occur in low-lying areas and in marshes where the topography locally or seasonally is intersected by the water table.[269] The salinity of the ponds vary seasonally and is related to the amount of recharge by ground water, rainfall, and evaporation. Marshes and small creeks, or swashes, are found on North Andros and dry up during the winter. Larger creeks such as Stafford Creek, London Creek, and Fresh Creek are occupied throughout the year.[270] The water table in these areas is usually within a meter of the surface.[271] There are at least 118 blue holes on North Andros north of North Bight, and approximately half as many on Mangrove Cay and South Andros.[272] Many of the blue holes are deep enough to penetrate the underlying freshwater lens and may be a source of potable water. Saline and hypersaline lagoons can be found on South Andros, but are not common on North Andros. Finally, man-made features such as trenches and canals may appear to contain freshwater, however, these are areas where the water table has been exposed to the surface. Surface water features (map Unit 5) comprise 11% of the total island area. The wetland areas (Map Unit 6) on North Andros comprise about 6% of the total island area. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Very large to enormous quantities of freshwater are available from the Lucayan Limestone aquifers (Map Unit 1). The lenses reach a maximum thickness of 43 m (141 ft) in some areas and the water table is within a meter or two of the surface. Recommended pumping rates for boreholes within lenses greater than 12 m (40 ft) in thickness are between 3 – 6.5 L/s (50 to 100+ gpm). Very small to large quantities of freshwater are available from lenses (Map Unit 2) less than 10 m (33 ft) in thickness. These lenses are found near Red Bay (northeast Andros), Stafford Creek (eastern and cental Andros) and The Bluff Settlement (southeastern Andros). Map Units 1 and 2 comprise 18% and just under 2% of the total area of Andros, respectively. Pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft).[273] This unit is suitable for hand pumps and uncased boreholes and abstraction should be spread over many boreholes. Table 6 presents the specific capacity (the rate of discharge of a well per unit of drawdown), recommended pumping rates, drawdown and distance required between each borehole with regards to thickness of the freshwater lens.

**Table 6. Relevant parameters for ground water on Andros Island**[274]

| Thickness of freshwater lens m (ft) | Range of Specific Capacities (gpm/ft) | Recommended pumping rate per bore hole L/s (gpm) | Drawdown for each borehole m (ft) | Distance required between boreholes m (ft) |
|---|---|---|---|---|
| 12 – 37 (40 – 120) | 1000 + | 6.5 (100 +) | 0.03 (0.10) | 78 (257) |
| | 1000 – 500 | 6.5 – 3 (100 – 50) | | 78 – 39 (257 – 128) |
| | 500 – 100 | 3 – 0.6 (50 – 10) | | 39 – 8 (128 – 26) |
| 6 – 9 (20 – 30) | 1000 + | 6.5 (100 +) | 0.03 (0.10) | 87 (288) |
| | 1000 – 500 | 6.5 – 3 (100 – 50) | | 87 – 44 (288 – 144) |
| | 500 – 100 | 3 – 0.6 (50 – 10) | | 44 – 9 (144 – 29) |
| 3 (10) | 500 + | 3 (50) | 0.03 (0.10) | 51 (167) |
| | 400 – 200 | 2.5 – 1.2 (40 – 20) | | 41 – 20 (134 – 67) |
| | 200 – 100 | 1.2 – 0.6 (20 – 10) | | 20 – 10 (67 – 33) |
| | 100 – 50 | 0.6 – 0.3 (10 – 5) | | 10 – 5 (33 – 17) |
| | 50 – 25 | 0.3 – 0.16 (5 – 2.5) | | 5 – 2.5 (17 – 8.3) |

Further recommendations for ground water abstraction on Andros include:[275]

1. Drill a borehole through the entire thickness of the lens in order to determine the maximum thickness of the freshwater zone. The borehole should be sampled at various depths for at least 10 days and then backfilled to above the freshwater-salt water interface and left open for abstraction.

2. Specific capacity tests of 30 or 60 minutes should be conducted to determine the appropriate abstraction rate.

3. Drawdown should not exceed 0.03 m (0.10 ft) and should be monitored during abstraction. Water levels and salinity should also be routinely monitored.

4. Production borehole should be spaced uniformly over the areas and pumped 24 hours a day continuously.

Holocene sand aquifers (Map Unit 3) along the coast of southern Andros have not been exploited, however, their location near the sea suggests the ground water is likely brackish to saline. The water table is within a meter or two of the surface. These aquifers are unsuitable for large-scale ground water extraction. Map Unit 3 comprised less than 1% of the total area of Andros.

The remote areas (Map Unit 4) in western and southern Andros comprise 64% of the total island area and have not been explored for ground water development. These areas are dominated by wetlands and are not easily accessible for ground water extraction. Chemical or biological contamination of the aquifers has not been reported for Andros Island.

In 2004, Hurricane Frances caused significant damage to the aquifer. Corrective action is being conducted by pumping great volumes, to induce rapid recharge from the underlying resources. The storm surge impacted about 1/2 of the water resources for barging to New Providence. The ground water lens was not, however, compromised beyond repair. The trenching system exacerbated the problem by serving as conduits for the passage of seawater throughout the system. The system should be isolated, by using valves. A long term solution would be to run perforated piping along the trench length bottom, backfilling all trench areas. This design would eliminate direct exposure of the underlying lens to the elements.

# Cat Island

| | |
|---|---|
| **Area:** | 150 $mi^2$ (2.8% of the total area) |
| **Estimated Population (2000):** | 1,548 (0.5% of the total population) |
| **Population Density:** | 10.32 people per square mile |
| **Largest City:** | Arthurs Town |
| **Location:** | Cat Island, located in the central Bahamas, is approximately 176 km (110 miles) southeast of New Providence. Its closest neighbors are Eleuthera Island to the northwest and San Salvador Island to the southeast. |

## Surface Water

Cat Island is long and narrow, stretching from the northwest to southeast. This island is home to the highest point in the country, Mount Alvernia, which stands 63 m (206 ft) above sea level. The terrain varies from flat to rolling hills. Annually, Cat Island receives 86 cm (34 inches) of rain. Wetlands (Map Unit 6) are prevalent along the southwestern coast of Cat Island. These areas are likely saline due to their proximity to the ocean and comprise about 9% of the total area of the island. Some ponds (Map Unit 5) also occur on the northern and southern ends of the island. These features are expected to be brackish and may also be saline during the drier winter months if evaporation exceeds precipitation. Map Unit 5 comprises 6% of the total area of the island. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Moderate quantities of freshwater are available from the limestone lens (Map Unit 2) between McQueens Settlement and Devils Point and the lens just north of Freetown Settlement.[276] The maximum thickness of the McQueens Settlement/Devils Point and Freetown lenses are 15 m (50 ft) and 12 m (40 ft), respectively. This unit, covering over 20% of the total island area, is suitable for hand pumps and uncased boreholes and abstraction should be spread over many boreholes. Meager quantities of freshwater are available from the lenses near Arthurs Town and south of Old Bight. Although the lens is relatively thick (12 m or 40 ft) near Arthurs Town, the specific capacity is very low, limiting pumping rates to less than 0.06 L/s (1 gpm). Near Old Bight, the lens is much thinner (6 m or 20 ft).[277] Drawdown of 0.01ft may be necessary in lenses of 5 m or less.[278] The water table of these units is within a meter or two of the surface. For lenses thicker than 9 meters, ground water extraction is best accomplished using trenches and may not be suitable for military exercises.

Cat Island has extensive Holocene aquifers (Map Unit 3) along its coasts, which comprise approximately 10% of the total area of the island. The water table is within a meter or two of the surface. Meager amounts of freshwater may be available from the thicker aquifers, however, these aquifers have not been extensively studied. These areas are likely unsuitable without site-specific reconnaissance. Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are unsuitable for ground water development and comprise 55% of the total island area. Chemical or biological contamination of the aquifers has not been reported for Cat Island.

# Crooked Island

| | |
|---|---|
| **Area:** | 93 $mi^2$ (1.7% of the total area) |
| **Estimated Population (2000):** | 341 (0.1% of the total population) |
| **Population Density:** | 3.67 people per square mile |
| **Largest City:** | Colonel Hill |
| **Location:** | Crooked Island is located 410 km southeast of New Providence. Its closest neighbor is Acklins Island, which is located a few kilometers to the south. |

## Surface Water

Crooked Island is relatively flat and low-lying. Both Acklins and Crooked Islands are enclosed in a shallow lagoon known as the Bight of Acklins. Crooked Island receives slightly more rainfall than Acklins Island, with annual precipitation averaging 96 cm (38 inches). There are no streams on Crooked Island and water at the surface may be classified as either lagoons, flooded marsh areas, or blue holes.[279] The lagoons (Map Unit 6) contain hypersaline to saline water. Three blue holes have been identified on Crooked Island and the one near Church Grove was found to be 8.2 m (27 ft) deep.[280] Surface water features (Map Unit 5) and wetland areas (Map Unit 6) cover 1% and 18% of the island's total area, respectively. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Fresh ground water sources are limited on Crooked Island. Limestone lenses are relatively small and occur (a) between Church Grove and Colonel Hill, (b) between Fairfield and Moss Town, (c) near Majors Cay, and (d) at Bullets Hill. The aquifers most suitable for ground water extraction at the Church Grove/Colonel Hill and Fairfield/Moss Town lenses. Moderate quantities of water are available from the larger Church Grove/Colonel Hill aquifer. This lens is 9 m (30 ft) thick and the water table is within a meter or two of the surface. A conservative estimate of pumping rates from uncased boreholes in this area is 1 – 1.5 L/s (~20 gpm). Pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft) for lens greater than 9 m (30 ft) thick and 0.003 m (0.01 ft) for lens less than 9 m (30 ft) thick.[281] This unit (Map Unit 2) comprises 11% of the total island area and is suitable for hand pumps and uncased boreholes and abstraction should be spread over many boreholes. Although pumping tests have not be carried out for the Fairfield/Moss lens, a study of core lithologies suggest that the specific capacity are lower than the Church Grove/Colonel Hill lens and only very small quantities of freshwater are available from this 7.5 m (25 ft) thick lens.[282] Meager amounts of water are obtainable from the three other small limestone lenses, each approximately 3 m (10 ft) thick. The water quality of these lenses is poor, as it is brackish in most areas. Large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities.

Meager quantities of ground water are available from the sandy coastal aquifers (Map Unit 3) located near Landrail Point and Winding Bay/Great Bay. These lenses reach a maximum thickness of 3 m (10 ft) in some areas and the water is generally brackish to saline.[283] The water table is within a meter or two of the surface. This unit, covering just 2% of the island, is not suitable for extraction. Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are also unsuitable for ground water development and comprise 68% of the total island area. Chemical or biological contamination of the aquifers has not been reported.

# Eleuthera Island

| | |
|---|---|
| **Area:** | 187 $mi^2$ (3.5% of the total area) |
| **Estimated Population (2000):** | 8,114 (2.6% of the total population) |
| **Population Density:** | 43.39 people per square mile |
| **Largest City:** | Governors Harbour |
| **Location:** | Eleuthera is 90 km (60 miles) east of New Providence and 360 km (240 miles) southeast of Florida. Eleuthera's closest island neighbors include Abaco Island to the northwest and Cat Island to the southeast. |

## Surface Water

Eleuthera Island is narrow, with hills, especially in the north. The island has substantial cliffs on both the eastern and western shorelines. Total annual rainfall averages over 110 cm (43 inches). Surface water bodies (Map Units 5 and 6) most prevalent in Eleuthera include (a) topographic lows, (b) blue holes, (c) man-made lakes and ponds, and (d) lagoons.[284] Ponds between The Bluff and Current Settlements occupy topographic lows and the water table is locally above ground level. These ponds are saline during the dry winter months. Man-made lakes and ponds, resulting from the removal of limestone for building and road materials, may appear to contain fresh (surface) water, however, these are areas where the water table has been exposed to the surface (i.e. fresh ground water that has been exposed to the surface). Shallow lagoons, such as Hatchet Bay Pond and Sweetings Pond, are brackish to hypersaline and the water may appear red due to the presence of algae. None of the lagoons on Eleuthera contain freshwater. Map Units 5 and 6 comprise 4% and 5% of the total island area, respectively. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Very small to small quantities of freshwater are available from the Lucayan limestone aquifer lenses (Map Unit 2). Lenses vary in thickness, with the thickest lenses occurring on North Eleuthera (21 m or 69 ft). The remaining lenses have thicknesses of 3 to 9 m (10 – 30 ft). The water table is within a meter or two of the surface. This unit accounts for 22% of the total island area. Table 7 presents the specific capacity (the rate of discharge of a well per unit of drawdown), recommended pumping rates, drawdown and distance required between each borehole with regards to thickness of the freshwater lens.

**Table 7. Relevant parameters for ground water extraction on Eleuthera Island**[285]

| Thickness of freshwater lens m (ft) | Range of Specific Capacities (gpm/ft) | Recommended pumping rate per bore hole L/s (gpm) | Drawdown for each borehole m (ft) | Distance required between boreholes (acres) |
|---|---|---|---|---|
| 15 – 21 (50 – 70) | 50 + | 0.3 (5) | < 0.03 (0.10) | 14 |
| | 50 – 25 | 0.15 (2.5) | 1.5 –3.0 (0.05 – 0.10) | 7 |
| | 25 – 10 | 0.06 (1.0) | 1.2 – 3.0 (0.04 – 0.10) | 3.6 |
| 9 – 12 (30 – 40) | 50 + | 0.3 (5) | < 0.03 (0.10) | 17 |
| | 50 – 25 | 0.15 (2.5) | 1.5 –3.0 (0.05 – 0.10) | 8 |
| | 25 – 10 | 0.06 (1.0) | 1.2 – 3.0 (0.04 – 0.10) | 4.2 |
| 6 (20) | 50 + | 0.3 (5) | < 0.03 (0.10) | 19 |
| | 50 – 25 | 0.15 (2.5) | 1.5 –3.0 (0.05 – 0.10) | 10 |
| | 25 – 10 | 0.06 (1.0) | 1.2 – 3.0 (0.04 – 0.10) | 4.9 |

Uncased boreholes should be used to abstract ground water from the limestone aquifer. Also, abstraction should be spread over many boreholes. Boreholes should be kept as shallow as possible and should be pumped at such a rate that a drawdown of 0.03 m (0.10 ft) is not exceeded.[286] Hand-dug wells are suitable for this unit. Large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities.

Very small to small quantities of freshwater are also available from the Holocene sands aquifer (Map Unit 3). Unlike the other Bahamian islands, the sandy aquifer is a very important source of freshwater. The parameters presented in Table 5 for the limestone aquifer can also be applied for lenses in the sandy aquifer. Uncased boreholes should be used to abstract ground water from these lenses. Also, abstraction should be spread over many boreholes. Pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft) for lenses greater than 9 m (30 ft) thick and 0.003 m (0.01 ft) for lenses less than 9 m (30 ft) thick.[287] The water table is within a meter or two of the surface and hand-dug wells are most suitable for this unit. The sandy aquifers of Map Unit 3 comprise 6% of the total island area.

Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are unsuitable for ground water development and comprise 63% of the total island area. Chemical or biological contamination of the aquifers has not been reported for Eleuthera Island.

# Exuma Islands (Great and Little)

| | |
|---|---|
| **Area:** | 112 $km^2$ (2% of the total area) |
| **Estimated Population (2000):** | 3,575 (1.2% of the total population) |
| **Population Density:** | 31.92 people per square mile |
| **Largest City:** | George Town, Great Exuma |
| **Location:** | Great Exuma and Little Exuma are the largest islands of the Exuma island chain that includes 365 cays (islands) stretching southeasterly between New Providence and Long Island. The Exumas are 188 km (125 miles) southeast of New Providence and about 528 km (350 miles) from Miami, Florida. |

## Surface Water

Great and Little Exuma are fairly small islands, consisting of hilly ridges created by the Northeast Trade Winds along the eastern shore.

Beyond the ridges, the remaining areas are predominantly low-lying. Rainfall on Great Exuma averages close to 100 cm (40 inches) per year, according to data from a rainfall station on Great Exuma, monitored from 1961 to 1990. Wetlands (Map Unit 6) are prevalent along the western coast of the Exuma islands. These areas are likely saline due to their proximity to the ocean. Ponds, such as Salt Pond on Little Exuma, also occur on this island. These features (Map Unit 5) are expected to be brackish and may also be saline during the drier winter months if evaporation exceeds precipitation. Map Units 5 and 6 account for 4% and 17% of the total area of the islands, respectively. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

The Exumas boasts extensive ground water resources, given their size and low annual rainfall. The maximum thickness of freshwater lenses in the Lucayan Limestone is 16 m (52 ft).[288] However, extraction rates must be kept low, as specific capacities are small compared to other Bahamian islands, such as Eleuthera. Only very small to meager quantities of freshwater are available from the limestone aquifers (Map Unit 2) on Exuma. The Holocene sand aquifers (Map Unit 3) provide additional ground water resources, specifically near Ocean Bight. The lenses can also yield very small to meager quantities. Although the water table is within a meter or two of the surface, these areas are likely unsuitable for ground water development. Map Units 2 and 3 comprise 18% and 4% of the total island area, respectively.

Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are also unsuitable for ground water development and comprise 57% of the total island area. Chemical or biological contamination of the aquifers has not been reported for the Exumas.

# Grand Bahama Island

| | |
|---|---|
| **Area:** | 530 $mi^2$ (10% of the total area) |
| **Estimated Population (2000):** | 46,954 (15.5% of the total population) |
| **Population Density:** | 88.59 people per square mile |
| **Largest City:** | Freeport |
| **Location:** | The northern most Bahamian island, Grand Bahama is 190 km (126 miles) north of New Providence and 78 km (52 miles) east of Palm Beach, Florida. Its closest neighbor is Abaco Island to the east. |

## Surface Water

Grand Bahama Island is very flat, the highest point being just 20.7 m (68 ft) above sea level. It also lacks the long ridges that characterize most other islands. The shoreline is often swampy, and the higher elevations of 6-9 m (20-30 ft) are scattered inland to create a very gently undulating plain.[289] Annual rainfall averages 152.4 cm (60 inches). Surface water bodies on Grand Bahama Island are limited to (a) marsh areas or ponds, (b) creeks, (c) blue holes, and (d) man-made features. Marsh/wetland areas (Map Unit 6) and ponds (Map Unit 5) cover a very large portion of the island. Some of these areas are seasonally fresh and some are permanently saline or tidal.[290] Creeks (Map Unit 5) are abundant on Grand Bahama and represent the exposed surface of the water table.[291] These features are full of water during the summer months, but when the water table drops in the winter, the creeks are completely dry. The salinity of the water in creeks is dependant on the depth of the creek channel, rainfall, ocean tides, and the thickness of an associated freshwater lens.[292] Many creeks are potential sources of potable water, however, ground water resources are plentiful and creeks are not viewed as sources of freshwater. There are several blue holes on the island, which may also contain freshwater. Together, Map Units 5 and 6 comprise nearly 40% of the total area of the island. Trenches and canals can have many negative effects on the quality and quantity of freshwater available from a ground water lens. The Grand Lucayan Waterway, for example, was excavated along the course of an existing creek, which is a source of recharge for the adjacent freshwater lenses. The canal reaches a depth of 1 – 2 m (4 – 6 ft) below mean sea level, thus promoting the loss of freshwater through saltwater intrusion. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Second only to Andros Island, Grand Bahama has the most extensive and plentiful ground water reserves of the Bahamian islands. Large to enormous quantities of freshwater are available from limestone lenses (Map Unit 1) on Grand Bahama Island and the water table is between 0 to 6 m (0 to 20 ft) of the surface. From Freeport Harbour to West End, the limestone lens aquifers vary in thickness from 3 m (10 ft) at the extreme western tip of the island, to 9 m (30 ft) near Freeport Harbour.[293] The limestone itself, is however, much thicker than the lens of the freshwater that is considered the limestone aquifer (see Table 1.) The lenses in this area may contain brackish to saline water, as they are heavily influenced by the tide. The freshwater lenses located between the Freeport area and the Grand Lucayan Waterway reach a thickness of 12 m (40 ft). Given the proximity of these lenses to the city of Freeport, ground water pollution is a concern. Contamination from septic tanks and storm water drainage wells is monitored regularly, as well as treated, by the GBUC. The area between the Grand Lucayan Waterway and August Cay contains the largest ground water resources. The lenses in this area are up to 12 m (40 ft) thick and the Lucayan limestone aquifer has a high specific capacity. Ground water may be brackish to saline in areas surrounding creeks. Map Unit 1 comprises over a third of the total area of the island.

Uncased boreholes should be used to abstract ground water from the limestone aquifer. Also, abstraction should be spread over many boreholes. Pumping rates should be monitored such that drawdown does not exceed 0.03 m (0.10 ft) for lenses greater than 9 m (30 ft) thick and 0.003 m (0.01 ft) for lenses less than 9 m (30 ft) thick.[294] A borehole depth should not exceed 30% of the original lens thickness the best quality water will be found at the center of lens where the lens is the thickest.[295] Hand-dug wells are also suitable for this unit.

Holocene sand aquifers (Map Unit 3) along the coast of southern Grand Bahama have not been exploited, however, their location near the sea suggests the ground water is likely brackish to saline. These aquifers are unsuitable for large-scale ground water extraction and account for less than 1% of the total land area of the island.

In 2004, Hurricane Frances and Jeanne damaged the freshwater lens by storm surges. After Frances, the chlorides increased from about 140 ppm to 360 ppm. A storm surge caused by Hurricane Jeanne created 6 ft of seawater over the main wellfields. At time of press, the increased salinities were expected to be reduced by a significant increase in pumping for a week or two. Hurricane Floyd in 1999 also caused a signficant amount of damage. The storm surge created by Floyd was greater than the surge from Frances. It was estimated that it would take 72 years to recover from the saltwater inundation in the wells from Floyd's storm surge.

The remote areas in southwestern Grand Bahama are dominated by wetlands and may not be appropriate for military exercises or tactical planning. Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are unsuitable for ground water development and comprise 28% of the total island area. Chemical or biological contamination of this aquifer is not a major concern.

# Great Inagua Island

**Area:** 599 mi$^2$ (11% of the total area)

**Estimated Population (2000):** 970 (0.3% of the total population)

**Population Density:** 1.62 people per square mile

**Largest City:** Matthew Town

**Location:** Great Inagua is 563 km (350 mi) southeast of New Providence and 89 km (55 mi) northeast of Cape Maisí, Cuba.

## Surface Water

Great Inagua is the largest of the southern islands. Ridges line the eastern and southern coasts, reaching over 30 m (100 ft) in several places, and also occupy the central part of the north coast.[296] The rest of the island is extremely flat, and lakes, of which the largest is Lake Rosa, occupy large parts of it. Little of this area is more than five feet above sea level. Similar to other Bahamian Islands, Great Inagua's surface water features can be classified as (a) hypersaline ponds and lagoons, (b) saline marsh or wetlands areas, (c) blue holes, (d) ephemeral ponds, and (e) man-made features.[297] Hypersaline ponds and lagoons (Map Unit 5) occupy a large portion of the island. In fact, Lake Rosa is the largest lake in The Bahamas and designated a Ramsar Wetland of International Importance. This lake, along with other salt ponds on the island, is hypersaline because evaporation exceeds precipitation on the southern Bahamian islands. Great Inagua is one of the driest islands in the whole region, with an average annual rainfall of just 66 cm (26 inches).[298] Large areas of the island, usually adjacent to salt ponds or coastal lagoons, are occupied by saline marshes or wetland areas (Map Unit 6). These areas intersect the saline water table and are wet most of the year.[299] Blue holes can be found on eastern Great Inagua and may contain freshwater. Ephemeral ponds and man-made features, such as canals, should not be considered sources of freshwater, as they contain saline to hypersaline water. Together, Map Units 5 and 6 comprise approximately 15% of the total area of the island. Chemical or biological contamination of the surface water has not been reported.

## Ground Water

The majority of central Great Inagua is dedicated parkland and is owned by the Bahamas National Trust; therefore, ground water investigations have been limited to the western portion of the island. Freshwater supplies in Great Inagua are poor due to an arid climate and low relief. The freshwater lenses have relatively small storage and salinity increases with depth.[300] Very small quantities are available from a freshwater lens (Map Unit 2) just north of Lake Rosa. This lens formed in the Lucayan limestone and is about 6 m (20 ft) thick. Five other small lenses were discovered in southwestern Inagua; however, these lenses are fairly thin and located near saline surface water. The water table is between 0 to 3 m (0 to 10 ft) of the surface. These areas, which account for only 1% of the total area of the island, are unsuitable for ground water development.

Holocene sand aquifers (Map Unit 3) along the coasts of Great Inagua have not been exploited, however, their location near the sea suggests the ground water is likely brackish to saline. The water table is within a meter or two of the surface. These aquifers, less than 1% of the total area of the island, are unsuitable for large-scale ground water extraction. Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are also unsuitable for ground water development and comprise 84% of the total island area. Chemical or biological contamination of the aquifers has not been reported for the island.

# Long Island

| | |
|---|---|
| **Area:** | 230 $mi^2$ (4.3% of the total area) |
| **Estimated Population (2000):** | 2,945 (1% of the total population) |
| **Population Density:** | 12.8 people per square mile |
| **Largest City:** | Clarence Town |
| **Location:** | Long Island is 242 km (150 miles) southeast of Nassau (New Providence). Its closest neighbors are the Exuma Islands to the northwest and Crooked Island to the southeast. |

## Surface Water

The entire length of Long Island is dominated by a ridge with rolling hills, often exceeding 30 m (100 ft) in height, with a maximum of 54 m (177 ft).[301] The island is relatively dry with an average rainfall of around 89 cm (35 inches) per year. Wetland areas (Map Unit 6) are present on the northern tip and along the western-central coast of Long Island. These areas are likely saline due to their proximity to the ocean. There are two sizeable lakes (Map Unit 5) on the southern tip of the island, which may also contain brackish to saline water. Map Units 5 and 6 account for 4% and 7% of the total island area, respectively. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Large portions of this island do not have access to fresh ground water resources, including the Clarence Town area. Meager to unsuitable quantities of ground water are available from the very limited limestone lenses (Map Unit 2), which have a maximum thickness of 6 m (20 ft). The Holocene sand aquifers (Map Unit 3) may provide additional ground water resources, however, it is expected that only meager supplies exist. The water table is within a meter or two of the surface for both units. These areas are likely unsuitable for military exercises. Map Units 2 and 3 comprise 8% and 5% of the total area of the island, respectively. Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are also unsuitable for ground water development and comprise 76% of the total island area. Chemical or biological contamination of the aquifers is not a major concern.

# Mayaguana Island

**Area:** 110 $mi^2$ (2% of the total area)

**Estimated Population (2000):** 262 (0.08% of the total population)

**Population Density:** 2.38 people per square mile

**Largest City:** Abrahams Bay

**Location:** Mayaguana, the eastern most Bahamian island, is 537 km (355 miles) southeast of New Providence and 706 km (468 miles) southeast of Palm Beach, FL. The closest island is Acklins Island to the west.

## Surface Water

Mayaguana is a flat, low-lying island. The island is relatively dry with an average rainfall of around 76 cm (30 inches) per year. Mayaguana boasts a variety of surface water bodies, which may be classified as flooded-topographic lows, lagoons, marsh or wetlands, and caverns.[302] A small area of wetlands (Map Unit 6) occurs along the southern, central coast, near Abrahams Bay. Ponds and lagoons (Map Unit 5) can be found along the northern coast of the island. In most cases, these surface water features are saline to hypersaline.[303] Blue holes have not been discovered on the island. Map Units 5 and 6 comprise less than 5% of the total area of the island. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

A freshwater lens was discovered on western Mayaguana Island. The lens (Map Unit 2) occurs in the Lucayan limestone aquifer and reaches a maximum thickness of 10.5 m (34 ft). Moderate quantities of freshwater are available from this lens. Water levels are within one to two meters of the surface. Uncased boreholes should be used to abstract ground water from the limestone aquifer. Also, abstraction should be spread over many boreholes. Recommended pumping rates are between 0.6 to 1.5 L/s (10 to 25 gpm). Drawdown and water quality should be monitored for increased salinities in an effort to avoid saltwater intrusion from overpumping.[304] Map Unit 2 accounts for just over 5% of the total area of the island.

Holocene sand aquifers (Map Unit 3) along the coasts of Mayaguana have not been exploited; however, their location near the sea suggests the ground water is likely brackish to saline. The water table is within a meter of the surface. These aquifers, which comprise 6% of the total area of the island, are unsuitable for large-scale ground water extraction.

East of Abrahams Bay, there is no freshwater source. The limestone bedrock in this area has many small sinkholes which prevent the formation of freshwater lenses.[305] The island receives much less rainfall than the northern Bahamian islands and the little recharge it does receive quickly infiltrates through the sinkholes and mixes with the saline water.[306] Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are also unsuitable for ground water development and comprise 84% of the total island area. Chemical or biological contamination of the aquifers has not been reported for Mayaguana Island.

# New Providence Island

| | |
|---|---|
| **Area:** | 80 $mi^2$ (1.5% of the total area) |
| **Estimated Population (2000):** | 212,432 (69% of the total population) |
| **Population Density:** | 2,655.4 people per square mile |
| **Largest City:** | Nassau |
| **Location:** | New Providence, the most densely populated island, is home to the capital city, Nassau. It is also one of the smallest Bahamian Islands. New Providence is 276 km (183 miles) southeast of Miami, Florida. |

## Surface Water

New Providence is one the wettest islands, receiving more than 130 cm (50 inches) of rainfall a year. The island's terrain is low and flat with a few small lakes and mangroves swamps. The southern coast of the island between Adelaide and Cay Point is dominated by lagoons and ponds (Map Unit 5). These areas are brackish or saline throughout the year. Lake Killarney, located in the center of New Providence, is surrounded by marshlands. The lake is quite shallow, only a meter or so deep, and is also brackish.[307] These features should not be considered sources of freshwater. Map Unit 5 accounts for 10% of the total area of the island. Surface water features may be polluted by industrial and urban runoff.

## Ground Water

Given the high population density on New Providence, all ground water resources are being fully exploited, possibly over exploited, in order to provide water for the entire population. Wellfields are located throughout the island. Ground water is barged from North Andros Island to supplement the water supply on New Providence. Additional water is supplied by a Seawater RO Plant. Many hotels along the coast have installed their own RO systems in order to provide water for the many tourists that visit the island. Nearly three quarters of New Providence’s public water supply is derived from North Andros and RO.[308]

Very small to meager quantities of water are available from the freshwater lenses of the limestone aquifer (Map Unit 2). The water table is within a meter or two of the surface and lens thickness varies across the island. Ground water is extracted via uncased boreholes and trenches. Ground water pollution is a concern on New Providence Island. Map Unit 2 accounts for nearly a quarter of the total area of the island. Areas (Map Unit 4) that are not underlain by limestone or sand aquifers are also unsuitable for ground water development and comprise 66% of the total island area. Industrial and urban runoff threaten the overall quality of the aquifer. The DEHS regularly monitors the public water supply.

Ground water supplies on New Providence are currently being exploited to their maximum potential. Ground water exploration during military exercises is not recommended.

# San Salvador Island

| | |
|---|---|
| **Area:** | 93 $mi^2$ (1.7% of the total area) |
| **Estimated Population (2000):** | 1,028 (0.3% of the total population) |
| **Population Density:** | 11.05 people per square mile |
| **Largest City:** | Cockburn Town |
| **Location:** | San Salvador, located in the central Bahamas, is approximately 311 km (193 miles) southeast of New Providence and 640 km (398 miles) east-southeast of Florida. |

## Surface Water

San Salvador receives more than 90 cm (35 inches) of rainfall annually. The island is composed of arc-shaped ridges with elevations over 30 m (100 ft). These ridges led to the formation of a large number of lakes trapped between the curving ridges. Away from the ridges there are extensive areas of less hilly rock land. The landlocked salt lakes (Map Unit 5) and wetlands (Map Unit 6) contain saline and brackish water and account for 40% of the total area of the island. Similar to the rest of the Bahamian islands, there are no streams on San Salvador Island. Large-scale chemical or biological contamination of the surface water has not been reported.

## Ground Water

Shallow wells extracting ground water from limestone lenses (Map Unit 2) yield very small amounts of freshwater. These lenses are approximately 6 to 7.5 m (20 – 25 ft) thick and the water table is between 0 to 3 m (0 to 10 ft) of the surface. Although public water supply wells are located in these lenses, they are unsuitable for military exercises, as the freshwater lenses are very thin and vulnerable to overexploitation. Map Unit 2 comprises less than 5% of the total area of the island.

Small to moderate quantities of freshwater are available from the sandy Holocene aquifers (Map Unit 3) along the western coast of the island, north of Cockburn Town.[309] These lenses, which account for 9% of the total area of the island, extend from the land surface to a depth of 6 to 7.5 m (20 – 25 ft). Ground water extraction from the remaining sandy aquifers on San Salvador has not been explored, however, these areas may yield similar results, especially near United Estates and Snow Bay. This unit is suitable for hand pumps and uncased boreholes and abstraction should be spread over many boreholes. Pumping rates should be monitored such that drawdown does not exceed 0.003 m (0.01 ft). The water table is within a meter or two of the surface.

Areas that are not underlain by limestone or sand aquifers (Map Unit 4) are unsuitable for ground water development and comprise 48% of the total island area. Chemical or biological contamination of the aquifers has not been reported for San Salvador Island.

# VI. Recommendations

## A. General

During the July 2003 visit with the numerous water resources and supply agencies, organizations and key individuals, it became clear that freshwater is a very precious resource on the islands. Fresh surface water is basically non-existent. The freshwater resources are primarily from the shallow aquifers, which are inadequately protected for the most part.

Freshwater resources should be established as a national resource. A national freshwater resources sector should be established to administer the proper use of the resource. This sector should cover permitting, licensing, and administering penalties.[310]

Overall, it appears that more regulation and legislation in the areas of water supply, water protection, water conservation, etc., needs to be in place. Existing legislation needs to be strengthened, and new legislation must be enacted, particularly regarding land use planning and restrictions. The development of a comprehensive land use policy would be a very effective way to control activities affecting the water resources. Legislation in one sector will not address the problems of all sectors. A comprehensive land use policy that is complimentary to legislation of specific sectors will cover all areas.[311] Land should be legally and properly zoned for protection. Many issues affecting the country and the ground water resources could be controlled by proper land use legislation, such as well field squatting, septic tank construction, private well permitting, etc. The recent study, 'Regulatory Framework for Integrated Groundwater Management and Pollution Control' by Water Management Consultant Environmental Study, November 2003, proposes the methods to accomplish proper protection of the ground water, which includes land use planning.[312]

The permitting of individual private wells on private property should be controlled and regulated. At present, there are no permitting requirements, therefore private wells can be established anywhere. It is estimated that about 40% of households in W&SC's jurisdiction use their own private wells. Point-of-use filtering systems and chlorination systems for these private wells have a high incidence of poor or improper maintenance. Exacerberating this problem is the lack of regulations covering these issues.[313,314]

Another overwhelmingly clear problem and very critical issue on the islands is improperly constructed septic tanks and soakaways. The installation and construction needs to be better managed with more quality assurance and quality control (QA/QC). Soakaways and septic tanks are large polluters. Improperly constructed septic tanks and soakaways, common throughout the country, can cause contaminants to enter the aquifers. The building department should be strengthened to allow stricter enforcement, in terms of personnel, technology, etc. Better enforcement of the proper construction of new soakaways and septic tanks is essential and a critical need for the long-term protection of the ground water resources. QA/QC on each island is needed. Most of the northern islands have inspectors, but the remaining islands are lacking in adequate inspectors.[315,316]

Other needs are water conservation guidelines and penalties; public education campaigns; recycling programs; and strengthening the education of the populace in the importance of ground water protection, proper soakaways and septic tank construction, water quality, conservation, recyling, etc. Better education is also needed for laborers who construct septic tanks and soakaways.[317,318,319] Additional needs include cheaper energy methods for running RO plants, such as a natural gas pipeline from Grand Bahama, and pesticide regulations. It is difficult to control the chemicals used by farmers without regulations. These chemicals easily get into the ground water. Studies have not been conducted on agricultural pesticide runoff to determine the effect of these pesticides on the ground water.[320,321]

Flood plain mapping is also needed, to show vulnerable areas, including technical assistance and funding. The current storm surge atlas needs to be extended to the southeast. Currently, the storm surge atlas includes the northwest and central Bahamas. Water Evaluation and Planning Software, from Boston, is also needed to help analyze the ground water situation for future water planning.[322]

Better management of the pumping wells is needed, particularly on New Providence. They are currently producing 2 MGD, but this is not a sustainable rate. Better management with improved layouts and pumping scenarios need to be in place for optimum aquifer protection. Saline intrusion is a critical problem. It is better and cheaper to use ground water for water supply, where the ground water is sustainable, than water from RO.[323]

Other recommendations include modeling or studies on the residence time versus the fate of pollutants, the type of pollutants (particularly hydrocarbons) entering the ground water, and prediction on what will happen over time. The remediation method that works best to correct the ground water contamination, and determination of the safe pumping yields (sustainability) of the aquifer on New Providence. It would also be useful to have the freshwater lens on each island mapped, with a determination of the maximum amount of water that can be pumped safely from each.[324] However, ground water modeling of the aquifers in The Bahamas is probably not possible at this time. The factors involved in ground water modeling are too vast for current modeling programs to deal with. A larger obstacle to successful ground water modeling is the lack of data required for modeling. Little of the data required for modeling is available for these aquifers.[325]

A lack of data exists for the water resources. More water studies are needed, involving the collection of good field operational data, such as pumping test info, detailed mapping of well locations, salinity contour maps, collection of historical data, etc. It is recommended that such studies be performed. Long-term monitoring programs to accumulate good historical data should be implemented. An over-simplified view is for the data to be compiled and available for the time when modeling programs become available to deal with the crucial factors of the ground water.

The recommendations outlined in the 'Regulatory Framework for Integrated Groundwater Management and Pollution Control', November 2003, if adopted, address most of the issues discussed in this assessment, and in this chapter. A brief summary of these recommendations is outlined in section B below.

# B. Integrated Groundwater Management and Pollution Control

The recent study prepared by Water Management Consultants for W&SC, November 2003, outlines regulatory strategies for protecting and preserving the ground water. The recommendations cover most of the problems and issues discussed in this assessment, and the implementation of the recommendations could alleviate the disastrous consequences of inaction. Their recommendations include:

- Treating ground water as a strategic national resource, affording protection from over-abstraction and pollution.

- The 15 regulatory instruments (see Chapter III, Section E) proposed should be enacted as soon as possible. An Act of Parliament will be required to enact these instruments.

- Addressing the ground water threats particular to each island, using the appropriate regulatory instruments, and the level of regulation that is most likely to effect change in abstractors and polluters, while affording the appropriate degree of ground water protection.

- Establishment of a new environmental regulatory body (DEPP) to regulate certain activities involving ground water abstraction, which give rise to ground water pollution. This new body should fall within the MOH and Environment.

Consequences of inaction in establishing a new framework for ground water management follow:

- ❖ Public water and sewerage services will not be adequately regulated;

- ❖ Outbreaks of water borne diseases;

- ❖ Saltwater intrusion and other contamination of the freshwater lenses on New Providence will occur, causing increased cost in more barged and desalinated water;

- ❖ Freshwater lenses in the Family Islands will also degrade, causing increased water supply costs;

- ❖ Higher costs will be incurred in general over the long term from inaction in regulating protection of the ground water. Once polluted, ground water is very expensive to clean up.

W&SC needs additional funds and the support of the government to address UFW, increased storage capacity, implementation of appropriate conservation methods and new standards for low-flush devices. For large scale developments, dual service lines to facilitate the reuse of treated effluent for irrigation and flushing should be required.

Ground water recharge by rain or storm water run-off collection/harvesting needs to be more fully explored.

## C. Watershed Protection and Management

A common concern of most government officials and technical experts is the impact of improper land use, and the lack of land use policies and proper zoning on the environment and water resources. Integrated watershed management can also control deforestation and the resulting impacts on the freshwater resources. Agricultural activity should also be included in the management and protection. Development of comprehensive watershed and basin management plans is needed to curb these impacts. 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., hydrologic and meteorological stations); (2) interim measures (i.e., flood plain management); (3) long-term measures (i.e., reforestation, wastewater and sewage treatment, and water supply); and (4) wetlands protection.

The Bahamas National Trust has been successful in creating protected areas, doubling the protected areas for the country in 2002.

The Water Resources Management Unit appeals for the protection of traditional abstraction areas for the next generation of wellfield use and biodiversity. Present abstraction areas are threatened by increased development. Many former abstraction areas have been lost to development. Proposed protected areas are delineated but the regulations are pending under either the Forestry Act or a Ground Water Resources Act. Internationally, priority is given to conserving and using natural sources (ground water resources) over alternate sources (RO).

Recognition that the environmental need for water must include the current and restoration needs of wetlands is well overdue. Generally, wetland areas naturally have a beneficial role in pollution control, the attenuation of flood peaks, and erosion and sediment control. In addition to these environmental benefits, the social and cultural aspects are also a key component to their protection and artifical development. Due to the decreasing natural areas for ground water recharge, wetlands along with storm water must therefore be recognized in the management of water resources. Research should be conducted to determine how wetlands can assist in the attenuation of flood peaks, erosion and sediment control, and potential recharge of the Ghyben-Hertzberg Lens. This will require a detailed analysis of the typical soils and organics from specific wetland areas, to determine precise composition and retention characteristics. Natural coastal protection, and the associated protection of the inland areas by the wetlands should be emphasized. A sustainable approach to the functional roles of wetlands can assist in the reduction of costs associated with both storm water management and ground water recharge structures. Wetland retention and their creation offer a more sustainable approach to flood management.

## D. Troop Exercise Opportunities

Installing water wells for water supply in rural areas during troop exercises can provide a valuable and much-needed product for the host nation. In rural areas, adequate supplies of potable water are essential to improving the health of the population. This in turn helps to reduce poverty. Much of the rural population lives in poverty, and lacks access to potable water services. Improved access to water services (and sanitation services) are often the most desired public services among the population, particularly the rural population, as they generally have low coverage of these services.

New Providence is overdeveloped, particularly in the eastern end, so the installation of ground water wells on this island should be closely coordinated with W&SC.

In addition to providing a water source, it is equally important to provide the means for water extraction (pumps), storage (cisterns, elevated tanks), and distribution. The construction of a well (or impoundment) and the installation of a pump have served no purpose if the well cannot be put into service. Treatment, including chlorination, should also be addressed.

### 1. Well Exercises

Fresh surface water is scarce to non-existent. The water supply needs of the country are met through ground water resources and RO. Overall, the quality of ground water is good throughout the country. Saline intrusion, however, is a big problem. Small hand pumps would be a good asset in selected locations, 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. New wells installed should be designed to protect against surface contamination. These wells could be a source of safe potable water in select rural areas.

The southern islands may be good locations to pursue for installing hand pump wells. These islands must rely on RO and barged water for their water supply. This is very expensive, and probably out of reach for the rural, poorer areas. Some wells in the south produce less than 1 gpm. Hand pumps should be installed to prevent overpumping.

### 2. Small Surface Impoundments

Fresh surface water, on a permanent, annual basis, is non-existent in The Bahamas. The construction of small impoundments for capturing water for water supply should not be considered for water supply projects.

## E. Water Quality and Supply Improvement

Adopting the regulations and recommendations of the Regulatory Framework discussed in section B will improve the water supply and quality. Other recommendations are discussed below.

Proper and adequate sewage treatment is also lacking throughout the country, with much effluent discharged into the sea and freshwater lenses without proper treatment. Proper collection and treatment is needed to improve the quality of the ground water resources of the country, because ground water is for the most part, shallow with little natural protection, and along with RO, provides most of the water supply for the country. Improper and inadequate sewage treatment negatively impacts ground water resources.

Proper land use planning, zoning and policy is one key element to protecting the ground water resources. Grand Bahama has already incorporated land use planning. Permitted private wells, and properly constructed soakaways and septic tanks would improve the quality and water supply a great deal. Eliminating the squatters in the well fields is crucial.

Many islands currently have RO, and more islands are planning for it. RO is the future for water supply in The Bahamas. Since 25% of the cost of RO is the power to operate the plant, cheaper energy sources are needed.

Other issues to note in improving water supply and quality is flood plain mapping for vulnerable areas and better coordination between DEHS, W&SC, BEST, and the Department of Public Works (DPW).

Even as serious as the water supply and quality problems are, realistic opportunities to improve the supply and quality may be limited to education of the populous and relatively small-scale, problem-by-problem progress. The enormity of needed environmental and societal change would take millions of dollars to correct.[326]

# VII. Summary

The water resources situation of the country is critical and of great concern. Some of the main aspects and issues include:

- The freshwater lenses serve as the source of the main water supply for the country. These lenses are very fragile and very vulnerable to salt water intrusion from over abstraction, and contamination. Other forms of water supply, desalination of brackish or seawater, and 'barged' water are far more expensive than freshwater from the lenses.

- The economy of the country is based on tourism. Water is a critical element in the tourism industry.
- Lack of a comprehensive land use planning law to protect and preserve the resources.
- Lack of adequate regulations protecting ground water.
- Lack of data.
- Uneven rainfall distribution, decreasing from north to south.
- Shallow unprotected freshwater aquifers amongst high incidence of improperly constructed soakaways and septic tanks.
- Degradation of the aquifers by hydrocarbons, improper waste treatment and disposal, pesticides, other agrochemicals, and the large number of squatters.
- Degradation of the aquifers by natural disasters, such as high rainfall events, storm surges, hurricanes, other severe weather phenomena, and climate change.
- No single agency responsible for management of freshwater resources.
- Lack of funding for W&SC.
- Rapid growth in urban areas increased demand beyond system capacity.
- Overpumping in some areas due to lack of aquifer management.
- Lack of water conservation practices.
- Lack of public awareness and education.
- Lack of coordination between the relevant ministries and agencies dealing with water.

Solutions to these issues present significant challenges to the water resources managers. Adopting a regulatory framework for managing the ground water as outlined in the recent study prepared by Water Management Consultants for the W&SC, November 2003, offer great potential in preserving the ground water.

The lack of a comprehensive land use policy constitutes the greatest weakness in protecting the water resources. This inadequacy results in improper land use degrading the shallow freshwater supplies of the country.

The long-term solution to water resources needs must incorporate a combination of proper management, proper regulations, conservation and changing societal habits in the use of water and land resources. Without this, the beneficial effects of water resources projects will be short-lived.

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 affect change. Proper management of the limited freshwater resources can adequately provide for the needs of the country, perhaps starting with education of the populous, and relatively small-scale, problem-by-problem programs.

# Endnotes

[1] Paul Simon, *Tapped Out: The Coming World Crisis in Water and What We Can Do About It*, New York: Welcome Rain Publishers, 1998, p. 198.

[2] George Tchobanoglous, and Edward D. Schroeder, *Water Quality,* Reading, Massachusetts: Addison-Wesley Publishing Co., 1987, pp. 1-4.

[3] S. Caircross, "Developing World Water," *The Benefits of Water Supply*, Hong Kong: Grosvenor Press International, 1987, pp. 30-34.

[4] Orlando San Martin, *Water Resources in Latin America and the Caribbean: Issues and Options*, February 2002, p. 9.

[5] The Government of the Bahamas, Office of the Prime Minister, The Bahamas Environment, Science, and Technology (BEST) Commission, *Bahamas Environmental Handbook*, Nassau, Bahamas: 2002, pp. 2-3.

[6] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org//enwww/eva2000/bahamas/informe/inf-02.htm, Accessed 28 November 2003.

[7] U.S. Library of Congress, "The Bahamas – Geography," *Caribbean Islands*, Internet, http://countrystudies.us/caribbean-islands/117.htm, Accessed 20 January 2004.

[8] ABC Country Book of the Bahamas, "The Bahamas – Geography," Internet, http://www.immigration-usa.com/wfb/the_bahamas_geography.html, Accessed 20 January 2004.

[9] PAHO, "Health in the Americas; the Bahamas," 1998, p. 47, Internet, http://www.paho.org/English/HIA1998/Bahamas.pdf, Accessed March 2004.

[10] Dr. Richard V. Cant, "Water Supply and Sewerage in a Small Island Environment: The Bahamian Experience," *Small Islands: Marine Science and Sustainable Development Coastal and Estuarine Studies*, Volume 51, 1996, p. 330.

[11] The Government of the Bahamas 3.

[12] U.S. Library of Congress.

[13] The Government of the Bahamas, The Bahamas Environment, Science, and Technology (BEST) Commission and ICF Consulting, *The Bahamas National Report: Integrating Management of Watersheds and Coastal Areas in Small Developing States of the Caribbean*, March 2001, p. 8.

[14] U.S. Library of Congress.

[15] The Government of the Bahamas, *The Bahamas National Report*.

[16] ABC Country Book of the Bahamas.

[17] The Government of the Bahamas, *The Bahamas National Report* 8.

[18] Department of Statistics, Ministry of Trade and Industry, (documents provided by CSO, given to Laura Roebuck July 2003), Table 6, p. 13.

[19] CDERA, prepared by Ivor Jackson, Ivor Jackson and Associates, *Case Study: Impact of Severe Weather Events on Tourism in the Bahamas*, p. 6, June 2003, Internet, http://www.cdera.org/conf/20030724confcc/20030724confcc-Bahamas%20Tourism-Ivor%20Jackson.ppt, Accessed 21 January 2004.

[20] The Government of the Bahamas, *Handbook* 3.

[21] The Government of the Bahamas, *The Bahamas National Report* 15.

[22] The Government of the Bahamas, *The Bahamas National Report* 8.

[23] The Government of the Bahamas, *Handbook* 5.

[24] Theodora.com, "The Bahamas: Economy - 2003," Internet, http://www.theodora.com/wfb2003/bahamas_the/bahamas_the_economy.html, Accessed 03 February 2004.

[25] Water and Sewerage Corporation, prepared by Water Management Consultants, *Environmental Study Loan No. LO 112/OC-BH, Regulatory Framework for Integrated Groundwater Management and Pollution Control*, Final Report, November 2003, p. 22.

[26] San Martin 7 and Figure 1.10.

[27] Dr. Jasminko Karanjac, "Bahamas II," *Water Resources of the Caribbean Countries*, 2003.

[28] San Martin 7 and Figure 1.10.

[29] The Government of the Bahamas, *Handbook* 5.

[30] NCBuy, "Bahamas Backgrounds: Economy," *Countries of the World*, Internet, http://www.ncbuy.com/reference/country/backgrounds.html?code=bf&sec=backeconomy, Accessed 20 January 2004.

[31] The Government of the Bahamas, *The Bahamas National Report* 9.

[32] World Resources Institute, "Country Profile-Bahamas," *EarthTrends: The Environmental Information Portal*, Internet, http://earthtrends.wri.org/text/COA/country_profiles/cp_COA_12.htm, Accessed 30 January 2004.

[33] The Government of the Bahamas, *Handbook* 6.

[34] Theodora.com.

[35] The Government of the Bahamas, *Handbook* 5-6.

[36] CountryReports.org, "The Bahamas," Internet, http://www.countryreports.org/content/bahamas.htm, Accessed 20 January 2004.

[37] Theodora.com.

[38] Cant.

[39] Water and Sewerage Corporation.

[40] CDERA 29.

[41] Cant 338.

[42] World Atlas, "Bahamas," Internet, http://www.worldatlas.com/atlas/namerica/crbfacts/bahmdata.htm, Accessed 16 January 2004.

[43] United Nations, "Agenda 21 Sustainable Development – Natural Resource Aspects of Sustainable Development in the Bahamas," Internet, http://www.un.org/esa/agenda21/natlinfo/countr/bahamas/natur.htm, Accessed 21 January 2004.

[44] CDERA 14.

[45] United Nations 2.

[46] CDERA 23.

[47] Douglas W. Gamble et al., "Lessons Learned from Hurricane Floyd Damage on San Salvador," *Bahamas Journal of Science*, November 2000, pp. 26-27.

[48] Personal communication, Dennis Garcia, Grand Bahama Utility Company, 20 September 2004.

[49] Personal communication, John A. Bowleg, W&SC, 15 September 2004.

[50] Personal communication, John A. Bowleg, W&SC, 15 September 2004.

[51] Personal communication, Dr. Richard Cant, W&SC, 27 September 2004.

[52] The Government of the Bahamas, *The Bahamas National Report* 47.

[53] CDERA 6.

[54] United Nations 13.

[55] The Government of the Bahamas, *The Bahamas National Report* 16.

[56] Water and Sewerage Corporation, Water Resources Management Unit, "Storm Water/Watershed Management, Urban Flooding, and Flood Control," pp. 7-8.

[57] Personal communication, Arthur Rolle, Department of Meteorology, 14 July 2003.

[58] Personal communication, Dr. Richard Cant, W&SC, 3 March 2004.

[59] Personal communication, Arthur Rolle.

[60] Water and Sewerage Corporation, *Storm Water/Watershed Management* 7, 8, and 12.

[61] Personal communication, Dr. Richard Cant, W&SC, 3 March 2004.

[62] Personal communication, John A. Bowleg, W&SC, 30 August 2004.

[63] The Government of the Bahamas, *The Bahamas National Report.*

[64] Personal communication, Dennis Garcia, Grand Bahama Utility Company, 11 February 2004.

[65] Water and Sewerage Corporation, *Storm Water/Watershed Management* 7-8.

[66] CDERA 31.

[67] Gamble et al. 31.

[68] Center for Research on the Epidemiology of Disasters, "EM-DAT: The OFDA/CRED International Disaster Database," Internet, http://www.cred.be/emdat/welcome.htm, Accessed 22 January 2004.

[69] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/nwww/eva2000/bahamas/inform/inf-00.htm, Accessed 28 November 2003.

[70] The Government of the Bahamas, *The Bahamas National Report* 20.

[71] The Government of the Bahamas, *The Bahamas National Report* 20.

[72] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/nwww/eva2000/bahamas/inform/inf-00.htm

[73] W&SC, "The Water Sector in the Bahamas – General Information," Internet, http://www.wsc.com.bs/wat_geninfo.html, Accessed 10 June 2003.

[74] Inter-American Development Bank, "Bahamas – Solid Waste Management Program," *Environmental and Social Impact Report*, p. 7, Internet, http://www.iadb.org/exr/doc98/pro/esir-bh0008.htm, Accessed 10 February 2004.

[75] The Government of the Bahamas, *Handbook* 96 -106.

[76] W&SC, "The Water Sector in the Bahamas – General Information".

[77] The Government of the Bahamas, *Handbook* 95 -101.

[78] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/nwww/eva2000/bahamas/inform/inf-00.htm

[79] W&SC, "Wastewater Management," Internet, http://www.wsc.com.bs/waste_wat_mang.htm, Accessed 10 February 2004.

[80] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/nwww/eva2000/bahamas/inform/inf-00.htm

[81] The Government of the Bahamas, *Handbook* 94.

[82] Inter-American Development Bank, "Bahamas – Solid Waste Management Program," *Environmental and Social Impact Report*, p. 8, Internet, http://www.iadb.org/exr/doc98/pro/esir-bh0008.htm, Accessed 10 February 2004.

[83] W&SC, *Environmental Study* 42.

[84] W&SC, *Environmental Study* 42.

[85] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/nwww/eva2000/bahamas/inform/inf-00.htm

[86] W&SC, prepared by Water Management Consultants, *Environmental Study Loan No. LO 112/OC-BH, Terms of Reference for the Development of a Regulatory Framework for Integrated Groundwater Management and Pollution Control,* Final Report, November 2003, p. 2.

[87] The Government of the Bahamas, *The Bahamas National Report* 20.

[88] The Government of the Bahamas, *The Bahamas National Report* 22.

[89] W&SC, *Environmental Study,* Executive Summary.

[90] W&SC, *Environmental Study* 31-32.

[91] W&SC, *Environmental Study* 25.

[92] Caribbean Planning for Adaptation to Global Climate Change (CPACC), Internet, http://www.cpacc.org/download/bahamas_summary.pdf, Accessed 5 January 2004.

[93] Caribbean Planning for Adaptation to Global Climate Change, "Regional Data Archive, December 2000," Internet, http://www.cpaccrac.org/RACbackgroundcom.htm, Accessed 28 October 2003.

[94] The Government of the Bahamas, *The Bahamas National Report* Executive Summary and p. 11.

[95] Dr. Richard V. Cant, "The Challenge of Developing Water Supply Strategies for All of the Bahamas," *Bahamas Journal of Science*, February 1997, pp. 5-7.

[96] W&SC, *Environmental Study* E-22.

[97] PAHO 63.

[98] W&SC, "Family Islands Reverse Osmosis," Internet, http://www.wsc.com.bs/rev_osm.html, Accessed 27 February, 2004.

[99] W&SC, *Environmental Study* 20 and E-22.

[100] Personal communication, John Gibb, PAHO, 15 July 2003.

[101] The Government of the Bahamas, *Handbook* 105.

[102] The Government of the Bahamas, *The Bahamas National Report* 12.

[103] The Government of the Bahamas, *Handbook* 27 and 105.

[104] The Government of the Bahamas, *The Bahamas National Report* 14.

[105] The Government of the Bahamas, *The Bahamas National Report* 13-14.

[106] The Government of the Bahamas, *Handbook* 27 and 106.

[107] Cant, *Water Supply and Sewerage in a Small Island* 335.

[108] The Government of the Bahamas, *The Bahamas National Report* 14-15.

[109] United Nations.

[110] CDERA 30.

[111] United Nations Environment Programme, “2.1 Desalination by reverse osmosis,” *Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean*, Internet, http://www.oas.org/usde/publications/unit/oea59e/ch20.htm, Accessed 21 January 2004.

[112] The Government of the Bahamas, *The Bahamas National Report*.

[113] Personal communication, Dr. Richard Cant, W&SC, 15 July 2003.

[114] Personal communication, Orjan Lindroth, Lindroth Development Company, 17 July 2003.

[115] W&SC, “The Water Sector in the Bahamas – Family Islands Water History,” Internet, http://www.wsc.com.bs/fi_water_hist.htm, Accessed 20 January 2004.

[116] The Government of the Bahamas, *The Bahamas National Report* Executive Summary.

[117] CEPIS, "Bahamas Analytical Report: Background," *Assessment of Drinking Water and Sanitation 2000 in the Americas*, Internet, http://www.cepis.ops-oms.org/enwww/eva2000/bahamas/inform/inf-05.htm, Accessed 28 November 2003.

[118] Cant, *Water Supply and Sewerage in a Small Island* 335.

[119] WHO/UNICEF, "Access to Improved Drinking Water Sources: Bahamas," p. 2, Internet, http://www.childinfo.org/eddb/water/latam/bahamas_water1.pdf, Accessed 20 January 2004.

[120] The Government of the Bahamas, *The Bahamas National Report*.

[121] Inter-American Development Bank, "Waterfields Company Limited," Internet, http://www.iadb.org/exr/bs/0930/sotero.ppt, Accessed 22 January 2004.

[122] W&SC, "The Water Sector in the Bahamas – Marine Operations," Internet, http://www.wsc.com.bs/mar_ops.htm, Accessed 20 January 2004.

[123] W&SC, *Environmental Study* C-5.

[124] Water and Sewerage Corporation, *Environmental Study* E-22.

[125] W&SC, *The Water Sector in the Bahamas – Family Islands Water History*.

[126] Personal communication, Dr. Richard Cant, W&SC, 15 July 2003.

[127] Personal communication, Orjan Lindroth.

[128] W&SC, *Environmental Study* E-36.

[129] ZNS Bahamas, "Headline News: Contract Signed for Potable Water in Long Island," Internet, http://www.znsbahamas.com/news.php?module=article_show&art_id=227, Accessed 20 January 2004.

[130] The Grand Bahama Chamber of Commerce, "Grand Bahama on the Move," Internet, http://www.thegrandbahamachamberofcommerce.com/gbisle3.html, Accessed 20 January 2004.

[131] The Government of the Bahamas, *The Bahamas National Report* 14.

[132] WHO/UNICEF 2.

[133] The Grand Bahama Chamber of Commerce.

[134] Cant, *Water Supply and Sewerage in a Small Island* 335.

[135] Karanjac.

[136] Charles Fawkes, "Consumers Second Look at Water and Sanitation," Internet, http://www.thenassauguardian.com/business/292467325784568.php, Accessed 10 December 2003.

[137] Cant, *Water Supply and Sewerage in a Small Island* 335.

[138] W&SC, *The Water Sector in the Bahamas – Family Islands Water History*.

[139] Fawkes.

[140] Karanjac.

[141] W&SC, *The Water Sector in the Bahamas – Family Islands Water History*.

[142] Personal communication, Dr. Richard Cant, W&SC, 15 July 2003.

[143] W&SC, *The Water Sector in the Bahamas – Family Islands Water History*.

[144] Personal communication, John A. Bowleg, W&SC, 30 August 2004.

[145] W&SC, *Environmental Study* E-31.

[146] Personal communication, John A. Bowleg, W&SC, 30 August 2004.

[147] W&SC, *The Water Sector in the Bahamas – Family Islands Water History*.

[148] Personal communication, John A. Bowleg, W&SC, 30 August 2004.

[149] Fawkes.

[150] Karanjac.

[151] Personal communication, John A. Bowleg, W&SC, 30 August 2004.

[152] The Government of the Bahamas, *The Bahamas National Report* 15.

[153] The Government of the Bahamas, *Handbook* 27.

[154] W&SC, *Environmental Study* 16.

[155] The Government of the Bahamas, *Handbook* 7.

[156] The Government of the Bahamas, *The Bahamas National Report* 15.

[157] Karanjac 6.

[158] United Nations, *Agenda 21*.

[159] Alyson Dykstra, "Crystal Clear, Concerns in the Caribbean," Internet, http://www.worldfoodprize.org/Youth/2002Proceedings/pdf/pcm.pdf, Accessed 21 June 2004.

[160] Michael Swann, *Water Safety Handbook*, obtained July 2003, p. 1.

[161] W&SC, *Environmental Study* Executive Summary.

[162] W&SC, *Environmental Study* Appendix E.

[163] W&SC, *Environmental Study* 18 and 24.

[164] Fawkes.

[165] W&SC, *Environmental Study* Appendix A.

[166] Fawkes.

[167] W&SC, *Environmental Study* 16.

[168] CDERA 29.

[169] W&SC, *Environmental Study* 16.

[170] United Nations, *Agenda 21*.

[171] W&SC, *Environmental Study* 16.

[172] Cant, *Water Supply and Sewerage in a Small Island* 336.

[173] Fawkes.

[174] W&SC, *Environmental Study* 16-17.

[175] W&SC, *Environmental Study* 17.

[176] International Food Policy Research Institute, "Irrigation and water resources in Latin America and the Caribbean: Challenges and Strategies," Internet, http://www.ifpri.org/divs/eptd/dp/papers/eptdp64.pdf, Accessed 22 January 2004.

[177] Nationmaster.com, "The Bahamas," Internet, http://www.nationmaster.com/graph-T/ene_ele_pro_by_sou_hyd, Accessed 6 January 2004.

[178] The Government of the Bahamas, *Handbook* 2.

[179] W&SC, *Environmental Study* E-29.

[180] The Government of the Bahamas, *The Bahamas National Report* 11.

[181] Nationmaster.com, "Transportation in the Bahamas," Internet, http://www.nationmaster.com/encyclopedia/The-Bahamas, Accessed 17 December, 2003.

[182] The Government of the Bahamas, *Handbook* 5.

[183] CDERA 7.

[184] The Government of the Bahamas, *Handbook* 5.

[185] Gwinnett Travel, "The Island of the New Bahamas," Internet, http://www.gwinnett-travel.com/article.shtml?ArticleID=114, Accessed 20 January 2004.

[186] CDERA 10.

[187] United Nations, *Agenda 21* 18.

[188] Meeting of the Health and Environment Ministers of the Americas, March 4-5, 2002, Ottawa, Health and Environment Issues in the Americas, Background Briefing Paper 1: Clean Water and Basic Environmental Sanitation, p. 1.

[189] ACP Bahamas, "The great outdoors", Internet, http://europe.eu.int/comm/development/body/publications/courier/courier178/en/en_014.pdf, Accessed 21 January 2004.

[190] ACP Bahamas.

[191] The Bahamas National Trust, Internet, http://www.bahamas.gov.bs/bahamasweb/visitingthebahamas.nsf/subjects/national+trust, Accessed 11 June 2003.

[192] Bahamas National Trust, "Exuma Cays Land and Sea Park," Internet, http://www.bahamasnationaltrust.com/nationalparks_eclsp.com, Accessed 13 July 2004.

[193] Bahamas National Trust, "The Success of the Exuma Cays Land and Sea Park as a Marine Fishery Reserve," Internet, http://www.bahamasnationaltrust.com/nationalparks_eclsp_marinefisheryreserve.html, Accessed 13 July 2004.

[194] Bahamas National Trust, "Bahamas National Park Successes Highlighted at World Parks Congress," Internet, http://www.bahamasnationaltrust.com/news_pr_wpc.html, Accessed 13 July 2004.

[195] Karanjac.

[196] The Government of the Bahamas, *The Bahamas National Report* 7.

[197] The Government of the Bahamas, *The Bahamas National Report* 7.

[198] The Government of the Bahamas, *The Bahamas National Report* 7.

[199] The Government of the Bahamas, *The Bahamas National Report* 7.

[200] The Government of the Bahamas, *The Bahamas National Report* 7.

[201] Bahamas Department of Meteorology, "Climate of the Bahamas," Internet, http://www.bahamasweather.org.bs/climate/climate_index.html, Accessed 2 October 2003.

[202] Karanjac.

[203] The Government of the Bahamas, *The Bahamas National Report* 7.

[204] The Government of the Bahamas, *The Bahamas National Report* 7.

[205] The Government of the Bahamas, *The Bahamas National Report* 7.

[206] The Government of the Bahamas, *The Bahamas National Report* 7.

[207] B. G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Bahamas: A Summary*, Surrey, England: 1977, p. 38.

[208] Little et al., *Land Resources of the Bahamas: A Summary* 38.

[209] Neil E. Sealey, *Bahamian Landscape*s: An Introduction to the Geography of the Bahamas, Second Edition, Nassau, Bahamas: Media Publishing, 1994, p. 66.

[210] Little et al., *Land Resources of the Bahamas: A Summary* 38.

[211] Little et al., *Land Resources of the Bahamas: A Summary* 38.

[212] Richard V. Cant and Philip S. Weech, "A Review of the Factors Affecting the Development of Ghyben-Hertzberg Lenses in the Bahamas," *Journal of Hydrology*, Vol. 84, 1986, p. 340.

[213] Sealey 69-73.

[214] James L. Carew and John E. Mylroie, *Geology and Hydrogeology of Carbonate Islands. Developments in Sedimentology,* “Chapter 3A: Geology of the Bahamas”, Amsterdam, The Netherlands: Elsevier Science B.V., 1997, p. 91.

[215] Little et al., *Land Resources of the Bahamas: A Summary* 38.

[216] Little et al., *Land Resources of the Bahamas: A Summary* 35.

[217] Little et al., *Land Resources of the Bahamas: A Summary* 41.

[218] Cant and Weech 335.

[219] Cant and Weech 335.

[220] Cant and Weech 335.

[221] Fiona F. Whitaker and Peter L. Smart, *Geology and Hydrogeology of Carbonate Islands. Developments in Sedimentology,* “Chapter 4: Hydrogeology of the Bahamian Archipelago”, Amsterdam, The Netherlands: Elsevier Science B.V., 1997, p. 187.

[222] Cant and Weech 341.

[223] The Government of the Bahamas, *Handbook* 23, 24, and 26.

[224] Christopher Russell, "The Future of Forestry in the Bahamas," *The Bahamas Journal of Science*, Volume 5, Number 3, June 1998, p. 2.

[225] Russell 3.

[226] The Government of the Bahamas, *Handbook* 23, 24, and 26.

[227] Russell 3.

[228] Russell 2.

[229] The Government of the Bahamas, *Handbook* 25.

[230] The Government of the Bahamas, *Handbook* 23, 24, and 26.

[231] Russell 8.

[232] The Government of the Bahamas, *Handbook* 25.

[233] Russell 6, 8, 9, and 10.

[234] The Bahamas National Trust, Internet, http://www.bahamas.gov.bs/bahamasweb/visitingthebahamas.nsf/subjects/national+trust, Accessed 11 June 2003.

[235] Personal Communication, Gary Larson, Bahamas National Trust, 23 July 2003.

[236] Bahamas National Trust, “Central Andros National Parks,” Internet, http://www.bahamasnationaltrust.com/nationalparks_canp.html, Accessed 13 July 2004.

[237] Bahamas National Trust, “Abaco National Park,” Internet, http://www.bahamasnationaltrust.com/nationalparks_anp.html, Accessed 13 July 2004.

[238] Cant and Weech 340.

[239] Cant and Weech 340.

[240] Cant and Weech 340.

[241] The Government of the Bahamas, *The Bahamas National Report* 18-19.

[242] The Government of the Bahamas, *The Bahamas National Report* 18-19.

[243] The Government of the Bahamas, *The Bahamas National Report* 15.

[244] PAHO, "Hurricane Floyd: PAHO Situation Report #5," Internet, http://www.reliefweb.int/w/rwb.nsf/0/99fcb2e4fb11e447c12567f2005a3175?OpenDocument, Accessed 3 December 2003.

[245] Personal communication, Dennis Garcia, Grand Bahama Utility Company, 20 September 2004.

[246] Personal communication, Dr. Richard Cant, W&SC, 27 September 2004.

[247] Sealey 97.

[248] W&SC, *Environmental Study* 461.

[249] Go-Abacos, "Average Monthly Temperatures (air and water) - Average Monthly Rainfall," Internet, http://www.go-abacos.com/clim/#anchor2410304, Accessed 1 April 2004.

[250] B.G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 1a: Abaco Island*, Surrey, England: 1976, p. 28.

[251] Little et al., *Abaco* 29.

[252] B.G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Bahamas: A Summary, Confidential Annex to Land Resource Study 27,* Surrey, England: 1976, pp. 16-17.

[253] Little et al., *Abaco* 50.

[254] Little et al., *Abaco* 35, 50.

[255] Little et al., *Abaco* 35.

[256] Little et al., *Abaco* 35.

[257] Little et al., *Abaco* 36.

[258] Little et al., *Abaco* 50.

[259] Little et al., *Abaco* 48.

[260] Little et al., *Abaco* 50.

[261] The Bahamas Guide, "Acklins and Crooked Islands," Internet, http://www.thebahamasguide.com/islands/acklins/index.html, Accessed 7 April 2004.

[262] R.N. Young, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 7a: Crooked Island and Acklins*, Surrey, England: 1976, p. 45.

[263] Young et al., *Crooked Island and Acklins* 79.

[264] Young et al., *Crooked Island and Acklins* 49.

[265] Young et al., *Crooked Island and Acklins* 49.

[266] Young et al., *Crooked Island and Acklins* 50.

[267] Young et al., *Crooked Island and Acklins* 79.

[268] The University of Miami, Department of Biology, "Atlas of Bahamian Environments," Internet, http://islands.bio.miami.edu/Classifications/intro.html, Accessed 8 April 2004.

[269] B.G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 4a: Andros Island*, Surrey, England: 1976, p. 45.

[270] Little et al., *Andros* 47.

[271] Little et al., *Andros* 47.

[272] Little et al., *Andros* 50.

[273] Little et al., *Andros* 79.

[274] Little et al., *Andros* 107.

[275] Little et al., *Andros* 108-109.

[276] Little et al., Confidential *Annex* 18.

[277] Young et al., *Crooked Island and Acklins* 79.

[278] Personal communication, Dr. Richard Cant, W&SC, 1 November 2004.

[279] Young et al., *Crooked Island and Acklins* 26.

[280] Young et al., *Crooked Island and Acklins* 27.

[281] Young et al., *Crooked Island and Acklins* 79.

[282] Young et al., *Crooked Island and Acklins* 39.

[283] Young et al., *Crooked Island and Acklins* 40.

[284] B.G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 2a: Eleuthera Island*, Surrey, England: 1976, p. 27.

[285] Little et al., *Eleuthera* 37.

[286] Little et al., *Abaco* 37.

[287] Little et al., *Abaco* 48.

[288] T.N. Wallis, H.L. Vacher, and M.T. Stewart, "Hydrogeology of Freshwater Lens Beneath A Holocene Strandplain, Great Exuma, Bahamas," *Journal of Hydrology*, Vol. 124, 1991, p. 96.

[289] The University of Miami.

[290] B.G. Little, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 5a: Grand Bahama*, Surrey, England: 1975, p. 26.

[291] Little et al., *Grand Bahama* 27.

[292] Little et al., *Grand Bahama* 28.

[293] Little et al., *Grand Bahama* 52.

[294] Little et al., *Abaco* 48.

[295] Little et al., *Grand Bahama* 71.

[296] The University of Miami.

[297] R.N. Young, et al., British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey, *Land Resources of the Commonwealth of the Bahamas, Volume 8a: Mayaguana and Inagua*, Surrey, England: 1975, p. 45.

[298] The University of Miami.

[299] Young et al., *Mayaguana and Inagua* 46.

[300] Young et al., *Mayaguana and Inagua* 48.

[301] The University of Miami.

[302] Young et al., *Mayaguana and Inagua* 30.

[303] Young et al., *Mayaguana and Inagua* 30.

[304] Little et al., *Abaco Island* 48.

[305] Young et al., *Mayaguana and Inagua* 31.

[306] Young et al., *Mayaguana and Inagua* 31.

[307] Personal communication, Orjan Lindroth.

[308] W&SC, "The Historical Development of The Public Water Supply System of New Providence," Internet, http://www.wsc.com.bs/np_water_hist.htm, Accessed 19 December 2003.

[309] Howard Klein, N.D. Hoy, and C.B. Sherwood, "Geology and Ground-Water Resources in the Vicinity of the Auxiliary Air Force Bases, British West Indies," *Geological Survey Open File Report* 1958, pp. 58-61.

[310] Cant, *Water Supply and Sewerage in a Small Island* 329 - 340.

[311] The Government of the Bahamas, *The Bahamas National Report*.

[312] W&SC, *Environmental Study*.

[313] Personal communication, Dwight King, Department of Public Works, 17 July 2003.

[314] Personal communication, Shantelle Lopez, Water and Sewerage Corportation, 16 July 2003.

[315] Personal communication, Dwight King.

[316] Personal communication, Michael Major, Department of Physical Planning, 14 July 2003.

[317] Personal communication, Dwight King.

[318] Personal communication, Orjan Lindroth.

[319] Personal communication, meeting notes of Laura Roebuck, from meeting with the Hotel Corporation of the Bahamas, and the National Disaster Committee, 15 July 2003.

[320] Personal communication, Orjan Lindroth.

[321] Personal communication, Carl Smith, National Disaster Management Agency, 15 July 2003.

[322] Personal communication, Arthur Rolle.

[323] Personal communication, Richard Cant, W&SC, 15 July 2003.

[324] Personal communication, Simeon Pinder, Department of Agriculture, 16 July 2003.

[325] Water and Sewerage Corporation, *Environmental Study* E-45, E-46, E-47.

# Bibliography

ABC Country Book of the Bahamas. “The Bahamas – Geography.” Internet, http://www.immigration-usa.com/wfb/the_bahamas_geography.html, Accessed 20 January 2004.

ACP Bahamas. “The great outdoors.” Internet, http://europe.eu.int/comm/development/body/publications/courier/courier178/en/en_014.pdf, Accessed 21 January 2004.

Bahamas Department of Meteorology. "Climate of the Bahamas." Internet, http://www.bahamasweather.org/Climate/climate_of_the_bahamas.htm, Accessed 2 October 2003.

Bahamas National Trust. "Abaco National Park." Internet, http://www.bahamasnationaltrust.com/nationalparks_anp.html, Accessed 13 July 2004.

Bahamas National Trust, "Bahamas National Park Successes Highlighted at World Parks Congress," Internet, http://www.bahamasnationaltrust.com/news_pr_wpc.html, Accessed 13 July 2004.

Bahamas National Trust. "Central Andros National Parks." Internet, http://www.bahamasnationaltrust.com/nationalparks_canp.html, Accessed 13 July 2004.

Bahamas National Trust. "Exuma Cays Land and Sea Park." Internet, http://www.bahamasnationaltrust.com/nationalparks_eclsp.com, Accessed 13 July 2004.

Bahamas National Trust, "The Success of the Exuma Cays Land and Sea Park as a Marine Fishery Reserve," Internet, http://www.bahamasnationaltrust.com/nationalparks_eclsp_marinefisheryreserve.html, Accessed 13 July 2004.

Bowleg, John, A., Water and Sewerage Corporation. Personal communication. 30 August, 15 September, 17 November 2004, and 18 November 2004.

Caircross, S. "Developing World Water." *The Benefits of Water Supply*. Hong Kong: Grosvenor Press International, 1987, pp. 30-34.

Cant, Richard V. "The Challenge of Developing Water Supply Strategies for All of the Bahamas." *Bahamas Journal of Science*, February 1997, pp. 5, 6, and 7.

Cant, Richard V., Water and Sewerage Corporation. Personal communication. 15 July 2003, 3 March 2004, 27 September 2004, and 1 November 2004.

Cant, Richard, V. "Water Supply and Sewerage in a Small Island Environment: The Bahamian Experience." *Small Islands: Marine Science and Sustainable Development Coastal and Estuarine Studies*, Volume 51, 1996, p. 329-340.

Cant, Richard V. and Philip S. Weech. "A Review of the Factors Affecting the Development of Ghyben-Hertzberg Lenses in the Bahamas." *Journal of Hydrology*, Vol. 84, 1986.

Carew, James L. and John E. Mylroie. "Chapter 3A: Geology of the Bahamas." *Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology.* Amsterdam, The Netherlands: Elsevier Science B.V., 1997.

Caribbean Planning for Adaptation to Global Climate Change (CPACC). Internet, http://www.cpacc.org/download/bahamas_summary.pdf, Accessed 5 January 2004.

Caribbean Planning for Adaptation to Global Climate Change (CPACC). "Regional Data Archive, December 2000." Internet, http://www.cpaccrac.org/RACbackgroundcom.htm, Accessed 28 October 2003.

CDERA, prepared by Ivor Jackson, Ivor Jackson and Associates. *Case Study: Impact of Severe Weather Events on Tourism in the Bahamas*. June 2003, p. 6, 14, 16, 23, 29-31. Internet, http://www.cdera.org/conf/20030724confcc/20030724confcc-Bahamas%20Tourism-

Ivor%20Jackson.ppt, Accessed 21 January 2004.

CEPIS. "Bahamas Analytical Report: Background." *Assessment of Drinking Water and Sanitation 2000 in the Americas*. Internet, http://www.cepis.ops-oms.org/indexeng.html, http://www.cepis.ops-oms.org//enwww/eva2000/bahamas/informe/inf-00.htm, http://www.cepis.ops-oms.org//enwww/eva2000/bahamas/informe/inf-02.htm, and http://www.cepis.ops-oms.org/enwww/eva2000/bahamas/informe/inf-05.htm, Accessed 28 November 2003.

Center for Research on the Epidemiology of Disasters. "EM-DAT: The OFDA/CRED International Disaster Database." Internet, http://www.cred.be/emdat/welcome.htm, Accessed 22 January 2004.

CountryReports.org. "The Bahamas." Internet, http://www.countryreports.org/content/bahamas.htm, Accessed 20 January 2004.

Department of Statistics, Ministry of Trade and Industry. (documents provided by CSO, given to Laura Roebuck July 2003). Table 6, p. 13.

Dykstra, Alyson. "Crystal Clear, Concerns in the Caribbean." Internet, http://www.worldfoodprize.org/Youth/2002Proceedings/pdf/pcm.pdf, Accessed 21 June 2004.

Fawkes, Charles. "Consumers Second Look at Water and Sanitation." *The Nassau Guardian*, 25 July 2003, Internet, http://www.thenassauguardian.com/business/292467325784568.php, Accessed 10 December 2003.

Gamble, Douglas W. et al. "Lessons Learned from Hurricane Floyd Damage on San Salvador." *Bahamas Journal of Science*. November 2000, p. 26, 27, 31.

Garcia, Dennis. Grand Bahama Utility Company. Personal communication. 11 February 2004, and 20 September 2004.

Gibb, John, PAHO. Personal communication. 15 July 2003.

Go-Abacos. "Average Monthly Temperatures (air and water) - Average Monthly Rainfall." Internet, http://www.go-abacos.com/clim/#anchor2410304, Accessed 5 April 2004.

Gwinnett Travel. "The Island of the New Bahamas." Internet, http://www.gwinnett-travel.com/article.shtml?ArticleID=114, Accessed 20 January 2004.

Hotel Corporation of The Bahamas, National Disaster Coordination, Personal communication, 15 July 2003.

Inter-American Development Bank. "Bahamas – Solid Waste Management Program." *Environmental and Social Impact Report*. Internet, http://www.iadb.org/exr/doc98/pro/esir-bh0008.htm, Accessed 10 February 2004.

Inter-American Development Bank. "Waterfields Company Limited." Internet, http://www.iadb.org/exr/bs/0930/sotero.ppt, Accessed 22 January 2004.

International Food Policy Research Institute. "Irrigation and water resources in Latin America and the Caribbean: Challenges and Strategies." Internet, http://www.ifpri.org/divs/eptd/dp/papers/eptdp64.pdf, Accessed 22 January 2004.

Dr. Karanjac, Jasminko. "Bahamas I" and Bahamas II." *Water Resources of the Caribbean Countries*. 2003.

King, Dwight, Department of Public Works. Personal communication. 17 July 2003.

Klein, Howard, Hoy, N.D., and Sherwood, C.B. "Geology and Ground-Water Resources in the Vicinity of the Auxiliary Air Force Bases, British West Indies." Tallahassee, Florida: United States Department of the Interior, Geological Survey Open File Report, 1958.

Larson, Gary. Bahamas National Trust. Personal communication. 23 July 2003.

Lindroth, Orjan. Lindroth Development Company. Personal communication. 17 July 2003.

Little, B. G. et al. "Land Resources of the Bahamas: A Summary." Surrey, England: Land Resources Division, Ministry of Overseas Development, 1977.

Little, B.G. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. "Land Resources of the Bahamas: A Summary, Confidential Annex to Land Resource Study 27." Surrey, England: 1976.

Little, B.G. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. "Land Resources of the Commonwealth of the Bahamas, Volume 1a: Abaco Island." Surrey, England: 1976.

Little, B.G. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. "Land Resources of the Commonwealth of the Bahamas, Volume 4a: Andros Island." Surrey, England: 1976.

Little, B.G. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. "Land Resources of the Commonwealth of the Bahamas, Volume 2a: Eleuthera Island." Surrey, England: 1976.

Little, B.G. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. "Land Resources of the Commonwealth of the Bahamas, Volume 5a: Grand Bahama." Surrey, England: 1975.

Lopez, Shantelle. Water and Sewerage Corportation. Personal communication. 16 July 2003.

Major, Michael. Department of Physical Planning. Personal communication. 14 July 2003.

Meeting of the Health and Environment Ministers of the Americas, March 4-5, 2002, *Ottawa. Health and Environment Issues in the Americas, Bacground briefing Paper 1: Clean Water and Basic Environmental Sanitation*.

Nationmaster.com. "The Bahamas." Internet, http://www.nationmaster.com/graph-T/ene_ele_pro_by_sou_hyd.htm, Accessed 6 January 2004.

Nationmaster.com. “Transportation in the Bahamas.” Internet, http://www.nationmaster.com/encyclopedia/The-Bahamas, Accessed 17 December, 2003.

NCBuy. “Bahamas Backgrounds: Economy.” *Countries of the World*. Internet, http://www.ncbuy.com/reference/country/backgrounds.html?code=bf&sec=backeconomy, Accessed 20 January 2004.

Notes from the Conference on the review of the draft *The Bahamas First National Communication to the UNFCCC, April 2001*. Breezes Hotel, Nassau, 9 October 2000.

PAHO. “Health in the Americas; the Bahamas.” 1998. Internet, http://www.paho.org/ENGLISH/HIA1998/Bahamas.pdf, Accessed March 2004.

PAHO, Relief Web. “Hurricane Floyd: PAHO Situation Report #5.” Internet, http://www.reliefweb.int/w/rwb.nsf/0/99fcb2e4fb11e447c12567f2005a3175?OpenDocument, Accessed 3 December 2003.

Pinder, Simeon, Department of Agriculture. Personal communication. 16 July 2003.

Rolle, Arthur, Department of Meteorology. Personal communication. 14 July 2003.

Russell, Christopher. "The Future of Forestry in the Bahamas." *The Bahamas Journal of Science*, Volume 5, Number 3, June 1998, p. 2, 3, 6, and 8-10.

San Martin, Orlando. *Water Resources in Latin America and the Caribbean: Issues and Options*. February 2002, p. 7, 9, and Figure 1.10.

Sealey, Neil E. *Bahamian Landscapes: An Introduction to the Geography of the Bahamas*. Second Edition. Nassau, Bahamas: Media Publishing, 1994.

Simon, Paul. *Tapped Out: The Coming World Crisis in Water and What We Can Do About It*. New York: Welcome Rain Publishers, 1998, p. 198.

Smith, Carl, National Disaster Management Agency. Personal communication. 15 July 2003.

Swann, Michael. *Water Safety Handbook*. Obtained July 2003, p.1.

Tchobanoglous, George and Edward D. Schroeder. *Water Quality*. Reading, Massachusetts: Addison-Wesley Publishing Co., 1987, pp. 1-4.

The Bahamas Guide. "Acklins and Crooked Islands." Internet, http://www.thebahamasguide.com/islands/acklins/index.html, Accessed 7 April 2004.

The Bahamas National Trust. Internet, http://www.bahamas.gov.bs/bahamasweb/visitingthebahamas.nsf/subjects/national+trust, Accessed 11 June 2003.

The Government of The Bahamas, Office of the Prime Minister, The Bahamas Environment, Science, and Technology (BEST) Commission. *Bahamas Environmental Handbook*. Nassau, 2002, p. 2-3, 5-7, 23-27, 94-106.

The Government of The Bahamas, Office of the Prime Minister, The Bahamas Environment, Science, and Technology (BEST) Commission and ICF Consulting. *The Bahamas National Report: Integrating Management of Watersheds and Coastal Areas in Small Developing States of the Caribbean*. March 2001.

The Grand Bahama Chamber of Commerce. "Grand Bahama on the Move." Internet, http://www.thegrandbahamachamberofcommerce.com/gbisle3.html, Accessed 20 January 2004.

Theodora.com. "The Bahamas: Economy – 2003." Internet, http://www.theodora.com/wfb2003/bahamas_the/bahamas_the_economy.html, Accessed 03 February 2004.

United Nations. "Agenda 21 Sustainable Development – Natural Resource Aspects of Sustainable Devopment in the Bahamas." Internet, http://www.un.org/esa/agenda21/natlinfo/countr/bahamas/natur.htm, Accessed 21 January 2004.

United Nations Environment Programme. "2.1 Desalination by reverse osmosis." *Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean*. Internet, http://www.oas.org/usde/publications/unit/oea59/ch20.htm, Accessed 21 January 2004.

U.S. Library of Congress. "The Bahamas – Geography." *Caribbean Islands*. Internet, http://countrystudies.us/caribbean-islands/117.htm, Accessed 20 January 2004.

University of Miami, Department of Biology. "Atlas of the Bahamian Environments." Internet, http://islands.bio.miami.edu/Classifications/intro.html, Accessed 8 April 2004.

Wallis, T.N., Vacher, H.L., and Stewart, M.T. "Hydrogeology of Freshwater Lens Beneath A Holocene Strandplain, Great Exuma, Bahamas." *Journal of Hydrology*, Vol. 124, 1991.

Water and Sewerage Corporation. "Family Islands Reverse Osmosis." Internet, http://www.wsc.com.bs/rev_osm.html, Accessed 27 February, 2004.

Water and Sewerage Corporation, prepared by Water Management Consultants. *Environmental Study Loan No. LO 112/OC-BH, Regulatory Framework for Integrated Groundwater Management and Pollution Control*. November 2003.

Water and Sewerage Corporation, prepared by Water Management Consultants. *Environmental Study Loan No. LO 112/OC-BH, Terms of Reference for the Development of a Regulatory Framework for Integrated Groundwater Management and Pollution Control*. November 2003, p. 1-7.

Water and Sewerage Corporation. "The Historical Development of The Public Water Supply System of New Providence." Internet, http://www.wsc.com.bs/np_water_hist.htm, Accessed 19 December 2003.

Water and Sewerage Corporation. "The Water Sector in the Bahamas – Family Islands Water History." Internet, http://www.wsc.com.bs/fi_water_hist.htm, Accessed 20 January 2004.

Water and Sewerage Corporation. "The Water Sector in the Bahamas – General Information." Internet, http://www.wsc.com.bs/wat_geninfo.html, Accessed 10 June 2003.

Water and Sewerage Corporation. "The Water Sector in the Bahamas – Marine Operations." Internet, http://www.wsc.com.bs/mar_ops.htm, Accessed 20 January 2004.

Water and Sewerage Corporation. "Wastewater Management." Internet, http://www.wsc.com.bs/waste_wat_mang.htm, Accessed 10 February 2004.

Water and Sewerage Corporation, Water Resources Management Unit. "Storm Water/Watershed Management, Urban Flooding, and Flood Control." p. 7, 8, 12.

Whitaker, Fiona F. and Peter L. Smart. *Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology*, "Chapter 4: Hydrogeology of the Bahamian Archipelago." Amsterdam, The Netherlands: Elsevier Science B.V., 1997.

WHO/UNICEF. "Access to Improved Drinking Water Sources: Bahamas." Internet, http://www.childinfo.org/eddb/water/latam/bahamas_water1.pdf, Accessed 20 January 2004.

World Atlas. "Bahamas." Internet, http://www.worldatlas.com/atlas/namerica/crbfacts/bahmdata.htm, Accessed 16 January 2004.

World Resources Institute. "Country Profile-Bahamas." *EarthTrends: The Environmental Information Portal*. Internet, http://earthtrends.wri.org/text/COA/country_profiles/cp_COA_12.htm, Accessed 30 January 2004.

Young, R.N. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. *Land Resources of the Commonwealth of the Bahamas, Volume 7a: Crooked Island and Acklins.* Surrey, England: 1976.

Young, R.N. et al. British Ministry of Overseas Development, Land Resources Division, prepared for the Bahamas Land Resource Survey. *Land Resources of the Commonwealth of the Bahamas, Volume 8a: Mayaguana and Inagua.* Surrey, England: 1975.

ZNS Bahamas. "Headline News: Contract Signed for Potable Water in Long Island." Internet, http://www.znsbahamas.com/news.php?module+article_show&art_id=227, Accessed 20 January 2004.

# Appendix A

## List of Officials Consulted

## and

## List of Agencies Contacted

# List of Officials and Agencies Consulted

| Name, Title | Agency/Firm | Address | Tel/Fax/Email |
|---|---|---|---|
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| Arthur W. Rolle, Director | Department of Meteorology | Seban House<br>Crawford St<br>Oakes Field<br>P O Box N-8330<br>Nassau | Tel: (242) 356-3726<br>Fax: (242) 356-3739<br>Email: awr.met@batelnet.bs |
| Jeffrey W. Simmons, Chief Climatologist | Department of Meteorology | Seban House<br>Crawford St<br>Oakes Field<br>P O Box N-8330<br>Nassau | Tel: (242) 356-3734/8<br>Fax: (242) 356-3739<br>Email: jws.met@batelnet.bs |
| John Gibb, Environmental Advisor | PAHO | P O Box N-4833<br>Union Court<br>Elizabeth Ave<br>Nassau | Tel: (242) 326-7299<br>(242) 325-0121<br>Email: gibbj@bah.paho.org |
| Dr. Richard V. Cant<br>AGM FI Operations & Water Environment | Water and Sewerage Corp. | P O Box N-3905<br>Nassau | Tel: (242) 302-5602<br>Fax: (242)322-7812/7813<br>Email: wcrcant@wsc.com.bs |
| John A. Bowleg<br>Engineer/Hydrologist | Water and Sewerage Corp, Water Resources Management Unit. | PO Box N-3905<br>Nassau | Tel: (242) 302-5607<br>Fax: (242) 322-7812<br>Email: wcjbowleg@wsc.com.bs |
| Stunce A. Williams, Project Officer | The Hotel Corporation of the Bahamas | P O Box N-9520<br>Nassau | Tel: (242) 356-4571<br>Fax: (242) 356-4846<br>Email: desworks@bahamas.net.bs |
| Carl F. Smith, National Disaster Coordinator | National Disaster Management Agency | Churchill Bldg<br>Rawson Square<br>P O Box N-7147<br>Nassau | Tel: (242) 322-6081/5<br>Fax: (242) 326-5456<br>Email: carlfsmith@bahamas.gov.bs |
| David L. Cates | Ministry of Foreign Affairs | | Tel: (242) 322-6081<br>Email: david.l.cates@bahamas.gov.bs |
| Chrystal Glinton | National Disaster Management Agency | | Email: bahdisoff@bahamas.gov.bs |
| Nakira Wilchcombe, Supervisor, Technical Operations | BEST | Nassau Ct<br>P O Box CB 10980<br>Nassau | Tel: (242) 327-4691<br>Fax: (242) 327-4626<br>Email: bestnbs@hotmail.com |
| Anthony Ryan, Laboratory Technologist | Department of Environmental Health Services (DEHS), EMRAD | P O Box N-8903<br>Nassau | Tel: (242) 326-7128<br>(242) 326-2845<br>Email: aryan33@hotmail.com |
| Dwight Allen, Deputy Chief Health Inspector | Department of Environmental Health Services (DEHS), EMRAD | P O Box SS 19048<br>Nassau | Tel: (242) 322-8037<br>Email: dwightal@excite.com |
| Shantelle Lopez, Graduate Engineer | Water and Sewerage Corp., Engineering and Planning | 87 Thompson Blvd<br>P O Box N-3905<br>Nassau | Tel: (242) 302-5549<br>Fax: (242) 302-5547<br>Email: wcslopez@wsc.com.bs |
| Simeon Pinder, Deputy Director | Department of Agriculture | P O Box N-3704<br>Nassau | Tel: (242) 325-7502/9<br>Fax: (242) 325-3960<br>Email: simeonpinder@bahamas.gov.bs |

# List of Officials and Agencies Consulted

| Name, Title | Agency/Firm | Address | Tel/Fax/Email |
|---|---|---|---|
| Dwight B. King, Acting Deputy, Buildings Control Officer | Department of Public Works | Ministry of Works Bldg<br>JFK Drive<br>Nassau | Tel: (242) 427-7483<br>(242) 302-9550<br>Fax: (242) 302-9765<br>Email: bking@mowt.bs |
| Racquel Greene, Assistant Engineer | Department of Public Works | P O Box N-8156<br>Ministry of Works Bldg<br>JFK Drive<br>Nassau | Tel: (268) 462-6236<br>Fax: (268) 462-6236<br>Email: eag@candw.ag |
| Orjan Lindroth | Lindroth Development Company | P O Box N-7776<br>Nassau | Tel: (242) 362-4179<br>Email: dmortimer@oldfortbay.com |
| Dennis Garcia, Manager | The Grand Bahama Utility Company Ltd. | P O Box F-40888<br>Freeport<br>Grand Bahama Island | Tel: (242) 352-6611<br>Fax: (242) 351-7167<br>Email: gbuc@batelnet.bs |
| Gary E. Larson, Executive Director | Bahamas National Trust | P O Box N-4105<br>Nassau | Tel: (242) 393-1317<br>Fax: (242) 393-4978<br>Email: glarson@bahamas.net.bs |

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# Appendix B

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# Glossary

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# Glossary

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|---|---|
| alluvial | Pertaining to processes or materials associated with transportation or deposition by running water. |
| alluvium | Sediment deposited by flowing water, as in a riverbed, flood plain, or delta. |
| 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. |
| archipelago | A sea that contains numerous islands; also, the island chain or group itself. |
| banana hole | Banana holes are voids that develop in the limestone bedrock below the water table in the freshwater lens by the mixing of chemically-distinct waters. Banana holes have limited vertical development but are horizontally extensive. |
| 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. |
| bedrock | The solid rock that underlies gravel, soil, or other unconsolidated, superficial material. |
| blue hole | A deep hole, usually deeper than sea level, formed by the solution and collapse of carbonate rock. Water levels are usually at the ground surface, and water chemistries can range from fresh to marine. |
| 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. |
| brine | Water saturated with or containing large amounts of a salt. |
| 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. |
| carbonate rock | A rock, such as limestone, that consist mostly of carbonate minerals, such as calcite. |
| cays | A small low island or reef formed of sand, coral, rock, or mud. |
| 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. |
| clastic | Consisting of rock fragments that have been transported from their places of origin. |
| confined aquifer | An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the aquifer itself. |
| 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. |
| distillation | A water treatment method where water is boiled and condense in a separate reservoir. Contaminants with higher boiling points than water do not vaporize and remain in the boiling flask. |
| drawdown | The lowering of the water level in a well as a result of withdrawal of water. |

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| eolianite ridge | A sand dune or deposit formed by the action of wind. |
| ephemeral pond | A pond that forms briefly and only in direct response to local precipitation. |
| evaporite | A sedimentary rock formed by the evaporation of a solution, usually seawater. Evaporite commonly forms either gypsum or anhydrite. |
| evapotranspiration | Loss of water from a land area through transpiration of plants and evaporation. |
| 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. |
| fracture | A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. |
| freshwater | 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. |
| geothermal | Pertaining to the heat of the interior of the earth. |
| Ghyben-Hertzberg lenses | Freshwater bodies named after the two hydrologists who first described their occurrence in coastal areas. The lenses are composed of three lateral zones: (1) a potable section where the chloride content ranges from 90 to 400 ppm; (2) a transition zone, approximately 1-2 m thick, in which chlorides increase rapidly from 400 to 1200 ppm; (3) a saline portion in which chlorides increase from 1200 ppm to levels approaching seawater. |
| groundwater | 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 |
| Holocene Epoch | A period of geologic time, which began during the Quaternary Period, from the end of the Pleistocene, approximately 8,000 years ago, to the present time. |
| hydrologic cycle | The movement of water and water vapor from the sea to the atmosphere, to the land, and back to the sea and the atmosphere again. |
| 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. |
| interbedded | Lying between beds of strata of different rock or mineral; interstratified. |
| 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. |
| karst | A topography formed over soluble rock (limestone, dolomite) characterized by sinkhole, caves, and underground drainage. |
| lagoon | A shallow body of water separated from a lake, sea, or mainland by a barrier. |
| 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.. |

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| marsh | An area of saturated ground dominated by grasslike aquatic plants. |
| mean low water | The average height of the low water over 19 years. |
| metamorphic | Rocks formed in the solid state from previously existing rocks in response to pronounced changes in temperature, pressure, and chemical environment. |
| non-aqueous phase liquids (NAPL) | Liquids that are sparingly soluble in water. |
| nitrate | A salt of nitric acid containing the univalent, negative radical $NO_3$. |
| oolitic limestone | A limestone rock, formed by oolithes cemented together. Oolithes are small, rounded calcium carbonate bodies, accreted by organisms, with diameters of 0.25 to 2.0 mm. |
| perennial | Pertaining to water that is available 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. |
| pesticide | A class of substances used to destroy insects, weeds, and other pest like rodents. Includes insecticides and herbicides. Even 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. |
| phosphate | A salt of phosphoric acid containing the negative radical $PO_4$, which possesses multiple valence states. |
| Pleistocene Epoch | 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. |
| 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. |
| 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 (Holocene) | 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 (saltwater or marine) | Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment. |
| salt pond | A standing body of water, which becomes saline when evaporation exceeds precipitation. |
| 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. |

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| 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. |
| sandstone | A soft to moderately hard sedimentary rock composed primarily of cemented quartz rains. This rock has good hydrogeological properties. |
| sedimentary (rocks) | A class of rocks formed from the accumulation and solidification of a variety of sediments. |
| sedimentation | The process of deposition of sedimentary material, especially by mechanical means from a state of air or water over time. |
| sinkhole | A funnel-shaped depression in the Earth's surface formed in a soluble rock by water. |
| soakaways | A hole where wastewater can drain away by filtering down through the soil. |
| specific capacity | The ratio of the discharge or yield of a well to drawdown after a period of sustained pumping. |
| specific yield | The quantity of water that a unit volume of saturated permeable rock will yield when drained by gravity. Expressed as a percent by volume. |
| 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. |
| stalactite | A conical deposit of mineral matter, usually calcite, that hangs from the ceiling of a cave, deposited from drops of water. |
| 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. |
| tidal creek | A creek whose directional flow is influenced by the rise and fall of the tide. |
| tidal flats | A marshy or barren tract of land that is alternately covered and uncovered by the tide. |
| Total dissolved solids (TDS) | The sum of all dissolved solids in water or wastewater. |
| trade wind | A major system of tropical winds moving from the subtropical highs to the equatorial low-pressure belt. It is northeasterly in the Northern Hemisphere and southeasterly in the Southern Hemisphere. |
| unconfined aquifer | An aquifer having a water table |
| upconing | The cone-shaped rise of saltwater beneath freshwater in an aquifer as freshwater is extracted from a well. |
| unconsolidated material | Sediment that is loosely arranged or unstratified, or whose particles are not cemented together. |
| 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. |
| wetlands | A lowland area, such as a marsh or swamp, that is saturated by surface or ground water. |
| yield | The volume per unit time (ex. Liters per second) of water produced from a well. |

# Appendix C

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# Surface Water and Ground Water Resources

## Tables and Figures

## Table C-1. Water Resources

| Map Unit No. (See Figs. C-1 through C-3) | Aquifer Characteristics | Quantity[1] | Quality[2] | Aspects of Ground Water Development | Remarks |
|---|---|---|---|---|---|
| 1<br>Fresh water generally plentiful | Unconfined, poorly-stratified, oolitic limestone of Pleistocene age. The limestone exhibits karstic features on most islands.<br><br>Fresh water occurs as Ghyben-Hertzberg lenses, which are composed of three layers: a fresh-water zone, a brackish- transition zone, and a salt-water zone on the bottom. Rain water is the only source of fresh water recharge to these lenses.<br><br>Located near the interior and coasts of the Bahamian islands. Lens thicknesses vary from 3 m (10 ft) on Grand Bahama Island (2638N07825W)[3], to 43 m (141 ft) on Andros Island (2426N07757W). | Moderate to enormous quantities available from large fresh water lenses located on Abaco (2628N07705W), Andros (2426N07757W), and Grand Bahama (2638N07825W) islands.<br><br>Yields from boreholes on Abaco Island (2628N07705W) range from 2 to 3 L/s, between 3 to 6.5 L/s on Andros Island (2426N07757W), and between 1.5 to 6 L/s on Grand Bahama Island (2638N07825W).<br><br>Specific capacities for Abaco Island (2628N07705W) range from 17 to 1,300 L/min/m. Specific capacities for Andros Island (2426N07757W) range from 150 to > 2,000 L/min/m. | Fresh water is available from the limestone aquifer lenses. TDS for the islands ranges from 90 to 400 mg/L. The water quality of the limestone is generally good.<br><br>Shallow ground water may be biologically contaminated near settlements. Near the coast, fresh water is underlain by brackish or saline water. | The terrain is flat on the Bahamian islands, with the exception of large sand dunes. Accessibility, siting, and drilling of wells should not be difficult, except in those areas surrounded by wetlands.<br><br>Depth to water ranges from 0 to 6 m.<br><br>Because saltwater zones underlie the fresh-water zones in the limestone lenses, caution should be exercised in pumping to prevent saltwater intrusion and drawdown should be monitored.<br><br>Pumping rates in this report refer to extraction from one borehole. In order to obtain larger quantities of water, a network of boreholes, wellfields and/or trenches should be used. Large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities. | Ground water should be extracted using shallow, hand-dug wells, hand or electric pumps in uncased wells, and/or trenches/pits.<br><br>Suitable for tactical wells, small submersible pump wells, and hand-pump wells.<br><br>Supports irrigation and municipal water supply wells. |
| 2<br>Fresh water locally plentiful | Unconfined, poorly-stratified, oolitic limestone of Pleistocene age. The limestone exhibits karstic features on most islands.<br><br>The aquifer may be confined in New Providence (2502N07724W), where a relatively impervious crust and soil layer was | Unsuitable to large quantities available from large fresh water lenses located on Abaco (2628N07705W), Acklins (2226N07400W), Andros (2426N07757W), Cat (2423N07530W), Crooked (2245N07413W), Eleuthera (2510N07614W), Great Exuma (2330N07545W), Great Inagua (2105N07318W), Long (2315N07504W), Mayaguana | Fresh water is available from the limestone aquifer lenses. TDS for the islands ranges from 90 to 400 mg/L. The water quality of the limestone is generally good.<br><br>Shallow ground water may be biologically contaminated near settlements, specifically throughout the heavily populated island of New Providence (2502N07724W). Near the coast, fresh water is underlain by brackish or saline water. | The terrain is flat on the Bahamian islands, with the exception of large sand dunes. Accessibility, siting, and drilling of wells should not be difficult, except in those areas surrounded by wetlands.<br><br>Depth to water ranges from 0 to 6 m. | Quantities are much less than the larger fresh water lenses of Unit 1.<br><br>Ground water should be extracted using shallow, hand-dug wells, hand or electric pumps in uncased wells, and/or trenches/pits.<br><br>Suitable for tactical wells, small |

**Table C-1. Water Resources (Continued)**

| Map Unit No. (See Figs. C-1 through C-3) | Aquifer Characteristics | Quantity[1] | Quality[2] | Aspects of Ground Water Development | Remarks |
|---|---|---|---|---|---|
| 2<br>Fresh water locally plentiful (continued) | found at the fresh water-saltwater interface.<br><br>Fresh water occurs as Ghyben-Hertzberg lenses, which are composed of three layers: a fresh-water zone, a brackish- transition zone, and a salt-water zone on the bottom. Rain water is the only source of fresh water to these lenses.<br><br>Located near the interior and coasts of the Bahamian islands. Thickness varies from 3 m (10 ft) on Crooked Island (2245N07413W) to 21 m (70 ft) on Eleuthera Island (2510N07614W). | (2223N07257W), New Providence (2502N07724W), and San Salvador (2402N07430N) islands.<br><br>Yields on Abaco Island (2628N07705W) range from 0.015 to 0.25 L/s. Specific capacities range from 17 to 1,300 L/min/m.<br><br>Yields on Acklins Island (2226N07400W) range from 0.06 to 1.0 L/s.<br><br>Smaller lenses on Andros Island (2426N07757W) such as those near Red Bay (2508N07811W) and The Bluff Settlement (2407N07733W) report yields between 0.06 to 3 L/s. Specific capacities range from 150 to > 2,000 L/min/m.<br><br>Lenses located near McQueens Settlement (2410N07528W) and Devils Point (2407N07528W) on Cat Island (2423N07530W) have yields ranging from 0.6 to 1.5 L/s. Smaller lenses near Old Bight (2415N07521W) and Arthurs Town (2438N07542W) report yields of 0.015 to 0.06 L/s.<br><br>Yields on Crooked Island (2245N07413W) are as high as 1.5 L/s from large lenses near Church Grove (2245N07413W), Majors Cay (2243N07407W), and Bullets Hill (2244N07405W). Although pumping tests have not been performed for the smaller Fairfield/Moss lenses (2247N07413W), recommended pumping rates are less than 0.25 L/s, based on the Land Resources Study, 1976.<br><br>Yields on Eleuthera Island (2510N07614W) range between 0.06 to 0.6 L/s. Specific capacities range from 1 to 754 L/min/m.<br><br>Yields are limited on Great Exuma Island | | Because saltwater zones underlie the fresh-water zones in the limestone lenses, caution should be exercised in pumping to prevent saltwater intrusion and drawdown should be monitored.<br><br>Extraction from the lenses on New Providence have shown signs of over abstraction. Additional development of these lenses is not recommended.<br><br>Pumping rates in this report refer to extraction from one borehole. In order to obtain larger quantities of water, a network of boreholes, wellfields and/or trenches should be used.<br><br>Large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities. | submersible pump wells, and hand-pump wells.<br><br>Ground water supplies on New Providence are currently being exploited to their maximum potential. Ground water exploration during military exercises is not recommended. |

**Table C-1. Water Resources (Continued)**

| Map Unit No. (See Figs. C-1 through C-3) | Aquifer Characteristics | Quantity[1] | Quality[2] | Aspects of Ground Water Development | Remarks |
|---|---|---|---|---|---|
| 2<br>Fresh water locally plentiful (continued) | | (2330N07545W) and range between 0.015 to 0.25 L/s.<br><br>Yields are limited on Great Inagua Island (2105N07318W) and range between 0.06 to 0.25 L/s.<br><br>Yields are also limited on Long Island (2315N07504W) and range between <0.015 to 0.06 L/s.<br><br>Yields on Mayaguana Island (2223N07257W) range from 0.6 to 1.5 L/s.<br><br>Yields on New Providence Island (2502N07724W) are estimated between 0.015 and 0.25 L/s.<br><br>The distribution of limestone lenses on San Salvador Island (2402N07430W) is limited. Yields of 0.06 to 0.25 L/s should be expected. | | | |
| 3<br>Fresh water locally plentiful | Well-sorted, fine-grained, unconsolidated sands of Holocene age. The sands are oolitic in some areas and highly porous, however, the pores are very small and surface tension is high.<br><br>Fresh water occurs as Ghyben-Hertzberg lenses, which are composed of three layers: a fresh-water zone, a brackish- transition zone, and a salt-water zone on the bottom. Rain water is the only source of fresh water recharge to these lenses.<br><br>Located along the coasts of the Bahamian islands. | Unsuitable to small quantities available from large fresh water lenses located on nearly all of the Bahamian islands.<br><br>Sandy aquifers are located along the coast of Abaco Island (2628N07705W), with a large lens near Treasure Cay (2640N7716W). Yields range from 0.015 to 0.25 L/s.<br><br>Yields from aquifers located near Chesters (2243N07355W) and Cold Rock (2228N07356W) on Acklins Island (2226N07400W) range from 0.015 to 0.06 L/s.<br><br>Yields from sandy aquifers along the coasts of Cat Island (2423N07530W) are limited and range between 0.015 to 0.06 L/s.<br><br>Yields from aquifers located near Landrail Point (2248N07421W) and Winding Bay (2243N07408W) on Crooked Island (2245N07413W) range | Fresh water may be available from the sandy aquifer lenses. TDS for the islands ranges from 90 to 400 mg/L, however, this fresh water zone is thin and the water quality of the sands is generally brackish.<br><br>Near the coast, fresh water is underlain by brackish or saline water. Over-pumping of the aquifer will lead to salt-water intrusion. | The terrain is flat on the Bahamian islands, with the exception of large sand dunes. Accessibility, siting, and drilling of wells should not be difficult, except in those areas surrounded by wetlands.<br><br>Depth to water ranges from 0 to 6 m.<br><br>Because saltwater zones underlie the fresh-water zones in the sandy lenses, caution should be exercised in pumping to prevent saltwater intrusion and drawdown should be monitored.<br><br>Wells should be screened and cased due to the unconsolidated nature of the material. | With the exceptions of Eleuthera (2510N07614W) and San Salvador (2402N07430W) islands, the aquifer is not suitable for tactical wells, small submersible pump wells, and/or hand-pump wells. |

## Table C-1. Water Resources (Continued)

| Map Unit No. (See Figs. C-1 through C-3) | Aquifer Characteristics | Quantity[1] | Quality[2] | Aspects of Ground Water Development | Remarks |
|---|---|---|---|---|---|
| 3<br>Fresh water locally plentiful (continued) | | from 0.015 to 0.06 L/s.<br><br>Eleuthera Island (2510N07614W) boasts the most extensive sandy aquifers and yields are between 0.06 to 0.6 L/s. Specific capacities range from 1 to 754 L/min/m.<br><br>Yields near Ocean Bight (2337N07355W) on Great Exuma Island (2330N07545W) range from 0.015 to 0.25 L/s.<br><br>Sandy aquifers along the coast of San Salvador Island (2402N07430W) boast yields of 0.25 to 1.5 L/s. | | Pumping rates in this report refer to extraction from one borehole. In order to obtain larger quantities of water, a network of boreholes, wellfields and/or trenches should be used.<br><br>Large scale ground water exploitation is not recommended for aquifers with lenses less than 9 m thick. Ground water extracted from these thin lenses will produce yields with increasing salinities. | |
| 4<br>Fresh water scarce or lacking | Older, karstic limestone bedrock, poorly- stratified, fossiliferous, and consisting of highly oolitic eolianite of Pleistocene age.<br><br>Fresh water lenses do not form in this aquifer, thus rain water infiltrates the aquifer and mixes directly with the brackish or saline water. | Unsuitable quantities of water available from this deep aquifer. | Quality is poor, as the water is brackish to saline. | Development is not recommended in this unit. | |

[1]Quantitative Terms:

| | |
|---|---|
| Enormous | $\geq$ 6 L/s (100 gal/min) |
| Very large | $\geq$ 3 to 6 L/s (50 to 100 gal/min) |
| Large | $\geq$ 1.5 to 3 L/s (25 to 50 gal/min) |
| Moderate | $\geq$ 0.6 to 1.5 L/s (10 to 25 gal/min) |
| Small | $\geq$ 0.25 to 0.6 L/s (4 to 10 gal/min) |
| Very small | $\geq$ 0.06 to 0.25 L/s (1 to 4 gal/min) |
| Meager | $\geq$ 0.015 to 0.06 L/s (0.25 to 1 gal/min) |
| Unsuitable | < 0.015 L/s (0.25 gal/min) |

[2]Qualitative Terms:

| | | |
|---|---|---|
| Fresh water | = | maximum TDS <1,000 mg/L; maximum chlorides (Cl), $\leq$600 mg/L; maximum sulfates ($SO_4$), $\leq$300 mg/L |
| Brackish water | = | maximum TDS $\geq$1,000 mg/L but $\leq$15,000 mg/L |
| Saline water | = | TDS >15,000 mg/L |

Hardness Terms:

| | | |
|---|---|---|
| Soft | $\geq$ | 0 to 60 mg/L $CaCO_3$ |
| Moderately hard | $\geq$ | 61 to 120 mg/L $CaCO_3$ |
| Hard | $\geq$ | 121 to 180 mg/L $CaCO_3$ |
| Very hard | $\geq$ | 181 mg/L $CaCO_3$ |

Conversion Chart:

| To Convert | Multiply By | To Obtain |
|---|---|---|
| liters per second | 15.84 | gallons per minutes |
| liters per second | 60 | liters per minute |
| liters per second | 950 | gallons per hour |
| liters per minute | 380 | gallons per day |
| gallons per minute | 0.063 | liters per second |
| gallons per minute | 3.78 | liters per minute |

[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:

**New Providence Island....................... 2502N07724W**

## Table C-1. Water Resources (Continued)

Geographic coordinates for New Providence Island are given as 2502N07724W equal 25° 02' north 77° 24' west and can be written as a latitude of 25 degrees and 2 minutes north and a longitude of 77 degrees 24 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates are approximate. The coordinates for most features are generally located at the central most point. For more detailed information refer to the List of Place Names section at the beginning of this assessment.

Note:

| | | | | | |
|---|---|---|---|---|---|
| $CaCO_3$ | = calcium carbonate | L/min/m | = liters per minute per meter | mg/L | = milligrams per liter |
| $Cl^-$ | = chloride | L/s | = liters per second | $SO_4$ | = sulfate |
| ft | = feet | m | = meters | < | = less than |
| gal/min | = gallons per minute | | | | |
| TDS | = total dissolved solids | | | | |
| > | = greater than | | | | |