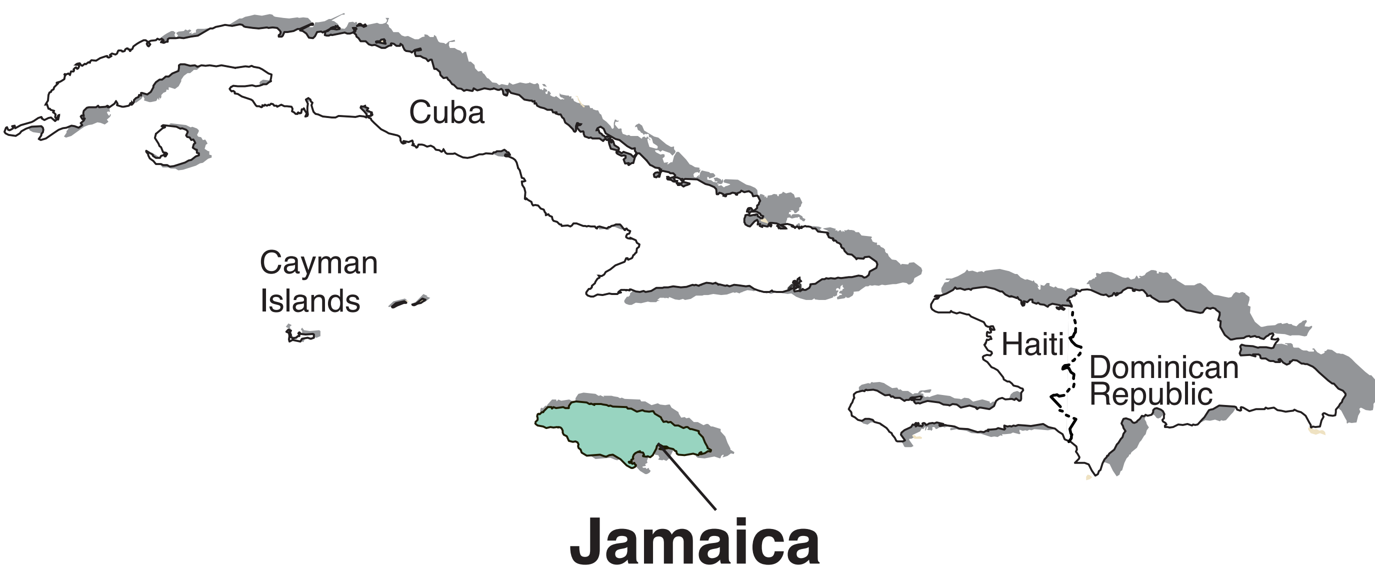
WATER RESOURCES ASSESSMENT OF JAMAICA

UNITED STATES SOUTHERN COMMAND



US Army Corps of Engineers
Mobile District &
Topographic Engineering Center

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Executive Summary

Jamaica is rich in hydrologic resources. Given the rainfall and abundant water resources, there is adequate water to meet demands, but the uneven rainfall distribution causes water supply problems in the drier areas of the island. Jamaica is heavily dependent on ground water for most of the water supply, most of which is used for irrigation. Much water is wasted due to acute irrigation inefficiencies. Many ground water sources, however, are becoming polluted due to the bauxite-alumina industry, saline intrusion in production wells in the southern plains, and excessive nitrates due to improper sewage disposal, particularly in Kingston.

Most of the environmental problems inherent in Jamaica are similar to those of the rest of the world, such as deforestation, inadequate and insufficient engineering structures to control flooding, erosion, and watershed management, all of which impact the water resources of the country.

Many agencies have responsibility for the water resources and supply of the country. Although currently there is no comprehensive water policy, the passage of the draft Water Sector Policy will be beneficial. Most of the water agencies conduct their missions by coordinating with other agencies, but funding constraints and frequent institutional reorganizations create duplication of work and inefficient use of resources.

Deforestation, with its negative environmental consequences, is a problem in Jamaica. The health of the reservoirs is a major concern. Two reservoirs that supply water to Kingston have significant siltation. About 10 out of the 15 reservoirs in the country are significantly silted. Some of the siltation, however, is caused by soil erosion due to the karst topography and agricultural practices. The draft watershed policy that is currently in review needs to be implemented to address deforestation and water resources management.

If the recommendations for watershed management are adopted, if progress is made toward reducing the untreated waste entering the water supply, and if a national water sector policy is implemented, positive, immediate, and long-term protection of the water resources could be realized.

Preface

In 1997 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 Jamaica. This assessment has two objectives. One objective is to provide an analysis of the existing water resources and identify some opportunities available to the Government of Jamaica to maximize the use of these resources. The other objective is to provide Jamaica and U.S. military planners with accurate information for planning various joint military training exercises and humanitarian civic-assistance engineer exercises.

A team consisting of the undersigned water resources specialists from the U.S. Army Corps of Engineers Mobile District and the Topographic Engineering Center conducted the water resources investigations for this report in 2000.

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Contents

Contents (Continued)

List of Acronyms and Abbreviations

Acronyms

GDP	gross domestic product
GNP	gross national product
KMA	Kingston Metropolitan Area
JPSCo	Jamaica Public Service Company
MOH	Ministry of Health
MOW	Ministry of Water
NGO	nongovernment organization
NDC	National Disaster Committee
NIC	National Irrigation Commission
NIDP	National Irrigation Development Plan
NMS	National Meteorological Service
NWC	National Water Commission
NRCA	Natural Resources Conservation Authority
OPDEM	Office of Disaster Preparedness and Emergency Management
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USSOUTHCOM	United States Southern Command
WHO	World Health Organization
WMU	Watershed Management Unit
WRA	Water Resources Authority
WRMDP	Water Resources Master Development Plan

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
Ca	calcium
$CaCO_3$	calcium carbonate
Cl	chloride
Fe	iron
gal/min	gallons per minute
J$	Jamaican dollar
km^2	square kilometers
L/min	liters per minute
m^3/s	cubic meters per second
Mg	magnesium
mg/L	milligrams per liter
mm	millimeters
Mm^3	million cubic meters
Mm^3/yr	million cubic meters per year
MW	megawatts
NaCl	sodium chloride
pH	hydrogen-ion concentration
PVC	Polyvinyl chloride
SO_4	sulfate
TDS	total dissolved solids
TSS	total suspended solids

List of Place Names

Place Name	Geographic Coordinates
Albert Town	1817N07733W
Alley	1748N07716W
Alligator Pond	1752N07734W
Annotto Bay	1816N07646W
Annotto River	1811N07627W
Appleton	1810N07744W
Back Rio Grande	1807N07627W
Bath	1757N07621W
Black River (Black River Basin)	1801N07751W
Black River (Rio Cobre Basin)	1808N07702W
Black River Basin	1806N07744W
Black River (town)	1801N07751W
Blue Mountain North Basin	1810N07642W
Blue Mountain Peak	1803N07635W
Blue Mountain South Basin	1757N07628W
Bog Walk	1806N07701W
Boundbrook River	1811N07628W
Breadnut Gully	1751N07710W
Broad River	1802N07751W
Browns Town	1824N07722W
Buff Bay	1814N07640W
Bunkers Hill	1823N07741W
Cabarita River	1813N07810W
Cabarita River Basin	1818N07807W
Caribbean Sea	1500N07500W
Castleton	1810N07649W
Cave River	1812N07721W
Caymanas	1801N07654W
Central Village	1759N07655W
Chapelton	1805N07716W
Clarks Town	1825N07734W
Clarks Town Pond	1825N07734W
Clarendon Parish	1759N07718W
Cockpit Country	1818N07743W
Coleburns Gully	1754N07704W
Constant Spring	1803N07648W
Danks	1806N07717W
Devon Point	1812N07649W
Discovery Bay	1828N07724W
Dornock Head Rising	1824N07727W

List of Place Names (Continued)

List of Place Names (Continued)

List of Place Names (Continued)

List of Place Names (Continued)

List of Place Names (Continued)

Place Name	Geographic Coordinates
Salt Island Creek	1754N07702W
Salt Island Lagoon	1753N07659W
Salt Ponds, The	1751N07633W
Salt River	1802N07643W
Santa Cruz Mountains	1758N07743W
Savanna-la-Mar	1813N07808W
Scotts Pass	1800N07723W
Sevens	1758N07713W
South Elim River	1807N07742W
South Negril River	1816N07821W
Spanish River	1814N07637W
Spanish Town	1759N07657W
Swift River	1812N07634W
Thomas River	1806N07716W
Trelawny Parish	1823N07738W
Troy	1815N07737W
Upper Black River Morass	1806N07743W
Wag Water River	1816N07647W
Wakefield Pond	1825N07743W
Wallywash Pond	1758N07748W
Wemyss Pond	1824N07746W
Westmoreland Parish	1814N07809W
West Town River	1810N07627W
White River	1825N07704W
Windsor	1810N07743W
Yallahs (town)	1752N07634W
Yallahs River	1752N07636W
Y.S. River	1803N07750W

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

Albert Town..1817N07733W

Geographic coordinates for Albert Town that are given as 1817N07733W equal 18°17' N 77°33' W and can be written as a latitude of 18 degrees and 17 minutes north and a longitude of 77 degrees and 33 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

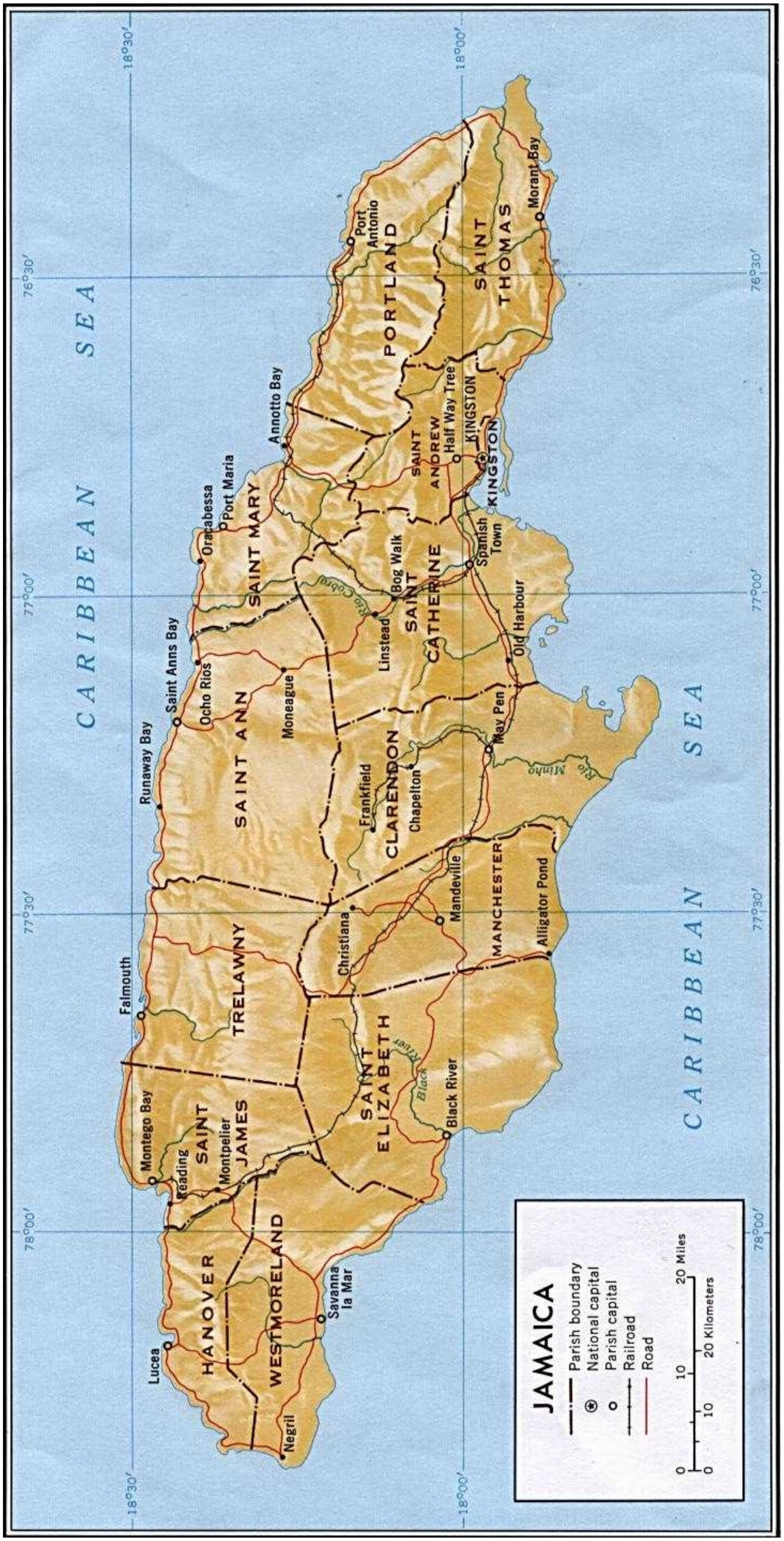


Figure 1. Country Map

Water Resources Assessment of Jamaica

I. Introduction

Water 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, it is expected to be 4 billion people. 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.

There is a direct relationship between the abundance of water, population density, and quality of life. 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.[1] 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 away. If the water source is more than 1,000 meters away, water use drops to less than 7 liters per day per person.[2] As well as being in abundant supply, the available water must have specific quality characteristics, such as the low concentration of total dissolved solids (TDS). The TDS concentration of water affects the domestic, industrial, commercial, and agricultural uses of water. The natural nontoxic constituents of water are not a major deterrent to domestic use until the TDS concentration exceeds 1,000 milligrams per liter. As TDS values increase to over 1,000 milligrams per liter, the usefulness of water for commercial, industrial, and agricultural purposes 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.

The purpose of this assessment is to document the general water resources situation in Jamaica. 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 is the result of an in-country information-gathering trip and information obtained in the United States by three water resources professionals. The scope is confined to a “professional opinion,” given the size of the country and the host of technical reports available on the various water resources aspects of Jamaica.

This information can be used to support current and potential future investments in managing the water resources of the country and to assist military planners during troop engineering exercise and theater engagement planning. The surface water and ground water graphics, complemented by the tables in appendix C, should be useful to water planners as overviews of available water resources on a country scale. The surface water graphic divides the country into surface water regions, based on water quantities available. The ground water graphic divides the country into regions with similar ground water characteristics.

In addition to assisting the military planner, this assessment can aid the host nation by highlighting its critical need areas, which in turn serves to support potential water resources development, preservation, and enhancement funding programs. Highlighted problems are the lack of access to water supply by much of the population, the density of the urban population in Kingston, the lack of wastewater treatment, and contamination by industrial processes associated with bauxite mining, sugar cane processing, and agricultural activities.

Responsibility for overseeing the water resources 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 the water resources (see appendix A). Most of these agencies conduct their missions by coordinating with other agencies, but funding constraints and frequent institutional reorganizations create duplication of work and inefficient use of resources.

II. Country Profile

A. Geography

The West Indies island of Jamaica lies in the northwestern Caribbean Sea, 98.4 kilometers (90 miles) south of Cuba. Its strategic location is between the Cayman Trench and the Jamaica Channel, the main sea lanes for the Panama Canal. With its 10,991 square kilometers of territory, Jamaica is similar in size to the U.S. state of Connecticut, and is the third largest of the Caribbean islands. See figure 2.

Figure 2. Vicinity Map

In general, the topography consists of coastal plains encircling an island that is bisected from east to west along its length by mountains and plateaus. Magnificent mountains dominate the island. The principal range runs east to west, and the summit, Blue Mountain Peak, at approximately 2,256 meters (7,402 feet), stands near the eastern end. A variety of minerals, such as limestone and bauxite, are found in the mountains. Central mountain ranges form the main watershed for rivers that drain either to the north or to the south coasts. The mountains contribute to the great diversity of scenery for which the island is famous, ranging from the stunted elfin forests of the highest peaks to the dry, sandy, cactus-growing areas of the south. There are rain forests in the highlands and flat alluvial plains located mainly in the southern half of the island, where they are often associated with coastal swamps/wetlands. Jamaica is situated along a frequent path of hurricanes, and is susceptible to tropical storms and hurricanes from July through November.[3]

Lava cones in the Blue Mountains and hot springs on the east and south coasts are vestiges of volcanic activity. Earthquakes occur due to the proximity of the plate boundary separating the small Caribbean Plate from the North American Plate. The two largest earthquakes to impact in historic times were those of 1692 and 1907. Because it is built on unconsolidated alluvial sands and gravels (the Liguanea Plain), Kingston is more susceptible to tremors than other areas.[4]

The island is divided into three counties, Cornwall, Middlesex, and Surrey, and is further subdivided into 14 parishes. Each parish has a capital town, which is its center of local government administration. Kingston, situated in the southeastern part of the island, is the capital city of the country. Kingston and Montego Bay are the two major urban centers of the country.[5]

B. Population and Social Impacts

The population in 1998 was 2,590,400, with a density of about 230 persons per square kilometer (see table 1). This population density is comparatively high for the Caribbean and Latin America, and is eight times the average for lower middle-income countries. In 1991 about 50 percent of the population lived in urban areas and 50 percent in rural areas. Almost half the population lives in the major urban areas of Kingston, Saint Andrew, and Saint Catherine. In 2010 the projected population is estimated to be 2,814,000. Two important demographic trends are the contraction in the household size and the proportion of the population in the younger age groups. The population remains basically young with over 60 percent under the age of 29.[6,7,8]

The parish of Kingston has the highest population density of 4,760 persons per square kilometer followed by Saint Andrew with 1,254 per square kilometer. Trelawny has the lowest population density of 83 persons per square kilometer. The regional disparities in population densities impact on regional threats to natural resources and environmental problems, in that, in some areas population pressure may lead to catastrophic and unsustainable use of natural resources while other areas remain underutilized and underdeveloped. The Kingston Metropolitan Area (KMA), including Portmore, is one of the largest urban areas in the Caribbean and contains about 26 percent of the country's population. More significantly, the land area of the KMA zone has expanded westward and is currently experiencing an annual growth rate of 2.30 percent, which represents the fastest growing of the country's urban areas. This kind of extensive, rapid, and poorly managed urbanization contributes significantly to pollution of the air and water resources and to severe waste management problems. Highly polluted water and airborne pollutants increase morbidity and respiratory diseases and other illnesses.[9]

Population growth leads to increased use of water for food production and household use, which, in turn, may exacerbate water and food shortages, ultimately leading to economic and social crises. Naturally scarce water supplies, poor water quality, or uneven distribution of water resources may have adverse effects on the health and ultimately the growth and distribution of populations.

The most significant demographic trend affecting water resources is population growth. More people and increasing consumption of food, consumer goods, and water for domestic use have created demands for clean fresh water that in many areas exceed water availability.

Table 1. Population Distribution

Parish	1998 Estimated Population	Capital	Area (km^2)
Clarendon	227,500	May Pen	1,196.3
Hanover	67,800	Lucea	450.4
Kingston	Included in Saint Andrew	Kingston	21.8
Manchester	185,900	Mandeville	830.1
Portland	79,300	Port Antonio	814.0
Saint Andrew	711,200	Half Way Tree	430.7
Saint Ann	163,700	Saint Anns Bay	1,212.6
Saint Catherine	411,600	Spanish Town	1,192.4
Saint Elizabeth	148,900	Black River	1,212.4
Saint James	178,000	Montego Bay	594.9
Saint Mary	113,000	Port Maria	610.5
Saint Thomas	91,900	Morant Bay	742.8
Trelawny	72,600	Falmouth	874.6
Westmoreland	139,000	Savanna la Mar	807.0
Total	**2,590,400**		**10,990.5**

Sources:

Statistical Institute of Jamaica (STATIN), *Demographic Statistical Report 1999*, Kingston, 1999.

STATIN, *Statistical Yearbook of Jamaica 1997*, 1998.

C. Economy

The economy of the country depends on its environment and natural resources. Bauxite/alumina manufacturing and tourism earn the most foreign exchange for the country. Tourism is the principal earner with an emphasis on Eco-tourism.[10] Historically, however, agriculture has provided employment for the largest number of people, but production has not kept pace with population growth.[11] The main crops were sugar cane and bananas, but their production declined with the mining/development of bauxite/alumina, which began in the 1950's.[12]

In 1996 the Gross Domestic Product (GDP), the sum of all goods and services produced, was J$202.1 billion, compared to J$162.6 billion in 1995. Agriculture has maintained a positive growth rate since 1992. Mining was the fastest-growing goods-producing sector. Positive economic indicators are the steady decline of the inflation rate and the relative stability of the Jamaican dollar. In 1995-96 population employment was about 83 percent. Also in 1996, it was estimated that about 26 percent of the population lived below the poverty level.[13]

Jamaica is the third largest producer of bauxite ore in the world and fourth in the production of alumina. Bauxite and alumina accounted for about 75 percent of total exports (1992). Caustic soda contamination of water supplies, bauxite and alumina dust, and ecosystem dislocation are principal environmental issues facing this industry. See chapter IV, section A4, for further information.

D. Flood Control

The Office of Disaster Preparedness and Emergency Management (OPDEM) is one of the many arms of the National Disaster Committee (NDC) chaired by the Prime Minister. The NDC is the main coordinating body for disasters affecting the country. Numerous agencies form the NDC and work alongside the OPDEM to fulfill its mandate. These agencies are placed on committees to maximize their effectiveness. The National Zonal Programme was put in place by the OPDEM after Hurricane Gilbert in 1988 for communities to be better prepared to react in a disaster. Flooding maps are available for four rivers. Maps are underway, but not yet complete, for many other rivers. However, when floodplain maps are developed, enforcement is difficult. No floodplain regulation exists now, but one is being drafted by OPDEM.[14,15]

Of all natural hazards capable of producing a disaster, a flood is the most common in causing loss of life, human suffering, inconvenience, and widespread damage to buildings, structures, crop, infrastructure, and other national assets. Severe weather conditions that lead to intense rainfall such as tropical depressions and hurricanes often lead to flooding.

Three types of floods are likely to occur in Jamaica:

- Flash flooding - can occur in almost any area, but is most common in mountain districts that are subject to frequent severe thunderstorms. Flash floods are often the result of heavy rains of short duration falling over a small area. This particular type of flooding can wash away roads and bridges, damage houses, and drown livestock.
- Riverine flooding - occurs in the valleys of large rivers with many tributaries. Usually, flooding develops from rainfall lasting for hours, sometimes days, and covering a wide area of watershed. The Rio Minho Valley in the plains of Clarendon is one such area affected by this type of flooding.
- Tidal flooding - occurs generally along the coast, usually when seas are swept toward the shore by high winds. A common cause of this type of flooding is the storm surge which occurs during and after hurricanes.

Floods are a natural hazard for Jamaica. Since the eighteenth century, the island has experienced more than 50 major events. A flood may be a natural phenomenon, but its effects are often exacerbated or caused by unwise human activities. For example, people increase their susceptibility to flooding by living in low-lying coastal areas, building in the flood plain of major rivers, or residing in the lower sections of closed limestone valleys such as New Market in Saint Elizabeth. Such risks could be minimized by identifying the susceptible areas via the Flood Plain Mapping Programme carried out by the OPDEM in the 1980's, learning the flood history of the area from older residents, and respecting the natural watercourses. Another major cause of flooding is blocked drainage. During periods of heavy rain, the refuse blocking drains has a dam effect, preventing the water from flowing freely. This creates overflows and ultimately flooding. Deforestation can also cause flooding. When trees are uprooted, there is no buffer to hold soil and consequently water in place. Without the tree root system, the rainwater runs freely down slopes carrying soil and debris with it. One of the theories as to why Portland was so devastated by flood rains recently is the adverse effects of deforestation in the hills of the parish.

Flood control structures used in Jamaica include (1) check dams; (2) retaining walls; (3) bunding; and (4) paved drains. Check dams are small gravity dams, usually constructed with rocks or concrete of variable height and width. These structures are located in small- or medium-sized gullies to stabilize riverbed slopes and prevent soil erosion. Retaining walls are rock/concrete block structures built on steep slopes anywhere in the watershed, where lands and/or homes are threatened by the erosion at the base of the foundation. Bunding is the general name used in Jamaica for flexible structures of variable thickness and length composed of galvanized wire mesh, stone, wild cane, and riverbed materials. Bunding is used to prevent bank erosion and landslides and to protect agricultural lands from being flooded. Paved drains are V-shaped concrete structures designed to quickly remove water from highly susceptible, erodible areas such as roadsides, under bridges, and steep slopes. The advantages of flood control structures are that maintenance is simple and no major equipment is required. The cost is relatively low, because the only imported material is galvanized wire. The major disadvantage is that they require regular maintenance.[16]

E. Legislative Framework

The Ministry of Water (MOW) was established in 1998 after the new government took over. It is the focal point for activities in the water sector and has assumed the role of the main coordinating agency in the sector. It has responsibility for planning, development, and operations in the water sector. This responsibility is discharged through the Water Resources Authority (WRA), the National Water Commission (NWC), the National Meteorological Service (NWS), and the National Irrigation Commission (NIC).

A draft National Water Sector Policy prepared by the MOW in January 1999 is in review, but needs revisions in areas. This policy outlines:

- the current situation and problems within the water sector;
- defines the objectives of the government to address the issues; and
- sets out the mode of implementation.

The principal water law in Jamaica is the Water Resources Act (1995), enacted in April 1996, making the WRA responsible for regulation, control, allocation, and management of the water resources of the nation. This Act allows the WRA to declare a water quality zone to protect water quality in the public interest. Working with the Natural Resources Conservation Authority (NRCA), the WRA can apply the principle ‘polluter pays’ and can force anyone polluting to clean up. The passing of the Water Resources Act marked a 25-year effort to address the deficiencies in legislation for the proper administration, development, and optimal use of the water resources.

Formerly known as the Underground Water Authority, the WRA produced a Water Resources Master Development Plan in 1990. This Plan consists of a main volume and eight annexes (appendices). This plan is currently being updated. The major activities of the WRA include:

- watershed management/resource protection;
- resource monitoring and assessment (quantity and quality);
- development planning;
- licensing of abstractions;
- flood studies; and
- public education.

The NWC is responsible for urban water supply throughout the island and is the largest provider of sewerage services. The NWC also has responsibility for many of the parish water systems and supplies 75 percent of the population with potable water. The NWC is a statutory body created in 1980 under the National Water Commission Act. It is the principal implementing agency responsible for water resources development in the nonagricultural sector.

The NIC is responsible for the development of agricultural water supply sources and for the operational aspects of the production and distribution. It was incorporated under the Companies Act in 1986. The primary goals of the NIC are to increase productivity and profitability in the agricultural sector and to achieve and maintain financial self-sustenance of the irrigation industry. The NIC was commissioned by the government to prepare a National Irrigation Development Plan (NIDP). This plan was produced in February 1998, using much information from the Water Resources Master Development Plan from 1990. The Master Plan of the NIDP assessed the current and potential state of the irrigated agricultural sector, the constraints and deficiencies facing the sector and proposed policy, and the strategy and development plans to relieve the constraints and overcome the deficiencies within the sector. The NIDP is scheduled for implementation over a 17-year period (until the year 2015). Fifty-one irrigation projects are proposed for implementation, with 27 of them recommended for implementation during the first 5 years of the plan.[17,18,19,20,21]

The management of watershed protection is vested principally in the NRCA, which was created by the Natural Resources Conservation Authority Act of 1991. The NRCA produced a draft Watershed Policy to address the most severe constraints to watershed management and to seek to employ strategies to ensure the sustainable use and development of watersheds. The policy states the essential elements of a national watershed management initiative. It seeks to define opportunities for the people, for the government and nongovernment organizations, and for the international community to participate in the sustainable management and conservation of watersheds of Jamaica in the interest of water supply and bio-diversity. The Watershed Protection Act (1963) is the law governing watersheds and is administered by the NRCA. The primary focus of the Act is the conservation of water resources by protecting land in or adjoining the watersheds. The Act is intended to ensure proper land use in vital watershed areas, reduce soil erosion, maintain optimum levels of ground water, and promote regular flows in waterways. In addition to this Act, several other pieces of legislation are pertinent to watershed management. The major ones are:

- Natural Resources Conservation Authority Act, 1991;
- Forest Act, 1996;
- Rural Agricultural Development Act, 1990;
- Water Resources Act, 1995;
- Town and Country Planning Act, 1988;
- Land Development and Utilization Act, 1966;
- Country Fires Act, 1988;
- The Mining Act, 1947; and
- Wildlife Protection Act, 1945.[22]

III. Current Uses of Water Resources

A. Water Supply and Distribution

Most of the water supply in Jamaica is from ground water resources, predominantly from limestone aquifers; and most of this water supply is used for agriculture in the Rio Minho and Rio Cobre basins. Ground water accounts for about 92 percent of the water supplied to all sectors (agricultural, domestic, industrial, and tourist). Rainfall is the primary source of water in the country, providing flow in the streams, direct recharge to the limestone and alluvial aquifers, and indirect recharge to the aquifers through the streams. In some rural areas, the rainfall is directly used as water collected by roofs or small ponds for households, small community supplies, or small irrigation.

The demand for water and the exploitable water resources of the island are unevenly distributed. The greatest demand for water occurs in the south, but most of the available water is in the north. Much of the rainfall occurs due to northeasterly trade winds, which are intercepted by the mountain ranges, resulting in the uneven distribution of rainfall over the island. This causes the northern slopes to receive significantly higher rainfall compared to the southern slopes. The northern slopes generally receive 3,000 to 5,000 millimeters of rain per year compared to the southern plains which receive less than 1,500 millimeters per year. Seasonal variability of the rainfall is also high, creating additional water supply problems. However, despite the uneven and seasonal rainfall distribution, the water resources are adequate to supply the needs of the island for the foreseeable future. Islandwide use of water is estimated at 913.1 million cubic meters per year, which is 24 percent of the reliable and safe yields of the surface and ground water (see table 2).[23,24] It is estimated that by 2015, consumption will increase to about 42 percent of the exploitable water resources. However, according to the 1990 Water Resources Master Development Plan (WRMDP), about 1 billion U.S. dollars must be invested in water supply schemes up to the year 2015 if the anticipated water demands are to be satisfied. This large investment may be difficult to fulfill, given the competing sectors of the limited resources. See table 3 for 1995 water supply and demand figures.

The use and allocation of the water resources (as of 1996) is not structured in a coordinated manner, and in many cases narrow user interests infringe upon other users. However, the WRMDP (1990) addresses this issue by taking a multipurpose approach to achieve the most efficient utilization of available water resources rather than a piecemeal approach, as represented by past activities in the water resources field.[25]

The NWC and the NIC respectively have responsibility for the development of nonagricultural and agricultural water sources nationally and for the operational aspects of their production and distribution.[26] In addition to the private capture of rainwater, water is provided to various supply systems from 140 wells, 116 rivers, and 147 springs.[27]

Water demand has increased steadily from an average of 144 million gallons per day in 1980 to about 190 million gallons per day in 1997. During the same period, the water supply has increased to 150 million gallons per day.[28] During the dry season, water shortages occur.[29] Saint James and Trelawny Parishes are oversupplied with nonagricultural water, predominantly in the urban areas.[30]

Table 2. Water Use by Basin and Sector, Mm^3/yr

Hydrologic Basin	Water Sector					
	Agriculture	Domestic Urban	Domestic Rural	Industrial	Tourism	Total
I	12.2	1.7	1.1	1.0	0.0	16.0
II	2.0	61.8	0.0	10.0	0.5	74.3
III	259.8	29.0	1.9	14.0	0.0	304.7
IV	329.0	12.5	7.6	19.0	0.1	368.2
V	31.5	2.5	2.8	1.0	0.2	38.0
VI	23.5	2.4	1.3	6.0	1.1	34.3
VII	2.2	14.6	1.9	4.2	4.9	27.8
VIII	0.0	2.0	1.3	4.2	0.9	8.4
IX	9.3	4.0	0.7	2.4	1.5	17.9
X	12.0	8.0	2.6	0	0.9	23.5
Total	**681.5**	**138.5**	**21.2**	**61.8**	**10.1**	**913.1**

Source:

Water Resources Authority, *World Day for Water*, "Jamaica's Water - Is There Enough?" Kingston, 22 March 1997.

Table 3. 1995 Average Water Supply and Demand (Mm^3/yr)

	Supply				Demands					
		Ground Water								
Basin	Surface Water[1]	Limestone Aquifer	Alluvial Aquifer	Total	Non-Agricultural	Agricultural	Export	Total	Surplus or Deficit	Import
Blue Mountain South	101.80	18.60	44.30	164.70	9.88	21.05	26.50	57.43	107.27	0.00
Kingston	10.20	15.30	20.90	46.40	89.90	0.00	0.00	89.90	-43.50	67.00
Rio Cobre	11.40	378.40	25.40	415.20	49.94	314.41	32.50	396.85	18.35	0.10
Rio Minho	26.70	361.00	78.00	465.70	42.00	260.45	8.30	310.75	154.95	9.00
Black River	48.90	624.60	--	673.50	27.77	24.30	8.30	60.37	613.13	1.2
Cabarita River	0.00	451.00	--	451.00	15.22	6.61	3.95	25.78	425.22	0.00
Great River	58.60	315.60	5.50	379.70	20.96	0.26	0.15	21.37	358.33	9.90
Martha Brae River	19.70	150.60	--	170.30	9.32	11.06	10.30	30.68	139.62	0.20
Dry Harbour Mountain	27.60	691.00	--	718.6	15.55	1.18	1.80	18.53	700.07	0.40
Blue Mountain North	333.00	270.20	7.30	610.50	12.27	5.28	28.10	45.65	564.85	1.10
Total	**637.90**	**3276.30**	**181.40**	**4,095.60**	**292.81**	**644.60**	**119.90**	**1,057.31**	**3,038.29**	**88.9**

[1]The value in the surface water column is the reliable yield, which is the amount of water expected 90 percent of the time.

Note:

Supply minus demands; positive means surplus, and negative means deficit. “Supply” means the available water resources including reliable yields of streams and safe yields of various aquifers.
Dash indicates information is not available or is not applicable.

Source:

Harza Engineering Company International L.P., Annex A-Water Resources, *Preparation of a National Irrigation Development Plan and Preparation of an Irrigation Investment Project, Master Plan*, Vol. 2, Kingston, October 1997.

1. Domestic Uses and Needs

It is the policy of the government that "potable water should be available to all citizens in such quantity and at such quality as to sustain life, irrespective of the citizen's ability to pay."[31]

According to the Ministry of Health (MOH) 1998 Annual Report, about 81 percent of the population has access to piped water, while about 3.8 percent of the population uses untreated water from rivers, springs, and ponds. Approximately 51 percent of the households that obtained drinking water from standpipes, wells, rivers, springs, or ponds travelled between 50 and 900 meters to obtain it. According to the State of Environment report from NRCA, in 1996, 85 percent of the population received treated water. The quality of piped water, however, is not always acceptable. Of 16,226 samples analyzed by the Environmental Control Division of MOH, 20.4 percent were negative and 24.5 percent of this amount tested positive for fecal coliform.[32,33]

Much of the domestic water supply comes from ground water sources. Production figures for selected parishes show the large percentage of domestic water supplies coming from ground water sources in 1997 (see table 4).

Table 4. Domestic Water From Ground Water Sources

Parish	Domestic Water Supplies In Mm³/yr		Percentage Ground Water
	Ground Water	Surface Water	
Saint Catherine	17.1	4.8	78%
Clarendon	9.2	0.7	93%
Saint Elizabeth	7.5	0.4	95%
Saint Thomas	2.4	1.6	60%
Manchester	1.5	0.3	83%

Sources:

National Water Commission-Systems, Internet, http://www.nwcjamaica.com/docs/systems.htm.

Water Resources Authority, *World Day for Water 1998*, "Groundwater: The Invisible Resource," Kingston, 1998.

Identified problems which occur in the nonagricultural sector (mainly domestic water supply) include:

- Inadequate resource assessments and, hence, a shortfall in projected yields;
- poor systems maintenance which result in frequent malfunctioning of components and high leakage losses;
- deterioration of water quality as a result of overpumping of wells or pollution;
- in some cases, no suitable sources in close proximity to demand areas exist, requiring interzone transfers; and
- insufficient storage facilities (reservoirs) to adequately store wet-season flows for dry periods.[34]

a. Urban Areas

Most urban residents have access to safe, piped, potable water. In the Kingston Metropolitan Area (KMA), about 97 percent of households have piped water; and in other towns, 79 percent of households have piped water (up from 73 percent in 1996). Urban households without piped water rely predominantly on standpipes. About half the standpipe users in urban areas travel 50 meters or less to obtain water.[35] Water treatment methods for surface water supply in urban areas mainly consists of sedimentation, coagulation, filtration, and chlorination. Deep wells are treated by chlorination only.

Two reservoirs, Mona and Hermitage, supply water to Kingston. In addition to rivers in the Kingston Basin, several rivers in the Blue Mountain South and Rio Cobre Basins supply water to Kingston. The Hermitage reservoir is fed by naturally flowing streams, but high sediment loads are threatening the usefulness of the reservoir. It is estimated that the capacity of the reservoir has been reduced by about 19 to 21 percent. The Hermitage Treatment Plant, constructed in the 1920's, treats 20 million gallons per day. The Mona Reservoir, which holds 880 million imperial gallons, is fed by Hope River, flowing through channels with sediment/flow control gates. Mona Reservoir feeds one treatment plant, Hope Treatment Plant, which treats 5 million gallons per day. Two more water treatment plants, Constant Spring (the largest) and Sea View, serve Kingston. During the dry season, the reservoirs reach critical levels and restrictions are imposed on the consumers. Many of the wells in the Liguanea Plain that supplied water for Kingston have been abandoned due to excessive nitrate levels. These levels were caused by sewage contamination and saline intrusion due to overpumping.[36,37] To meet the growing domestic demand of the KMA, surface and ground water is imported from adjacent river basins, a practice that is affecting irrigation in some of these basins.[38]

The Kingston distribution system is over 100 years old. Severe head loss in pipes occurs due to calcium deposits from the limestone aquifers. In addition to being old, the distribution system has a confusing layout which is poorly documented. The flow of water is not circular; dead ends are present which collect rust, and hard water creates calcium deposits which constrict or block flow. Probably half the water is lost to poor systems mechanics through the pipes. Red zones exist where large corporations and private citizens illegally tap the water supply. Many of the pressure-reducing valves do not work.[39]

b. Rural Areas

Rural residents obtain water through a variety of sources, such as standpipes, streams, catchment tanks, and truck deliveries. About 39 percent of rural households have piped water (up from 33 percent in 1990, but a decline from 43 percent in 1996). About 25 percent of rural households get water from standpipes; 22 percent use rainwater tanks; and 8 percent obtain water from rivers, streams, and ponds. Of the rural households that rely on standpipes, more than half travel more than 50 meters and about 13 percent travel more than 1,000 meters for access.[40] Concrete aprons are also used to collect surface water. Trucks with open-topped water tanks deliver water to rural areas and distribute to local supply points where people walk to collect it. Water treatment of water supplies mainly consists of chlorination only.[41]

The quality of piped water in rural areas is poorer than in urban areas. The worst affected area is Portland, where 47 percent of the samples tested negative for residual chlorine and 53 percent tested positive for fecal coliform. Other poor performers were Saint Mary, Trelawny, and rural Saint Andrew.[42]

The lower population in rural areas means that the cost of water provision is often higher than in urban areas, while lower incomes in many rural areas make it hard for some customers to meet the full cost of high-quality services.[43]

2. Industrial and Commercial Uses and Needs

The industrial area of Kingston obtains water from Saint Catherine, from Tullis Springs, which provides about 7 million gallons per day.[44] As of the mid-1980's, the industrial sector, including industries with privately developed water systems, used about 8 percent of the capacity. Small industries with low water requirements are supplied from the domestic water supply systems. The bulk of the industrial water is used by the bauxite mining and processing and the sugar processing companies.[45]

3. Agricultural Uses and Needs

The agricultural sector is the major water user on the island, and is one of the key sectors of the Jamaican economy. In 1985 an estimated 681.5 million cubic meters were supplied to this sector, representing 75 percent of the total water supply for the island in that year. The main demand for water in agriculture is for irrigation. The uneven geographical and seasonal distribution of rainfall over the island makes irrigation necessary for the successful cultivation of crops. The demand for irrigation water is greatest in the south, due to lower rainfall and more extensive irrigable lands than are in the north. In 1985 irrigation water in Saint Thomas, Saint Catherine, Clarendon, and Saint Elizabeth accounted for more than 70 percent of the total water supply in each of these parishes. Saint Catherine and Clarendon represent the two most important agricultural areas. In 1985 the supply of irrigation water to these parishes amounted to 86 percent of the total supplied to the agricultural sector islandwide in that year.[46] However, there is a high rate of saltwater intrusion in these parishes.[47] Maximum agricultural water demands are in the Rio Cobre and Rio Minho Basins, which are about 71 percent and 89 percent, respectively, of the total demands in these basins. The reliable surface water yields are about 2.7 percent and 5.7 percent, respectively, of the total reliable supply. Therefore, much of the agricultural demands are met from ground water. However, use of ground water for irrigation is expensive due to high operational costs.[48] Many irrigation well fields on the south coast have high salinity problems.[49] To meet the domestic demands of the KMA, surface water is imported from the Yallahs River of the Blue Mountain South Basin. This practice has impacted the agricultural system in the downstream reaches of the river.[50]

Presently, 36,090 hectares of agricultural land is irrigated, representing only one-half of the potential irrigable land in the island. Less than 30 percent of agricultural land is currently irrigated in each of Saint Thomas, Saint Elizabeth, Trelawny, and Westmoreland. The National Irrigation Commission is working toward bringing under irrigation all potential irrigable land by the year 2015. If accomplished, the estimated demand for irrigation water will increase by 75 percent to 1,337.9 million cubic meters in that year. While the greatest demands will continue to occur in Saint Catherine and Clarendon, the greatest increases are projected for Saint Thomas, Saint Elizabeth, Trelawny, and Westmoreland where demands will increase more than twofold.

Past and present total irrigation water demands have not been met. Irrigation water use is limited by the underdevelopment of sources and infrastructure for its supply, increasing salinity of ground water, and the abandonment of several production wells in the southern part of the arable plains. Without significant development by the year 2015, only one-half of the demand for irrigation water can be met by the existing irrigation water supply facilities. Many of these are in a state of disrepair and require renewal work if they are to operate at their original design capacities.

Irrigation in Jamaica is characterized by low efficiencies and significant wastage of water. Conveyance of water from source to farmland is hindered by the poor condition of many of the existing waterworks. An estimated 20 percent of water is lost in irrigation water supply systems. Further losses occur due to the 'continuous flow' method of delivering water to farmland. Farmers experience a lack of control in the application of irrigation water, and runoff losses from farmland are consequently large.[51]

The use of irrigation water for the principal crop, sugar cane, is uneconomical at the present yields. Investments in irrigation schemes must be accompanied by the adoption of modern cultivation practices to increase yields or by crop diversification. One method of crop diversification would be to introduce high-value crops, as the cost of irrigation water is generally higher than the water residual value (product value of water) with traditional crops.[52] At present, sugar cane is irrigated at efficiencies between 35 and 40 percent in Clarendon and 50 percent in Saint Catherine. Application efficiences with furrow irrigation can be improved to 55 or 60 percent.[53,54] Clarendon has the most acute irrigation water shortage.[55]

B. Hydropower

The Jamaican Public Service Company (JPSCo) is responsible for providing electricity for public use. However, many large private organizations, such as the bauxite-alumina companies, sugar estates, and cement factories, supply electricity for their own use. JPSCo operates eight hydroelectric plants throughout the country. These plants have a total installed capacity of 23.8 megawatts, which only supplies 1 percent of Jamaica's energy needs (see table 5).[56] One of the Rio Bueno hydroelectric plants is actually an extension of the older Rio Bueno plant. With this addition, the design discharge increased from 60 to 86 percent of the average river flow.[57] The Rams Horn Hydroelectric Plant uses water from the Hermitage Reservoir. After passing through Rams Horn, the water is then used by the Constant Spring Plant, along with water conveyed from the Ginger River. Even though hydroelectricity does not significantly contribute to Jamaica's energy needs, it may do so in the future. There are numerous schemes and plans for new hydroelectric plants. The Back Rio Grande is rated as the best suited site for a new hydroelectric plant. This plant will have a potential generating capacity of 50.5 megawatts.[58]

Table 5. Hydropower Plants

Plant Location	Design Discharge (m^3/s)	Design Head (m)	Installed Capacity (MW)
Upper White River	6.4	70.1	3.8
Lower White River	5.1	115.2	4.9
Black River at Maggotty Falls	8.5	88.4	6.3
Rio Bueno (1)	4.8	89.9	2.5
Rio Bueno (2)	--	--	1.1
Roaring River (Dry Harbour Mountains Basin)	2.8	152.4	3.8
Constant Spring	--	--	0.8
Rams Horn	--	--	0.6

Note: Dash indicates information is not available.

Sources:

H. Chin, *Journal of the Geological Society in Jamaica,* "Seminar on Water Resources of Jamaica," Vol. XVIII, Kingston, 1979.

Jamaican Public Service Company, *Hydro Power in Jamaica*, Internet, http://www.pcj.com/hydro.htm, Accessed April 2000, p. 1.

C. Stream Gage Network

Since 1955 the WRA has been managing an islandwide hydrological network providing long records of good quality data on streamflows and ground water levels. These data are primarily used to assess the resources available for water supply, but they are also useful for flood and drought assessment as well as engineering design.

The monitoring network consists of 93 streamflow gaging stations. Recording stations make up 47 of these and provide continuous records of streamflow. Forty-six nonrecording stations provide data on daily average streamflow.

To facilitate monitoring, the island has been divided into three areas: south-central, western, and eastern Jamaica. Monitoring is carried out by three teams, each having 3 to 4 hydrologists/technicians and over 60 local observers islandwide at nonrecording streamflow stations.[59]

However, based on current and future needs, there is an inadequate level of water resources assessment. There is a basic need to expand the hydrologic data network and to upgrade the levels of water resources investigation to conform to the minimum requirements for the successful implementation of water supply and water management projects.[60]

See figure 3 for the locations of selected stream data collection stations.[61]

D. Waterway Transportation

Most of the rivers in Jamaica are not navigable. The height of the mountains causes them to run swiftly in deep beds, and their courses are sometimes broken by waterfalls. One exception is the Black River, the largest river in Jamaica. It is 73 kilometers (44 miles) long, and for 28 kilometers (17 miles) from its mouth, it is navigable for small vessels. The Milk River is navigable for about 3 kilometers (2 miles).

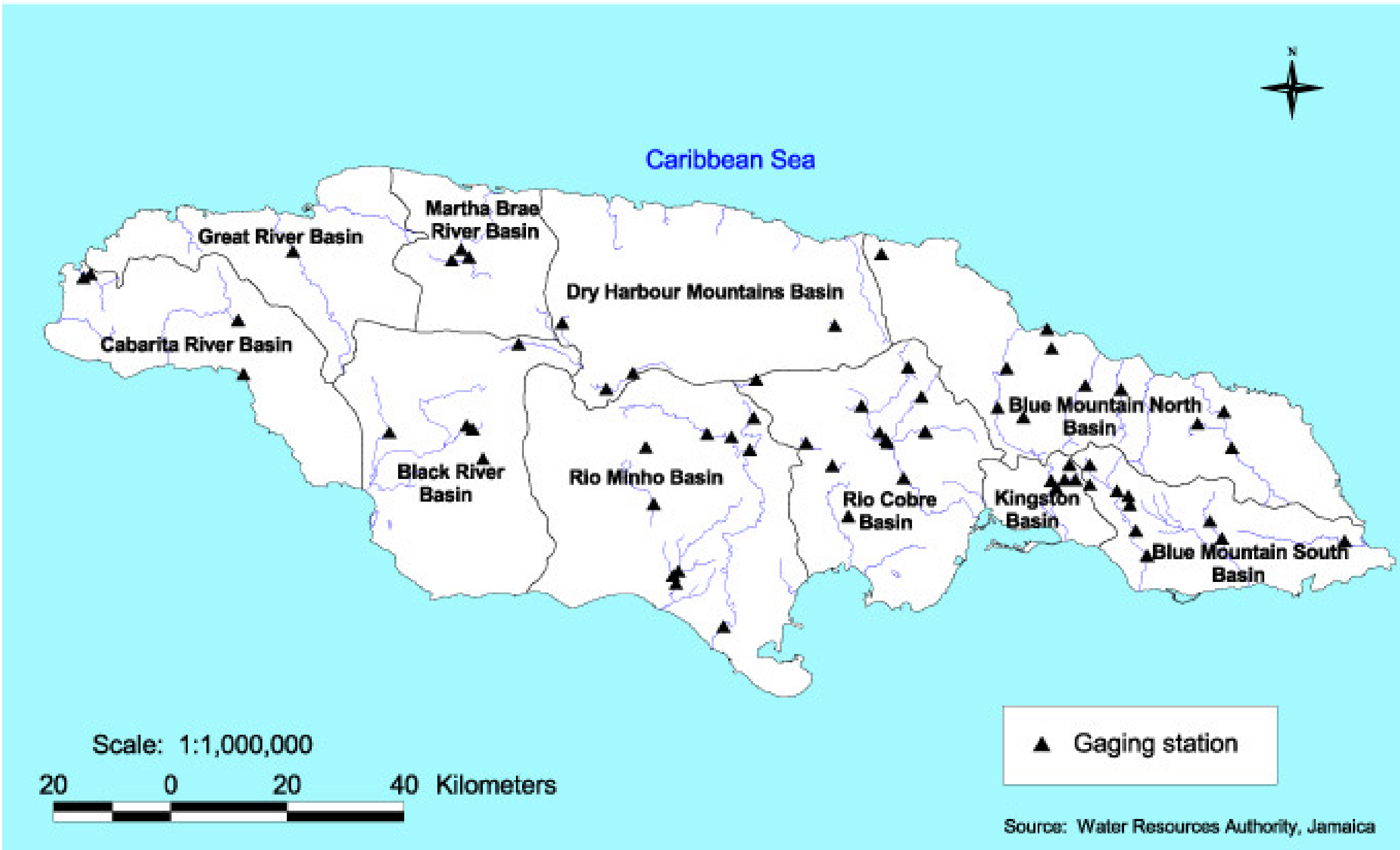


Figure 3. Gaging Stations

Kingston Harbour, the seventh largest natural harbor in the world, contains about 13 kilometers (8 miles) of navigable water. The channel is very deep, and modern developments have made Kingston Harbour an excellent port for shipping of all kinds, including the largest container vessels.[62] It is strategically located close to two of the world's major trade routes. It has an established reputation as the leading transshipment center for both the Caribbean and Central America.[63]

E. Recreation

Several waterfalls have been developed as inland tourist attractions. Among these are: Dunns River Falls (Ocho Rios area of Dry Harbour Mountains Basin); Somerset and Reach Falls (both in the Blue Mountain-North Basin); and Y.S. River Falls (Black River Basin). Rafting is practiced on the lower reaches of the Rio Grande (Blue Mountain North Basin), Martha Brae River (Martha Brae River Basin), and the Great River (Great River Basin). The Black River is used for recreational purposes and has potential for sport fishing. There are also about 35 mineral springs used for recreational and therapeutic purposes.[64]

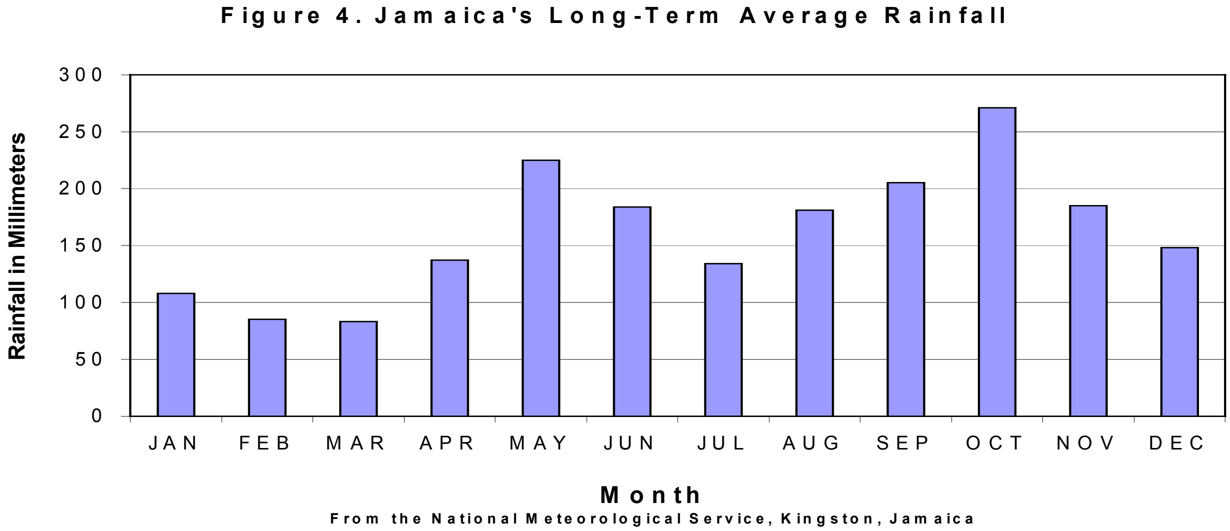
IV. Existing Water Resources

A. Surface Water Resources

1. Precipitation and Climate

Jamaica has a maritime tropical climate. It is hot and humid along the coast, and has a mountainous, temperate interior. On average, the temperature of Jamaica ranges from 26 degrees Celsius (79 degrees Fahrenheit) in February to 30 degrees Celsius (86 degrees Fahrenheit) in August. Temperatures on the north coast are slightly less, due to north-northeast trade winds. In the mountains, temperatures are cooler. On average, the temperature changes by 2 degrees Celsius (3 degrees Fahrenheit) with every 300 meters (1,000 feet) change in altitude.[65] At Blue Mountain Peak, the maximum average temperature is 21 degrees Celsius (70 degrees Fahrenheit), and it has a mean annual temperature of 13 degrees Celsius (56 degrees Fahrenheit).[66,67]

Precipitation in Jamaica varies seasonally and spatially. The average annual rainfall is 1,981 millimeters (78 inches). However, the heaviest rainfall is concentrated over the Blue Mountains. They receive over 5,080 millimeters (200 inches) of rain annually, compared to less than 762 millimeters (30 inches) that the city of Kingston receives.[68] Kingston and most of the southern coast is located in the rain shadow of the Blue Mountains and receives much less rain than the northern coast. Maximum rainfall occurs in May and October, but October generally receives the most rain. The months of February and March generally receive the least amount of rainfall, and a secondary drop in precipitation occurs in July (see figure 4). Between July and November, Jamaica is subject to tropical storms and hurricanes. These can have devastating winds and torrential rains that destroy crops, buildings, roads, and personal property. The country is also subject to northers between September and November. These strong winds generally blow 3 to 4 days bringing cold air and rain from North America, mainly affecting the north coast. These winds are not very significant, except that the banana crop can be damaged by moderate wind speeds. Jamaica is also subject on an average of every 15 years to periodic droughts, which have the most impact on the southern coast.[69]



2. River Basins

Jamaica is divided into 10 hydrological basins (see table 6). These basins are areas that are drained by a specific surface water system. Generally, there is no flow from one basin to another. These 10 basins are further divided into 26 Watershed Management Units (WMUs) for the purposes of water management, development, and assessment. Each WMU is a watershed or group of watersheds that are drained by one river system. Generally, all of the rivers flow north or south from a central mountainous area. An exception is the Plantain Garden River, which follows a fault and flows from west to east. Also, it can be generally stated that rivers flowing northward have a more constant flow; and they carry less sediment, due to geology, and less human activity.

Table 6. Hydrologic Information for the Major Basins

Basin Number (See Fig. C-1)	River Name	Drainage Area (km^2)	Rainfall (Mm^3/yr)	Evapo-transpiration (Mm^3/yr)	Surface Water Runoff (Mm^3/yr)	Surface Water Reliable Yield[1] (Mm^3/yr)
I	Blue Mountain South	759	1,694	912	662	101.8
II	Kingston	232	312	208	81	10.2
III	Rio Cobre	1,218	2,009	1,450	187	11.40
IV	Rio Minho	1,892	2,420	1,641	225	26.7
V	Black River	1,274	2,530	1,530	346	48.9
VI	Cabarita River	946	1,890	1,019	420	0
VII	Great River	886	1,685	863	467	58.6
VIII	Martha Brae River	616	1,154	673	279	19.70
IX	Dry Harbour Mountains	1,574	2,450	1,302	457	27.6
X	Blue Mountain North	1,551	5,068	2,346	2,452	333

[1]The reliable yield is the amount of water that you can expect to find 90 percent of the time.

Sources:

Harza Engineering Company International/National Irrigation Commission of Jamaica, *National Land and Water Atlas of Jamaica*, Kingston, February 1998.

Underground Water Authority of Jamaica, *Water Resources Development Master Plan*, Kingston, March 1990.

The Blue Mountain North Basin is located in the most northeastern section of the country, and it is the wettest basin. In this basin, all streams flow to the north. There is a high density of streams, and they usually display branching, tree-like patterns. These patterns arise because of the underlying impermeable shale, metamorphic and volcanic rocks. Water cannot sink into the subsurface, so it must run off. This makes streamflow very dependent on the amount of precipitation. In this area, there is usually a wide range between high and low flow values. Large peak flows are achieved very rapidly after moderate rains, and then streams will subside almost as quickly to low flow values. The “flashy” nature of these streams causes short-duration floods and severe erosion. Streams in this basin usually have steep gradients in their middle and upper reaches, decreasing near the coast. Because of the irregular flow, most streams in this basin cannot be used to generate hydroelectricity. Yet, the primary location for a new plant in Jamaica is on a tributary of the Rio Grande, the Back Rio Grande. Most streams in this basin are intermittent. However, there are five large streams in this basin. From the Wag Water, Swift, and Rio Grande Rivers, small to moderate amounts of fresh water are perennially available. From the Spanish and Buff Bay Rivers, very small to moderate amounts of fresh water are perennially available. Located near the head of the Wag Water River is the Hermitage Reservoir. This reservoir supplies water to the city of Kingston at a rate of 0.54 cubic meter per second.[70]

The Blue Mountain South Basin is located in the most southeastern section of the country. Generally, all of the streams flow to the south, except for the Plantain Garden River. This river follows a fault and flows from west to east. There is a high density of streams in this basin, and they generally have a branching, tree-like pattern. This basin receives less rain than the Blue Mountain North Basin due to the effects of the Blue Mountains. The Plantain Garden River drains a large part of the Blue Mountains, and is the largest river in Saint Thomas Parish, with small to moderate amounts of fresh water perennially available. The Morant, Negro, and Yallahs Rivers have very small to small quantities of fresh water perennially available. However, there is a pipeline, located south of Llandewey on the Yallahs River, which transports about 26.7 million cubic meters per year (0.84 cubic meter per second) to the city of Kingston.[71] About 13.3 million cubic meters per year (0.42 cubic meter per second) of water is also diverted from the Negro River to Kingston.[72] These diversions may reduce these rivers to little more than intermittent streams in the dry season. Both the Morant and Yallahs Rivers have wide, rocky channels in their lower reaches with deep deposits of alluvium. These rivers may become intermittent in dry months, but then have torrential flows after moderate rains. The mid-to-upper reaches of these rivers have steep gradients, flow very quickly, and transport large amounts of sediments. Downstream, the river gradients flatten, flow decreases rapidly, and deposition of carried sediment occurs.

The Kingston Basin is very dry. Kingston, the capital and largest city in Jamaica, is located here. Most of the streams are intermittent. The upper reaches of the Hope River have fresh water perennially available in very small to small quantities; the lower reaches of the Hope River may become intermittent in dry months. Very small to small quantities are also available from the Mona Reservoir. The Hope River feeds this reservoir, which has a storage capacity of 3.03 million cubic meters, supplying Kingston at a rate of 0.20 cubic meter per second.[73] The Mona Reservoir is essential to the water supply of Kingston, supplying 11 percent of the total water supply.[74] Sediment and flood control gates along the diversion help to control the sedimentation in the reservoir. Water is also supplied to the city of Kingston from the upper part of the Rio Cobre in the Rio Cobre Basin, from the Yallahs and Negro Rivers in the Blue Mountain South Basin, and from the Hermitage Reservoir in the Blue Mountain North Basin. Most of the streams in this basin have very steep gradients in their upper courses, display dendritic patterns, and carry significant sediment loads.

The Dry Harbour Mountains Basin is located in the north-central part of the country. Most of the rivers in this basin are very small in length, generally rising less than 10 kilometers from the coast. One exception is the White River, which is located on the eastern side of the basin. The White River, Rio Bueno, and Laughlands Great River all have small to moderate amounts of fresh water perennially available. Fresh water is perennially available in very small to small quantities from the Pear Tree Bottom, Cave, and Roaring Rivers. The Quashies River has meager to very small amounts of fresh water seasonally available. There are also many intermittent streams near the coast that have fresh water seasonally available. Streams in this basin are different than the streams in the Blue Mountain North Basin, because their flows are much less variable. This is because these streams are fed and in some places feed the interior karstic limestone aquifer. For instance, the water in the upper reaches of the White River may, in places, disappear into the limestone aquifer and then rise several kilometers downstream. In the central area of this country, fresh water is scarce or lacking due to this karstic environment. Drainage in this area is primarily underground, and any precipitation is quickly channeled or absorbed into the subsurface. In fact, two rivers in the southern part of the Basin--the Cave and the Quashies Rivers--have sinkholes as their natural outlets. These rivers drain the central mountains, flow for several kilometers, and then the water disappears into the subsurface. Water from these two streams flow underground and supply Dornock Head Rising, a spring and the source of the Rio Bueno.

The Rio Cobre Basin is located in the southeastern part of the country, and it is primarily drained by the Rio Cobre River and its tributaries. Small to moderate amounts of fresh water are perennially available from the middle reaches of the Rio Cobre. However, in dry seasons, parts of this large river may sink into the limestone subsurface and rise several kilometers downstream. Very small to small amounts of fresh water are available from the upper reaches of the Rio Cobre and a tributary, the Rio Pedro. From the Pedro River, Rio Doro, Indian River, and Rio Magno Gully, meager to very small quantities of fresh water are seasonally available. Meager to moderate quantities of fresh to brackish water are seasonally available from Coleburns Gully, the Fresh River, Salt Island Creek, and the lower reaches of the Rio Cobre. During the wet seasons, the water in these streams is generally fresh; but during the dry seasons, these streams may become brackish due to evaporation. Water from the upper Rio Cobre is exported to supply Kingston. Also, there are plans to develop the Fresh River as a water supply for Kingston. Water is also diverted from the Rio Cobre for irrigation purposes. In the northernmost part of this basin, there is a small area in which fresh water is scarce or lacking. This is due to the underground drainage in a karstic limestone area. The Pedro River flows from west to east, and its natural outlet is a sinkhole. Water from this river is believed to flow underground to the Black River, a tributary of the Rio Cobre. Near the coast, large areas of mangrove swamps and marshy areas contain brackish to saline water. The Great Salt Pond is another feature in this basin that contains brackish to saline water. Located on the coast, it was once separated from the sea by a sandbar, but a permanent channel was built in the 1970’s. Streams in the upper reaches of the Rio Cobre and its tributaries have very steep gradients, carry a lot of sediment, and display a dendritic pattern. Progressing downstream, the river slows and becomes more meandering with increasing sedimentation.

The Rio Minho basin is located in the south-central part of the country. The northernmost part of the basin is very mountainous; the streams in this area have steep gradients, are very swift flowing, and carry a lot of sediment. Very small to moderate quantities of fresh water are perennially available from the upper part of the Rio Minho. Very small to small quantities of fresh water are perennially available from the Pindars River and the middle reaches of the Milk River. Meager to moderate amounts of fresh water are seasonally available from the upper reaches of the Milk River and from numerous small or intermittent streams in the eastern part of the basin. Fresh to brackish water is seasonally available from the Rhymesbury, Saint Anne’s, Main Savanna, and Breadnut Gullies, Hilliard River, lower reach of the Milk River, and lower reaches of the Rio Minho. The lower reach of the Milk River is subject to salt water intrusion, and is navigable for about 3 kilometers (2 miles) for small vessels.[75] Along the coast, there are large areas of mangrove swamps and marshy areas that contain brackish to saline water. Fresh water is scarce or lacking in the entire western part of the basin, which is a karstic limestone area. Any precipitation is quickly channeled into the subsurface. In fact, a lot of surface water throughout the basin is lost to the underlying limestone and alluvial aquifers. For example, parts of the upper reaches of the Milk River and of the lower reaches of the Rio Minho may sink into the alluvial aquifer. As water flows to the mid-to-lower reaches of the Rio Minho, the river becomes meandering, and begins depositing its large sediment load.

The Black River Basin is located in the southwestern part of the country. The Black River mainly drains this basin. It is the largest river in Jamaica and is navigable for 28 kilometers (17 miles) from the mouth of the river.[76] The middle and upper reaches of the Black River have small to moderate amounts of fresh water perennially available. This part of the river also flows through a swamp that contains fresh to brackish water. During wet seasons, enough fresh water may be produced to make this swamp fresh. Surface water in this area has been under pressure by agricultural development, and water may be diverted from the Black River for irrigation. The lower part of the Black River may range from fresh to brackish, due to significant seawater mixing. Generally, the farther away from the coast, the fresher is the water. This is true for the Lower Black River Morass. This is a large mangrove swamp and marsh area. The upper parts of the swamp can range from fresh to brackish, and the lower parts from brackish to saline. Numerous streams flow through this swamp. One of them, the Y.S. River, has fresh water perennially available in very small to moderate amounts in its upper reaches. In its lower reaches, the water may range from fresh to brackish. Another river that flows through the swamp is the Broad River. This river can range from fresh water in its upper reaches to saline water near its confluence with the Black River. Fresh water is perennially available in very small to small quantities from the upper reach of the South Elim River, a tributary of the Black River, and from the Hectors River. The Hectors River flows from east to west, and has a sinkhole as its natural outlet. Water from this river flows underground to the Black River. Meager to very small amounts of fresh water are seasonally available from the Wallywash Pond in the southern part of this basin. It is located in a down-faulted part of the Earth's crust between two roughly parallel faults, and it is probably fed by three springs. Near the coast is another large pond that contains brackish to saline water. The rest of the parish generally has little to no surface water, due to the karstic limestone subsurface. Any surface water is quickly channeled or absorbed into the subsurface.

The Martha Brae River Basin is located in the northwestern part of the country. The Martha Brae River is the primary river that drains this basin, and it has small to moderate quantities of fresh water perennially available in its middle and lower reaches. Very small to small quantities are available from the upper reaches of the Martha Brae, Roaring, and Mouth Rivers. The Mouth River flows from south to north, and has a sinkhole as its natural outlet. Drainage from this river has been shown to flow underground and supply the Fontabelle Spring, located east of the Martha Brae River. Near the coast, numerous intermittent streams rise a few kilometers from the coast. In the south and eastern part of the country, fresh water is scarce or lacking. This area is underlain by a karstic limestone aquifer. Any water that runs off the central mountains is quickly channeled or absorbed into the subsurface. The Martha Brae River maintains a constant flow due to ground water aquifers which give it a constant base flow. This prevents the stream from having such dramatic changes between high and low flows as displayed in the Blue Mountain North Basin.

The Cabarita River Basin is located in the extreme southwestern part of Jamaica. The primary river in this basin is the Cabarita River. This river has very small to small quantities of fresh water perennially available. However, parts of the lower reaches of this river may disappear into the limestone aquifer and reappear several kilometers farther downstream. The Roaring River, a tributary of the Cabarita River, has very small to moderate quantities of fresh water perennially available. Fresh water is seasonally available from the Orange River, South Negril River, and numerous intermittent streams in the eastern part of the basin. Numerous mangrove swamps and marshy areas are near the coast. The largest one is the Negril Great Morass. This is separated from the sea by a narrow strip of land, and contains mainly brackish to saline water. However, where streams enter the swamp and when precipitation is high, fresh water lenses can be found. In the eastern part of the basin, fresh water is scarce or lacking. This area is underlain by a karstic limestone aquifer, and any precipitation and surface water is quickly absorbed or channeled into the subsurface.

The Great River Basin is located in the most northwestern part of Jamaica and is primarily drained by the Great River. The Great River has small to moderate quantities of fresh water perennially available. The course of this river follows a fault. Very small to small quantities of fresh water are perennially available from the Montego River, and meager to very small quantities of fresh water are seasonally available from the Lucea East River. Numerous small or intermittent streams are along the coast and on the western side of the basin. These streams generally have steep gradients in their upper courses, are swift, and carry a lot of sediment. In the southeastern part of the basin, fresh water is scarce or lacking due to the karstic limestone aquifer. Any surface water is quickly absorbed or channeled into the limestone subsurface.

3. Reservoirs, Ponds, and Swamps

Kingston, Jamaica's capital and most populated city, is located in one of the driest parts of the country. Therefore, the two reservoirs that supply this city, while small in size, are very important to the city. The larger reservoir is the Mona Reservoir. This is located in the Kingston Basin, with the western side of the reservoir bordering Long Mountain. It has a storage capacity of 3.03 million cubic meters. This reservoir supplies Kingston with a yield of 0.20 cubic meter per second, and is fed by water diverted from the Hope River.[77] The Hope River drains the southern side of the Blue Mountains. Generally, the area that the Hope River drains is very rugged, with most slopes greater than 25 degrees. Flows can be characterized as "flashy," rapidly achieving a high peak flow after rains and then quickly subsiding into low flow rates. Water is generally fresh; but deforestation, improper farming practices, and seasonal flow patterns have caused a sedimentation problem. The building of sediment and flow-control gates has reduced this problem. Since 1957 the capacity of the reservoir has been reduced by 2 percent due to sedimentation.[78] Also there is major concern over pesticide use and the overuse of fertilizers, which may contaminate this water supply with nitrates and phosphates. The Hermitage Reservoir is located in the Blue Mountain North Basin, and is located far upstream near the headwaters of the Wag Water River. Streams that feed the reservoir drain the Blue Mountains, and are characterized by flash flows. The Hermitage has a storage capacity of 1.49 million cubic meters, and supplies 0.54 cubic meter per second of water to the city of Kingston.[79] Since 1957 the capacity of the reservoir has been reduced by 21 percent due to sedimentation.[80] Most of the slopes surrounding the reservoir and its tributaries are greater than 25 degrees, and the area is generally very rugged.[81] Sedimentation is a serious problem, due to deforestation and soil erosion from unsuitable farming practices.

Throughout Jamaica there are numerous ponds that supply fresh, fresh to brackish, or brackish to saline water. Some of these are in the form of blue holes. The water in these holes may be near sea level on the surface, but extend several meters below sea level. They were formed by the dissolution and collapse of limestone when the sea level was much lower than it is today. These deep collapse features were then filled with ground water or seawater. The Moneague Blue Hole, located in the Dry Harbour Mountains Basin, was once a good freshwater source. However, this has recently become contaminated. The contamination is believed to be from a bauxite lake, Mt. Rosser Pond, which has a high sodium effluent.

Fresh water may be available in about 20 small ponds throughout Gales Valley in the Martha Brae River Basin. These ponds do not appear to be sinkholes, but rather surface water that has accumulated in low-lying areas. The soils in these areas are clayey, preventing most of the water from draining to the subsurface. Generally, these ponds have a surface area of less than 0.01 square kilometer (2 acres), but there are a few exceptions.[82] The Wemyss Pond is dammed, and is fed by a spring with a discharge of 1 to 2 cubic feet per second. However, during droughts this spring may cease to flow. Another exception is the Wakefield Pond. This pond has a surface area of 0.04 square kilometer (10.7 acres), and has a maximum depth of 6.1 meters (20 feet). The water in this pond is soft, with a total hardness of 30 milligrams per liter of calcium carbonate. On the border between the Martha Brae River and the Dry Harbour Mountains Basin, there is another large pond. The Clarks Town Pond has a surface area of 0.01 square kilometer (2.5 acres) and a maximum depth of 4.8 meters (15 feet). This water is moderately hard, with 108 milligrams per liter of calcium carbonate.[83] In the Cabarita River Basin there are numerous small ponds surrounding the town of Little London. Finally, in the Black River Basin, the Wallywash Pond may be a good seasonal source of fresh water. This pond is located in a down-faulted block of the Earth's crust between two roughly parallel faults. Wallywash Pond is most likely fed by three springs, at an approximate rate of 0.04 cubic meter per second, and has a maximum depth of 4.9 meters (16 feet).[84] Many of these ponds are not depicted in figure C-1 due to the map scale.

Salt Island Lagoon is a fresh to brackish pond, which appears to be either fed by surface water runoff or by springs. Salt Island Lagoon is located in the Rio Cobre basin, along with a brackish to saline pond, the Great Salt Pond. This pond was once separated from the sea by a sandbar, but a channel was dug to permanently connect it to the sea. It has a surface area of 1.8 square kilometers (448 acres), and its salinity is variable, depending on evaporation and precipitation.[85] Other brackish to saline ponds are the Parottee Great Salt Pond and the Salt Ponds. The Parottee Great Salt Pond is located in the Black River Basin. This pond is excessively saline. The Salt Ponds are located in the Blue Mountains South Basin. These ponds are side by side and are connected to each other and to the sea by manmade channels. The larger pond has a maximum depth of 4.3 meters (14 feet), and the smaller pond has a maximum depth of 1.2 meters (4 feet). The larger pond is 10 times more saline than the sea, and the smaller pond is less saline on the surface, but equally saline 0.9 meter (3 feet) below the surface.[86] These ponds may have a bright red color during drought. Bacteria that thrive during dry conditions cause this color.

On Jamaica's south coast and to a lesser extent on the north coast, brackish to saline mangrove swamps and marshy areas occur. There are four main swamp areas; the Upper Black River Morass, the Lower Black River Morass, the Negril Great Morass, and the Great Morass at Morant Point. The Upper Black River Morass and the Lower Black River Morass are located in the Black River Basin. The Upper Black River Morass is fresh to brackish and is fed by freshwater sources, such as the Black and South Elim Rivers. This swamp is under developmental pressure, and some of the swamp has already been drained for farming. The Lower Black River Morass can range from freshwater in the north to saline water in the south. However, this can vary with the amount of precipitation because there are numerous rivers flowing through the swamp. The Negril Great Morass, located in the Cabarita River Basin, covers an area of 22.9 square kilometers (5,657 acres), and it comprises about one-fifth of all wetland areas in Jamaica.[87] Water in this swamp may also range from fresh to saline, depending on the amount of precipitation. The Great Morass at Morant Point, located in the Blue Mountain South Basin, contains mainly brackish to saline water. However, depending on precipitation, parts of the swamp may contain freshwater. Three streams flow through the swamp that originate from blue holes. The water in these streams may be fresh, but there is probably significant seawater mixing near the coast.

4. Deforestation Effects and Other Contamination

Deforestation has become a major problem, adversely affecting the surface water quality. It is estimated that forest cover has been disappearing at a rate of 3.3 percent per year.[88] This destruction is for lumber, charcoal, cutting of roads, and the expansion of coffee crops and other farmland. It is also done with little to no environmental consideration. The farmland which is deforested is usually marginal, the better land being already developed. With the destruction of the forest cover, water runs off the surface at a faster rate. This causes the rivers to achieve larger peak discharges at a faster rate, increasing the intensity of flooding. Most rivers have increased sediment loads due to this problem, and it could harm the coral reefs and mangrove swamps. Deforestation also decreases the productivity of the soil on the cleared land and lessens the amount of infiltration, causing dryer than expected conditions. Debris and sediment from deforestation can also clog drainage systems and create unnecessary flooding. For example, the Cave River in the Dry Harbour Mountains Basin has a sinkhole as its natural outlet. Due to vegetal debris and silt, the capacity of the sinkhole has been reduced causing numerous floods. The sediment and vegetal debris can also clog drainage systems in towns, making flooding situations worse.

Surface water is generally fresh; however, some major threats to the water quality are from industry, human and animal wastes, insecticides, and herbicides. Most of the mineral industry is based on bauxite mining, and some of the bauxite produced is refined into alumina on the island. Bauxite mining is surface mining, which is land intensive, noisy, and dusty. Jamaica can produce about 3 million tons of alumina per year. The refining process creates a thick fluid called “red mud” which has high levels of sodium and hydroxide ions, iron oxides, and organic substances. About 1 ton of red mud waste or residue will be produced from each ton of alumina. The land mass cannot accommodate this high volume of waste. This waste is often ponded into lakes, either manmade or karst depressions, with no consideration of the environmental effects. The effluent is free to seep into the subsurface, or to mix with precipitation, creating caustic ponds. The disposal of the wastes from alumina processing is a major environmental problem. Other industries that may cause pollution are milk, citrus, and sugar factories. These effluents may affect the pH (hydrogen-ion concentration) of the streams and cause an undesirable odor, discoloration, turbidity, and high coliform bacteria counts, due to the high organic content.

Human and animal wastes are another threat to the water quality. About 51 percent of Jamaicans use pit latrines.[89] People building on flood plains using this disposal method increase the amount of waste entering the stream. Generally, surface water quality is poor around and downstream of populated places. The nutrient-rich effluent encourages the growth of algae and other plants, and increases coliform levels. This is evident in the Black River.

There have not been very many studies on the amount of pesticide and herbicide pollution in Jamaica. However, in a recent study, 14 out of 17 major rivers had detection of insecticide residues.[90] The amounts of these substances entering the water depend on leaching and runoff. Soil erosion, increased by deforestation, and precipitation help to increase the amounts of pesticide and herbicide pollution in streams.

B. Ground Water Resources

Fresh ground water from wells and springs is an essential resource and a major source of safe (potable) water. Water from springs and wells is used for agricultural, industrial, public, and private purposes. However, the availability of ground water is highly variable. Continued access to safe and reliable supplies of ground water is a major concern. Ground water resources in urban areas are threatened by pollution, and aging or undeveloped distribution systems throughout the country are inadequate. These are important issues that the Government of Jamaica and many private organizations are working to improve.

Ground water constitutes 84 percent total available water resources. Hundreds of wells are drilled into limestone and alluvial aquifers throughout the country. Yields of 125 liters per second are not uncommon, and yields of up to 315 liters per second have been obtained. Wells are usually concentrated near populated areas. About 59 percent of the island is covered by aquifers, which are mostly in the central and western plains and valleys (see appendix C, figure C-2, map units 1 and 2). About 85 percent of these aquifers are composed of karstic, highly fractured limestone, and about 15 percent are composed of alluvial material. Relatively impermeable rocks that contain little or no ground water cover the remaining 41 percent of the island. These rocks are composed of volcanic and metamorphic basement rocks, hard limestones, marls, and clays. Outcrops of impermeable basement rocks are concentrated in the eastern mountains and along the central east-west oriented ridge of the island (see appendix C, figure C-2, map units 3 and 6). Volcanic and metamorphic rocks, chalky limestones, marls, and clay aquicludes are scattered along the coast (see appendix C, figure C-2, map units 4 and 5).[91]

Saltwater intrusion has a negative impact on the ground water resources of the country. Overpumping from coastal aquifers has caused saltwater intrusion from the Caribbean Sea. Although ground water is generally safer than untreated surface water supplies, many shallow aquifers are becoming biologically contaminated, primarily due to improper waste disposal. Other contaminants affecting ground water are agriculture runoff and effluents from industrial processes, such as bauxite mining, sugar refining, and rum production.[92]

1. Aquifer Definition and Characteristics

To understand how ground water hydrogeology works 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 flow 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.

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

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

2. Hydrogeology

Variations in geological structures, geomorphology, rock types, and precipitation contribute to the varying ground water conditions in different parts of the country. The primary fresh water aquifer systems are karstic, highly fractured limestones (map unit 1), and alluvial aquifers (map unit 2). Other fresh water aquifers are within less fractured limestones (map units 3 and 4); coastal and interior valley clay and shale deposits (map unit 5); and volcanic and metamorphic basement rocks (map unit 6). Brackish to saline water has contaminated parts of these aquifer systems (map units 7-1, 7-2, 7-4, 7-5, and 7-6). Each aquifer system is described in table C-2 and depicted on figure C-2. Descriptions are based upon the interpretation of the most recent hydrogeological information available.[93]

The depth to water in the coastal plain and near riverbeds is generally less than 30 meters. In the mountains, depth to water may be greater than 300 meters, and may be too great for economical use.[94] Aquifer thickness is generally greater than 1,500 meters. Seasonal fluctuation of the water table can be great, especially in limestone aquifers that feed surface streams. Ground water and surface water are hydraulically interconnected in the limestone areas. Ground water may flow through well-defined underground channels for several kilometers, intermittently emerging at the surface. Overpumping is lowering yields in the most heavily populated parts of the country, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation of ground water availability. Aquifers are generally locally recharged by rainfall. Recharge to limestone aquifers occurs rapidly, increasing the risk of ground water contamination especially after rains.[95]

Access to well sites is generally unhindered in the plains and major river valleys. Outside the coastal plain, access is generally very difficult because of the overall poor quality of the road network, the rugged terrain, and the steep slopes. Locally, wet ground and urban congestion also hinder access. Access is most difficult in the rough terrain of the Cockpit Country and in the densely vegetated mountains extending across the middle of the island.[96]

a. <u>Limestone Aquifers (map units 1, 3, and 4)</u>

Fresh water is generally plentiful from karstic, highly fractured white and yellow limestone. Limestone is located throughout the country, especially in the central and western parts of the island. Fractures and solution cavities have increased the natural porosity and permeability of the limestone. Springs of varying yields are common. Limestone aquifers receive large amounts of recharge and store and transmit water through extensive systems of fractures and solution cavities. Limestone aquifers are widely tapped for domestic and irrigation supply wells. Locally, wells in these aquifers can have extremely high yields, but wells that fail to intersect water-bearing fractures can be dry or have very small yields.

Fresh water is locally plentiful from hard, fractured, limestone aquifers which are interbedded with chalk, soft marls, reefs, tuffs, shales, and fine-grained sedimentary deposits (map units 3 and 4). Typically, these rocks have not been strongly deformed by folding and faulting, which results in an uneven distribution of fractures within the limestone. Well yields in chalky limestone are generally much lower than yields from fractured and karstic limestone aquifers. Chalky limestones along the coast are generally less than 1,000 meters thick. Less permeable, fractured limestone formations are generally less than 300 meters thick, and are typically composed of very thin layers of limestone interbedded with sands and clays. Reef deposits along the northern coast are less than 50 meters thick.[97]

b. Alluvial Aquifers (map unit 2)

Fresh water is generally plentiful from productive aquifers in alluvium in the southern coastal plain and major river valleys (map unit 2). Aquifers are most extensive and accessible near the middle reaches of the Rio Minho and the Milk River. Ground water in the alluvial deposits is typically found in layers of sand and gravel that are separated by layers of silt and clay.[98] Aquifer thickness varies between 30 and 600 meters, generally being thickest along the southern coast. The alluvial deposits are widely tapped for domestic and irrigation supply wells.[99]

c. Other Aquifers (map units 5 and 6)

Fresh water is scarce or lacking in areas containing low-permeability clays and shales, and basement rock composed of lavas, tuffs, limestones, shales, and low-permeable conglomerates. Water yields are generally less than 5 liters per second. Locally, wells drilled into fracture zones may have higher yields (map units 5 and 6).[100]

d. Brackish to Saline Aquifers (map units 7-1, 7-2, 7-4, 7-5, and 7-6)

Brackish to saline water is generally plentiful from limestone aquifers near Kingston and along the southern coasts of Saint Andrew, Saint Catherine, and Clarendon Parishes. Ground water may be contaminated by saltwater intrusion, sewage infiltration, and overpumping from wells. Ground water near Moneague and Nain is contaminated by leachate from red mud ponds used to store sodium-rich waste from bauxite mining (map unit 7-1). Aquifer descriptions are identical to map unit 1, only water quality differs.[101]

Brackish to saline water, due to saltwater intrusion and contamination, is generally plentiful from alluvial aquifers near Kingston, in the southern parts of the Rio Minho and Rio Cobre Basins, along the northern coast near Falmouth, and along the southern coast near Alligator Pond (map unit 7-2). Aquifer descriptions are identical to map unit 2, only water quality differs.[102]

Brackish to saline water, due to saltwater intrusion, is locally plentiful from chalky limestone near Montego Bay (map unit 7-4). Aquifer descriptions are identical to map unit 4, only water quality differs.[103]

Brackish to saline water is scarce in the clay and shale deposits along the southwest coast near Black River and along the northwest coast near Montego Bay (map unit 7-5). Brackish to saline water is scarce in the basement rock east of Liguanea Plain and along the southwest coast (map unit 7-6). Locally, wells drilled into fracture zones may have higher yields. Aquifer descriptions are identical to map units 5 and 6, respectively, only water quality differs.[104]

C. Water Quality

1. Surface Water Quality

Surface water in Jamaica is generally fresh. However, it has been and is used as a method to carry away both human and industrial waste. The quality of water found in many of Jamaica's rivers is threatened, due to overburdening with wastes. Generally, pollution that factories produce is organic waste from sugar and other food processing activities. This does not affect the water quality except that it can change the pH of the water, and cause an undesirable odor, discoloration, turbidity, and high levels of coliform bacteria. Human wastes are another problem. Most sewage is not handled by a central sewage treatment system, but is disposed of on-site. This causes biological contamination near and downstream of populated areas. Another problem that causes contamination is dumping solid wastes into gullies, sinkholes, and mined limestone pits. For example, at a municipal dump in the lower Rio Cobre Basin, mevinphos, a toxic insecticide, was dumped there. This killed many animals and waterfowl, and sent several people to the hospital. To date, there have been very few studies on pollution from insecticides and pesticides. However, new studies have indicated that this may become a major, if seasonal, problem in Jamaica.

2. Ground Water Quality

Ground water quality is generally fresh. Water is generally hard due to the large percentage of limestone covering the island. Water originating from white limestone aquifers frequently shows high turbidity.

Karstic limestone allows water to move rapidly between the surface water and ground water environments via fractures, sinkholes, springs, and caves. This rapid movement creates a high potential for surface contaminants to pollute large volumes of ground water in a short period of time. Effluents from sewage soak-away pits, bauxite processing plants, and sugar cane refineries are the most prevalent manmade sources of ground water contamination. The primary method of sewage disposal is the use of hand-dug soak-away pits. As a result, ground water sources near these pits may have high fecal coliform levels.[105]

Overpumping from limestone and alluvial aquifers in the Liguanea Plain and the lower reaches of the Milk River, Rio Minho, Rio Cobre, and Montego River Basins has caused saltwater intrusion from the Caribbean Sea. Many wells in the Kingston area have been shut down due to poor water quality resulting from saltwater intrusion and high nitrates from sewage infiltration. Saltwater intrusion has also degraded water quality along the southern coast near the Black River and Alligator Pond and along the northern coast near Montego Bay. Contaminated water usually has high amounts of sodium, calcium, chloride, and calcium carbonate. Chloride concentrations generally increase with depth as a result of upconing of saltwater in wells drilled below sea level.[106]

V. Water Resources Parish Summary

A. Introduction

This chapter summarizes the water resources information of Jamaica, which can be useful to water planners as a countrywide overview of the available water resources. Figure C-1, Surface Water Resources, divides the country into surface water categories identified as map units 1 through 9. Table C-1, which complements figure C-1, details the quantity, quality, and seasonality of the significant water features within each map unit and describes accessibility to these water sources. Figure C-2, Ground Water Resources, divides the country into ground water categories identified as map units 1 through 7. Table C-2, which complements figure C-2, details predominant ground water characteristics of each map unit including aquifer materials, aquifer thickness, yields, quality, and depth to water. A summary based on these figures and tables is provided for each of the 14 parishes.

B. Water Conditions by Map Unit

Figure C-1, Surface Water Resources, divides the country into nine map unit categories based on water quantity, water quality, and seasonality. Map units 1 through 3 depict areas where fresh surface water is perennially available in very small to moderate quantities. Map units 4 through 7 depict areas where fresh surface water is seasonally available in meager to moderate quantities during high flows. Map units 8 and 9 depict areas where meager to moderate quantities of fresh to brackish water are available from ponds and swamps. Figure C-1 also divides the country into 10 hydrographic basins and zones labeled I through X. The locations of selected stream gaging stations are also depicted on figure C-1.

Figure C-2, Ground Water Resources, divides the country into seven map unit categories based on water quantity, water quality, and aquifer characteristics. Map units 1 and 2 depict areas where fresh ground water is generally plentiful in very small to enormous quantities. These areas appear, at a country scale, to be the most favorable areas for ground water exploration. Map units 3 and 4 depict areas where fresh ground water is locally plentiful up to large quantities. At the local level, these areas might be suitable for ground water exploration, but they require additional site-specific investigations. Map units 5 and 6 depict areas where unsuitable to very small quantities of fresh water may be available. At the country scale, these areas appear to be the least favorable areas for ground water exploration. Map unit 7 depicts areas where fresh ground water is scarce or lacking and where brackish to saline water is available.

Surface water and ground water quantity and quality are described for each parish by the following terms:

Surface Water Quantitative Terms:

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

Ground Water Quantitative Terms:

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

Qualitative Terms:

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

C. Water Conditions by Parish

The following information is compiled for each parish from figures C-1 and C-2 and tables C-1 and C-2. The write-up for each parish consists of a general and regional summary of the surface water and ground water resources, derived from a country-scale overview. Locally, the conditions described may differ. The parish summaries should be used in conjunction with figures C-1 and C-2 and tables C-1 and C-2. Additional information is necessary to adequately describe the water resources of a particular parish or region. Specific well information is limited and for many areas unavailable. 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.

Clarendon

Area:	1,196.3 square kilometers (10.9 percent of the country)
Estimated Population (1998):	227,500 (8.8 percent of the population)
Population Density:	190 people per square kilometer
Parish Capital:	May Pen
Location:	In the south-central part of Jamaica, with the Caribbean Sea as its southern boundary. The northern boundary follows both the Pedro and Cave Rivers, with Saint Ann Parish to the north. The western border follows a part of the Milk River, with Manchester Parish to the west.

Surface Water:

Fresh water is perennially available from major rivers. Very small to moderate quantities of fresh water are available from the Rio Minho, as depicted by map unit 2. Very small to small quantities of fresh water are available from the Cave River, the middle reaches of the Milk River, and the Pindars River as depicted by map unit 3. Meager to very small quantities are seasonally available from the Pedro River, as depicted by map unit 4. Fresh water is seasonally available from numerous intermittent streams, the Milk River, and the upper reaches of Saint Anne's Gully, as depicted by map unit 5. Fresh to brackish water is available from the Saint Anne's, Rhymesbury, Main Savanna, and Breadnut Gullies; and from the Lower reaches of Rio Minho, Milk, and Hilliards Rivers, as depicted by map unit 6. Fresh water is scarce or lacking in the swamp and morass areas, as depicted by map unit 9, and in areas where much of the drainage is underground due to the underlying limestone formation, as depicted by map unit 8. The natural outlets for the Cave and Pedro Rivers are sinkholes. The water from the Cave River flows underground to the Dornock Head Rising, a spring that is the source of the Rio Bueno. Water from the Pedro River is believed to eventually flow underground to the Black River, a tributary of the Rio Cobre, in the Parish of Saint Catherine. The northernmost part of the parish is mountainous, with knife-edged ridges and slopes from 20 to 35 degrees.[107] Streams in these mountains are generally fast moving and intermittent with steep gradients. In the central part of the parish is a limestone plateau that has gentle topography. Most surface water is absorbed into the limestone subsurface. Near the coast are alluvial plains. Generally, the slopes of these plains are less than 2 degrees.[108] From 1951 to 1980, the mean annual rainfall was 1,428 millimeters (56 inches).[109] Within the parish, yearly averages can range from 1,067 millimeters (42 inches) to 2,261 millimeters (89 inches).[110] Generally, rainfall increases from the coast to the more mountainous areas.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and alluvial aquifers in the central and southern parts of the parish. The limestone aquifers are depicted in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. Map unit 2 depicts alluvial aquifers in sediment-filled valleys in the center of the parish. The parish capital May Pen is in map unit 2. Very small to very large quantities of water are available from this map unit. Water consumption throughout this parish is great. Well yields may decrease during periods of high demand. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

Very small to large quantities of fresh water are available from lower capacity, fractured, and karstified limestone in map unit 3 in the north. Yields may be smaller in the upper elevations of mountainous areas. Aquifer thickness is less than 500 meters. Depth to water may be over 300 meters in places, less in the valleys. Successful wells may depend upon encountering water-bearing fractures.

Small to enormous quantities of brackish to saline water are available from alluvial sediments and limestone aquifers. Overpumping from wells has caused saltwater deep beneath the surface to contaminate the formerly fresh aquifers located closer to the surface. Contaminated water usually has high amounts of sodium, calcium, chloride, and bicarbonate. The chloride concentrations generally increase with depth and may be as high as 1,000 milligrams per liter. Water quality may improve over time as pumping rates decrease. The rest of the northern part of the parish is composed of volcanic and metamorphic basement rock, as depicted in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. Springs are common throughout map unit 6.

Seven sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Hanover

Area:	450.4 square kilometers (4.1 percent of the country)
Estimated Population (1998):	67,800 (2.6 percent of the population)
Population Density:	151 people per square kilometer
Parish Capital:	Lucea
Location:	In the northwestern part of the country, with the Caribbean Sea forming the north and western boundaries. The Great River forms the eastern boundary, which divides the parish from Saint James Parish. Westmoreland Parish is to the south.

Surface Water:

Small to moderate amounts of water are perennially available from the Great River, as depicted by map unit 1. This river drains a large section of the eastern part of the parish. Some tributaries of the Great River cut ravines into the topography. Meager to very small amounts of fresh water are seasonally available from the Lucea East River, as depicted by map unit 4. Fresh water is seasonally available from the Orange River, upper reaches of the Lucea East and Cabarita Rivers, and from numerous intermittent streams, as depicted by map unit 5. The Orange River meanders through swampy terrain, and has a mature profile. Fresh water is scarce or lacking in the southeastern part of the parish, as depicted by map unit 8. This is due to the karstic nature of the limestone subsurface. Any surface water is quickly absorbed into the subsurface. Water is also scarce to lacking in the Negril Great Morass, on the western side of the country, as depicted by map unit 9. This is a wet and swampy area, which covers 22.9 square kilometers (5,657 acres) and comprises one-fifth of all wetland areas.[111] It is separated from the sea by a narrow sandy spit. Water in this morass may range from brackish to saline. However, some fresh water may be found during the wet seasons, due to the presence of numerous dykes and levees found in the morass that may effectively channel the flow. The mean annual rainfall from 1951 to 1980 was 2,302 millimeters (91 inches).[112] Generally, the mountainous areas get above average rainfall, and the coast gets much less. Elevation ranges from sea level to a height of 545 meters (1,789 feet), and topography ranges from youthful to mature.[113] In the mountains, most of the streams are swift with steep gradients and rocky beds.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers in the east, along the central southern edge, and in the southwest. Large to enormous quantities of fresh water are available from fractures and solution cavities in the limestone depicted by map unit 1. The limestone is generally thickest toward the coast and overlies basement rock. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

Coastal clays and shales depicted by map unit 5 near the Negril Great Morass may yield unsuitable to very small quantities of fresh water. Access may be difficult. The rest of the parish is composed of volcanic and metamorphic basement rock and impermeable limestone. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. The parish capital Lucea is in map unit 6.

No sewage treatment plants exist in this parish. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Manchester

Area:	830.1 square kilometers (7.6 percent of the country)
Estimated Population (1998):	185,900 (7.2 percent of the population)
Population Density:	224 people per square kilometer
Parish Capital:	Mandeville
Location:	In southwest Jamaica, with the Caribbean Sea to the south. The eastern boundary follows part of the Milk River, but generally follows an irregular line, dividing Manchester from the parish of Clarendon. In the north, the boundary follows the Hectors River, dividing Manchester from the parish of Trelawny. The parish of Saint Elizabeth is to the west.

Surface Water:

This parish had a mean annual rainfall of 1,706 millimeters (67 inches) from 1951 to 1980.[114] Fresh water is scarce or lacking in most of the parish due to the underlying limestone aquifer, as depicted by map unit 8. The topography displays typical cockpit karst features, with many steep-sided, closed depressions separated by rugged and uneven peaks. There is minimal surface drainage in this type of karst terrain; any surface runoff or precipitation quickly infiltrates to the subsurface. Fresh water is perennially available in very small to small quantities from the Hectors River in the northernmost part of the parish. The Hectors River flows west, and has a sinkhole as its natural outlet. Water from this river flows underground, out of the parish, and eventually flows into the Black River. Fresh water is seasonally available from intermittent streams, such as the upper reaches of the Milk River, as depicted by map unit 5. This stream is fed by a spring that may stop flowing during dry seasons.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and the alluvial aquifers covering most of the parish. The limestone aquifers are shown in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The limestone is generally thickest toward the coast and overlies basement rock. The parish capital Mandeville is in map unit 1. Map unit 2 depicts small alluvial aquifers in sediment-filled valleys in the west and along the eastern parish border. Very small to very large quantities of water are available from map unit 2. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures.

Very small to large quantities of fresh water are available from map unit 3 in the north from lower capacity, fractured, and karstified limestone, which covers less than 25 percent of the parish. Yields may be smaller in the upper elevations of mountainous areas. Aquifer thickness averages 500 meters. Depth to water may be over 300 meters in places, less in the valleys. Successful wells may depend upon encountering water-bearing fractures. Access may be difficult in mountainous areas.

The rest of the parish is composed of volcanic and metamorphic basement rock and impermeable limestone, depicted in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance.

No sewage treatment plants exist in this parish. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Portland

Area:	814 square kilometers (7.4 percent of the country)
Estimated Population (1998):	79,300 (3.1 percent of the population)
Population Density:	97 people per square kilometer
Parish Capital:	Port Antonio
Location:	In northeast Jamaica, with the Caribbean Sea to the northeast, Saint Mary's Parish to the west, and the ridge of the Blue Mountains to the south.

Surface Water:

Fresh water is perennially available from the major streams throughout the parish. The Rio Grande and Swift River have small to moderate flows, as depicted by map unit 1. The Spanish River and Buff Bay River have very small to moderate flows, as depicted by map unit 2. The rest of the parish has fresh water seasonally available from numerous intermittent streams, as depicted by map unit 5. However, intermittent streams can have seasonally high discharges. For example, four small streams, located east of the Rio Grande near Port Antonio, with a drainage area of less than 4.8 square kilometers (3 square miles), had the following peak flows for an unusual rain event in January 1998:[115]

Stream	Peak Flow
East Town River	19 m^3/s (664 ft^3/s)
West Town River	62 m^3/s (2,208 ft^3/s)
Annotto River	54 m^3/s (1,905 ft^3/s)
Boundbrook River	25 m^3/s (895 ft^3/s)

Portland had the highest mean annual rainfall of 3,670 millimeters (144 inches) in Jamaica between 1951 and 1980.[116] However, rainfall amounts can spatially vary from an annual mean of 2,540 millimeters (100 inches) at the coast to 5,034 millimeters (200 inches) or more in the mountains.[117] The high rainfall in this parish is due to topography, hurricanes, and northers. The elevation changes from sea level to 2,256 meters (7,402 feet).[118] All streams have seasonal variations in flow. In the upper reaches, streams usually have steep gradients which level out near the coast. Streams may have torrential flows after moderate rains. Deforestation, poor land use, and building on floodplains have increased the sediment load carried in streams, and they have reduced the conveyance capabilities of channels, raising flood levels.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and alluvial aquifers in the eastern and northern parts of the parish. The limestone aquifers are shown in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. Map unit 2 depicts alluvial aquifers in sediment-filled valleys in the northwest and along the Rio Grande. Very small to very large quantities of water are available from map unit 2. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in the mountainous areas to the north. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures.

Unsuitable to small quantities of fresh water are available from the less karstified, fine-grained, chalky limestone depicted in map unit 4 along parts of the northern and eastern coast. Limestone in this area is less fractured and more permeable than the limestone in map unit 1. Successful wells may be drilled in these areas, although yields will be significantly less than those drilled in the fracture zones in map unit 1. Depth to water varies, but is generally less than 100 meters. Springs are scattered throughout the area.

The rest of the parish is composed of volcanic and metamorphic basement rocks, depicted in map unit 6. The parish capital Port Antonio is in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. Springs may flow from fractures during the wet season.

Two sewage treatment plants exist in this parish. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint Andrew and Kingston

Saint Andrew Area:	430.7 square kilometers (3.9 percent of the country)
Estimated Population (1998):	711,200 (27.5 percent of the population - includes Kingston)
Population Density:	1,572 people per square kilometer (includes Kingston)
Parish Capital:	Half Way Tree
Location:	In southeast Jamaica, with Kingston Harbour forming the southern boundary. The parish of Saint Catherine is to the west, and Saint Thomas is to the east. The northern boundary generally follows the ridge of the Blue Mountains, and borders the parishes of Saint Mary and Portland.
Kingston Area:	21.8 square kilometers (0.2 percent of the country)
Estimated Population (1998):	Included in Saint Andrew
Population Density:	Included in Saint Andrew
Parish Capital:	Kingston
Location:	Same as for Saint Andrew.

Surface Water:

Fresh water is perennially available from some of the major streams and reservoirs. Small to moderate quantities are available from the Wag Water River, as depicted by map unit 1. Very small to small quantities are available from the Yallahs and Hope Rivers and from the Mona and Hermitage Reservoirs, as depicted by map unit 3. The Mona Reservoir supplies the City of Kingston at a rate of 0.20 cubic meter per second, and has a storage capacity of 3.03 million cubic meters.[119] The Hermitage Reservoir supplies Kingston at a rate of 0.54 cubic meter per second, and has a storage capacity of 1.49 million cubic meters.[120] Fresh water is seasonally available from the Fresh River, as depicted by map unit 6, and from intermittent streams, as depicted by map unit 5. This is the most populated parish in the country. To supply the capital Kingston, water is imported from the Rio Cobre, the Yallahs River, and from the Hermitage and Mona Reservoirs. A scheme is also proposed to import water from the Fresh River as a water supply for Kingston. From 1951 to 1980, the mean annual rainfall for the parish was 1,583 millimeters (62 inches).[121] However, rainfall is unevenly distributed. It varies from a mean annual of 686 millimeters (27 inches) near the coast to 3,175 millimeters (125 inches) in the far north of the parish.[122] Elevations in the parish range from sea level to 1,529 meters (5,015 feet).[123] Generally, topography is youthful, only differing in the degree of dissection. Due to the steep topography, the streams have steep gradients, are swift, and carry a lot of sediment. The accumulations of sediment in the Hermitage and Mona Reservoirs have reduced their capacities by 21 percent and 2 percent, respectively.[124,125] Deforestation and subsequent erosion have exacerbated this problem. In addition, “flash” floods are common after heavy rains, which may temporarily interrupt transportation. The watershed that divides the north-flowing rivers from the south-flowing rivers is closer to the south coast in this area than any other place in the country.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers in the west-central part of the parish. The limestone aquifers are depicted in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. Water consumption in this parish is high. Well yields may decrease during periods of high demand. Depth to water varies, but is generally less than 100 meters. Depth to water is close to sea level near Kingston. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures.

Unsuitable to enormous quantities of brackish to saline water are available from the alluvial sediments and limestone aquifers in the southwestern part of the parish in map units 7-1, 7-2, and 7-6. The parish capital Half Way Tree is in this area. Overpumping from wells has caused saltwater deep beneath the surface to contaminate the formerly fresh aquifers located closer to the surface. Sewage infiltration from surface waste is also a source of ground water contamination. Contaminated water usually has high amounts of sodium, calcium, chloride, and bicarbonate. The chloride concentrations generally increase with depth and may be as high as 1,000 milligrams per liter. Water quality may improve over time as pumping rates decrease. The rest of the parish is composed of volcanic and metamorphic basement rock, depicted in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. Springs may flow from fractures during the wet season.

A central sewage treatment system and 13 sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint Ann

Area:	1,212.6 square kilometers (11 percent of the country)
Estimated Population (1998):	163,700 (6.3 percent of the population)
Population Density:	135 people per square kilometer
Parish Capital:	Saint Ann's Bay
Location:	In the north-central part of the country, with the Caribbean Sea to the north, Saint Mary's Parish to the east, Clarendon and Saint Catherine Parishes to the south, and Trelawny Parish to the west. The eastern border, between the parishes of Saint Ann and Saint Mary, follows the White River.

Surface Water:

Fresh water is perennially available from the major streams in this parish. Small to moderate amounts are available from the Rio Bueno, the Laughlands Great River, and the White River, as depicted by map unit 1. Very small to small quantities are available from the Pear Tree Bottom, Roaring, and Cave Rivers, as depicted by map unit 3. Meager to very small quantities are seasonally available from the Pedro River, as depicted by map unit 4. Except for the Cave and Pedro Rivers, streams in this parish tend to have a higher sustained base flow from the interior limestone aquifer than streams in the eastern part of the country. This makes their flows less dependent on rainfall and their flow rates more constant, decreasing the range between their peak and low flows. Sinkholes are the natural outlets for the Cave and Pedro Rivers. Water from Cave River travels underground to Dornock Head Rising, a spring which is the source of the Rio Bueno. Water from Pedro River is believed to feed the Black River, a tributary of the Rio Cobre. Near the coast, fresh water may be found seasonally from intermittent streams, as depicted by map unit 5. Most of the parish lies in map unit 8, where water is scarce or lacking. Rainfall that occurs over this area is quickly absorbed into the limestone subsurface. This area is part of the Cockpit Country where, due to solution and collapse features, the topography is difficult to traverse. This area has high peaks, steep hills, ravines, gullies, and sinkholes. The parish mean annual rainfall was 1,596 millimeters (63 inches) from 1951 to 1980.[126]

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers in the central part of the parish. These limestone aquifers are depicted in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The limestone is generally thickest toward the coast and overlies basement rock. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures.

Very small to large quantities of fresh water are available from lower capacity, fractured, and karstified limestone in the south in map unit 3. Yields may be smaller in the upper elevations of mountainous areas. Aquifer thickness is less than 500 meters. Depth to water may be over 300 meters in places, less in the valleys. Successful wells may depend upon encountering water-bearing fractures. Unsuitable to small quantities of fresh water are available from fine-grained chalky limestone in the north in map unit 4. Successful wells may depend upon encountering water-bearing fractures. Springs are common in fault zones, some of which exist along the border between map units 1 and 4.

Contamination from bauxite mining has increased the sodium and the hydrogen-ion concentrations in some limestone aquifers in the southeast in map unit 7-1. The rest of the parish is composed of volcanic and metamorphic basement rock, depicted in map unit 6. The parish capital Saint Ann's Bay is in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance.

Two sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint Catherine

Area: 1,192.4 square kilometers (10.9 percent of the country)

Estimated Population (1998): 411,600 (15.9 percent of the population)

Population Density: 345 people per square kilometer

Parish Capital: Spanish Town

Location: In southeastern Jamaica, with the Caribbean Sea forming the southern boundary. The eastern boundary follows the Ferry River for part of the river's length. It then follows an irregular line dividing Saint Catherine from the parishes of Saint Mary and Saint Andrew. The northern boundary follows an irregular line dividing Saint Catherine from the parishes of Saint Ann and Saint Mary. The western boundary follows an irregular line dividing Saint Catherine from the parish of Clarendon.

Surface Water:

Fresh water is perennially available from the larger streams in the parish. Small to moderate quantities of fresh water are available from the middle reaches of the Rio Cobre, as depicted by map unit 1. Very small to small quantities of fresh water are available from the upper reaches of the Rio Cobre and from the Rio Pedro, as depicted by map unit 3. Fresh water is seasonally available from Rio Magno Gully, Indian River, and the Rio Doro in meager to very small amounts, as depicted by map unit 4. In addition, water is seasonally available in numerous intermittent streams, as depicted by map unit 5. Fresh to brackish water is available from the Fresh River, Salt Island Lagoon, Salt Island Creek, Coleburns Gully, and from the lower reaches of the Rio Cobre, as depicted by map unit 6. The water may become brackish during the dry seasons from more saline irrigation water, and subsequent evaporation. Fresh water is scarce or lacking in swamps or marshes along the coast and around the Great Salt Pond, as depicted by map unit 9. The Great Salt Pond is about 1.8 square kilometers (0.7 square miles) in area. One stream flows through the swamp that borders the pond. The pond originally was separated from the sea by a sandbar, but a permanent connecting channel was created in the 1970's.[127] Saint Catherine is the largest parish in Jamaica. The mean annual rainfall for the parish from 1951 to 1980 was 1,428 millimeters (56 inches).[128] Spatially, the mean annual rainfall varies from 762 millimeters (30 inches) in the southeast to over 2,540 millimeters (100 inches) of rain in the northern mountains.[129] Elevation ranges from sea level to over 914 meters (3,000 feet) in the north.[130]

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and alluvial aquifers in the central and northern parts of the parish. The limestone aquifers are shown in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. Map unit 2 depicts alluvial aquifers near the coast and in sediment-filled valleys in the center of the parish. Very small to very large quantities of water are available from these areas. Water consumption throughout this parish is great. Well yields may decrease during periods of high demand. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in the mountainous areas to the south. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

Very small to large quantities of fresh water are available from lower capacity, fractured, and karstified limestone in the north in map unit 3. Yields may be smaller in upper elevations in mountainous areas. Aquifer thickness averages 500 meters. Depth to water may be greater than 300 meters in places, but generally less in the valleys. Successful wells may depend upon encountering water-bearing fractures.

Small to enormous quantities of brackish to saline water are available from alluvial sediments and limestone aquifers in the southwestern part of the parish in map units 7-1 and 7-2. The parish capital Spanish Town is in map unit 7-2. Overpumping from wells has caused saltwater deep beneath the surface to contaminate the formerly fresh aquifers located closer to the surface. Contaminated water usually has high amounts of sodium, calcium, chloride, and bicarbonate. Chloride concentrations generally increase with depth and may be as high as 1,000 milligrams per liter. Water quality may improve over time as pumping rates decrease. Contamination from bauxite mining has increased the sodium and hydrogen-ion concentrations in some limestone aquifers in the north. Dunder contamination in the Rio Cobre Basin causes discoloration, odor, high turbidity, and high coliform bacteria counts. The rest of the parish is composed of volcanic and metamorphic basement rock, depicted in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance.

A central sewerage system and 15 sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint Elizabeth

Area:	1,212.4 square kilometers (11 percent of the country)
Estimated Population (1998):	148,900 (5.8 percent of the population)
Population Density:	123 people per square kilometer
Parish Capital:	Black River
Location:	In the southwestern part of Jamaica, with the Caribbean Sea forming the southern boundary. On the east, an irregular line divides Saint Elizabeth from the parish of Manchester. On the north, an irregular line separates Saint Elizabeth from the parishes of Trelawny and Saint James. The parish of Westmoreland borders Saint Elizabeth on the west.

Surface Water:

Fresh water is perennially available from some of the major streams in the parish. Small to moderate amounts are available from the upper and middle reaches of the Black River, as depicted by map unit 1. Very small to moderate quantities are available from the upper reaches of the Y.S. River, as depicted by map unit 2. Very small to small quantities are available from the South Elim River, as depicted by map unit 2. Fresh water is seasonally available from ponds, swamps, and the lower reaches of the Y.S. and Black Rivers. Meager to very small quantities of water are available from the Wallywash Pond, as depicted by map unit 4. Fresh to brackish water is found in the Upper Black River Morass and in part of the Lower Black River Morass, as depicted by map unit 7. The Y.S. and Black Rivers bring significant amounts of fresh water into both swamps. During high flow periods, water found in these areas will probably be fresh; and during periods of low flows, water may become brackish. Fresh water is scarce or lacking in parts of the Lower Black River Morass; extreme lower reaches of the Black River, Broad River, and Parottee Great Salt Pond; and in the Cockpit Country, as depicted by map unit 8 and 9. Except for the Cockpit Country, there is significant saltwater intrusion into these areas, especially during low stream flows. The Cockpit Country has many steep-sided, closed depressions, separated by rugged, uneven peaks. These are due to limestone solution and collapse. Any surface water in this area is quickly channeled into the subsurface. The mean annual rainfall from 1951 to 1980 was 1,838 millimeters (72 inches).[131] Generally, the mean annual rainfall is much less along the coast in the south than in the northern mountains. The Black River is the largest river in the country, and is navigable upstream from the mouth of the river for 28 kilometers (17.4 miles) by small vessels.[132]

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and the alluvial aquifers throughout the parish. The limestone aquifers are shown in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The limestone is generally thickest toward the coast and overlies basement rock. The parish capital Nain is in map unit 1. Map unit 2 depicts a small sediment-filled valley in the east. Very small to very large quantities of water are available from the alluvial aquifer in this valley. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in mountainous areas to the north. These northern areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures. Springs are scattered throughout the northwestern part of the parish.

Very small to large quantities of fresh water are available from lower capacity, fractured, and karstified limestones along the northern parish boundary and southern Santa Cruz mountains in map unit 3. Yields may be smaller in the upper elevations of mountainous areas. Aquifer thickness averages 500 meters. Depth to water may be over 300 meters in places. Successful wells may depend upon encountering water-bearing fractures.

Large to enormous quantities of brackish to saline water are available from limestone aquifers west of Nain. Contamination from bauxite mining has increased the sodium and the hydrogen-ion concentrations in this area, depicted in map unit 7-1. Small to large quantities of brackish to saline water contaminated by saltwater intrusion are available from a narrow strip of sediments along the southeastern coast, depicted in map units 7-5 and 7-6. The rest of the parish is composed of coastal and interior valley clays, shales, and volcanic and metamorphic basement rock, depicted in map units 5 and 6. Coastal aquifers composed of clays, shales, and basement rock are brackish to saline due to saltwater intrusion. Overpumping from wells has caused saltwater deep beneath the surface to contaminate the formerly fresh aquifers located closer to the surface. Contaminated water usually has high amounts of sodium, calcium, chloride, and bicarbonate. The chloride concentrations generally increase with depth. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. Access may be difficult in swampy areas near the Black River.

No sewage treatment plants exist in this parish. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint James

Area:	594.9 square kilometers (5.4 percent of the country)
Estimated Population (1998):	178,000 (6.9 percent of the population)
Population Density:	299 people per square kilometer
Parish Capital:	Montego Bay
Location:	On the northwestern side of the country. The Caribbean Sea forms the northern boundary, while the Great River forms the western boundary. Saint James is bordered on the southern side by the parish of Saint Elizabeth and on the east by the parish of Trelawny.

Surface Water:

Fresh water is perennially available from the major streams throughout the parish. The Great River has small to moderate flows, as depicted by map unit 1. The course of this stream follows a fault, and its tributaries may be very fast moving, carving steep ravines. The other major river is the Montego River, which has very small to small flows, as depicted by map unit 3. Another area that may be significant is Gales Valley, which has numerous small ponds on the eastern side of the parish. One of them, Wemyss Pond, is fed by a spring with a flow of 0.03 to 0.06 cubic meter per second (1 to 2 cubic feet per second), but may stop flowing during dry months.[133] However, most of the ponds are fed by surface runoff. The rest of the area in the parish is divided into two sections, one with intermittent streams (map unit 5) and one that has little to no surface drainage due to the karstic nature of the limestone aquifer (map unit 8). Due to the large amount of limestone in this parish, some small streams may disappear or have segments that sink into the limestone and resurface farther downstream.

Between 1951 and 1980, Saint James had an annual mean rainfall of 1,791 millimeters (71 inches).[134] The parish is also subject to torrential rains during hurricanes. After torrential rains, “flash” floods may occur. These may cause temporary road blockages; however, these floods are usually of short duration. In elevation, the parish ranges from sea level to a maximum elevation of 701 meters (2,300 feet).[135] Topography ranges from youthful to mature. Generally, the topography becomes more youthful southward, away from the coast. In youthful areas, the streams are fast moving, with steep gradients and rocky beds. They also may carry a lot of sediment due to inappropriate land use practices.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and the alluvial aquifers covering about one-fifth of the parish. The limestone aquifers are shown in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The limestone is generally thickest toward the coast and overlies basement rock. A small area of alluvial aquifer material exists on the eastern edge of the parish, depicted in map unit 2. Very small to very large quantities of water are available from sediments in this valley. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in mountainous areas to the south. Access is generally good in this flat, alluvial, interior valley. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures. Wells provide 40 percent of existing water supplies. Springs are common along fault zones.

Very small to large quantities of fresh water are available from lower capacity, fractured, and karstified limestone in the south in map unit 3. Aquifer thickness averages 500 meters. Yields may be smaller in upper elevations of mountainous areas. Unsuitable to small quantities of fresh water are available from fine-grained, chalky limestone in the north in map unit 4.

Unsuitable to small quantities of brackish to saline water are available from relatively impermeable soft marls and lower capacity limestone, clays, and shales along the northern coast in map units 7-4 and 7-5. Overpumping from wells has caused saltwater deep beneath the surface to contaminate the formerly fresh aquifers located closer to the surface. Contaminated water usually has high amounts of sodium, calcium, chloride, and bicarbonate. The chloride concentrations generally increase with depth and may be as high as 1,000 milligrams per liter. The rest of the parish is composed of volcanic and metamorphic basement rock and impermeable limestone, depicted in map unit 6. Ground water exploration is not recommended during military exercises without site-specific reconnaissance. Springs are common along fault zones.

One sewage treatment plant exists in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Ground water may be locally contaminated by the sewage treatment facility located in the parish capital Montego Bay. This sewage treatment system is in the process of being upgraded, which may improve ground water quality in the future.

Saint Mary

Area: 610.5 square kilometers (5.6 percent of the country)

Estimated Population (1998): 113,000 (4.4 percent of the population)

Population Density: 185 people per square kilometer

Parish Capital: Port Maria

Location: In northeastern Jamaica, with the Caribbean Sea forming the northern boundary. The western boundary is the White River, which divides the parish of Saint Ann from Saint Mary. The parish of Portland forms the eastern boundary. The parishes of Saint Catherine and Saint Andrew form the southern boundary.

Surface Water:

Fresh water is perennially available in small to moderate quantities from the Wag Water and White Rivers, as depicted by map unit 1. The rest of the parish has fresh water seasonally available from intermittent streams, as depicted by map unit 5. Parts of the upper reaches of the White River may sink into the limestone aquifer and then rise again farther down stream. Because of a constant base flow from the underlying limestone formation in the western part of the parish, the White River has much less seasonal flow variations than the Wag Water River. From 1951 to 1980, the mean annual parish rainfall was 1,908 millimeters (75 inches).[136] However, rainfall can vary from 1,397 millimeters (55 inches) on the northwest coast to at least 3,810 millimeters (150 inches) in the mountains in the southeast part of the parish.[137] Elevations range from sea level to a maximum of 1,275 meters (4,183 feet) only 13 kilometers (8 miles) from the coast.[138] The topography is youthful, and the physical geography is varied. Near the coast, there are alluvial areas that have slopes from flat to 3 degrees. Farther inland, there are gently sloping, rounded hills with slopes from 10 to 20 degrees. In the southeastern part of the parish, there are mountains with knife-edged ridges, deep valleys, and slopes from 25 to 40 degrees.[139] In the northwestern part of the parish, there is a limestone plateau with some flat parts, but it is deeply dissected in other areas. Because of the youthful nature of the topography, many streams in their upper courses are swift, have steep gradients, and may carry large amounts of sediment.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers on the western border of the parish and the alluvial aquifers in the northeast near Annotto Bay. A small area of limestone aquifers is along the western edge of the parish in map unit 1. Large to enormous quantities of fresh ground water are available from fractures and solution cavities. Very small to very large quantities of water are available from alluvial aquifers in a sediment-filled valley in the northeast in map unit 2. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in mountainous areas to the north. Springs are scattered throughout the northwest. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures.

Unsuitable to small quantities of fresh water are available from the less karstified, fine-grained, chalky limestone in the north and northwest in map unit 4. Limestone in these areas is less fractured and more permeable than the limestone in map unit 1. Successful wells may be drilled in these areas, although yields will be significantly less than those drilled in the fracture zones in map unit 1. Depth to water varies, but is generally less than 100 meters.

Most of the parish is composed of volcanic and metamorphic basement rock and impermeable limestone, depicted in map unit 6. The parish capital Port Maria is in map unit 6. Ground water exploration is not recommended during military exercises without site-specific reconnaissance. Springs may flow from fractures during the wet season.

One sewage treatment plant exists in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Saint Thomas

Area:	742.8 square kilometers (6.8 percent of the country)
Estimated Population (1998):	91,900 (3.6 percent of the population)
Population Density:	124 people per square kilometer
Parish Capital:	Morant Bay
Location:	On the southeast corner of the country. The Caribbean Sea forms the southern and eastern boundaries. The parish of Portland forms the northern boundary, and the parish of Saint Andrew forms the western boundary.

Surface Water:

Fresh water is perennially available in small to moderate amounts from the Plantain Garden River, as depicted by map unit 1. This is the only major river that flows in an west-east direction. All of the other major streams flow in north-south directions. Very small to small amounts are perennially available from the Yallahs, Negro, and Morant Rivers. There is a pipeline on the Yallahs River, located south of Llandewey, which supplies about 0.84 cubic meter per second (26.5 million cubic meters per year) to the City of Kingston.[140] From the Negro River, about 0.42 cubic meter per second (13.3 million cubic meters per year) of water may be diverted to Kingston.[141] The Yallahs, Negro, and Morant Rivers have youthful topography with steep gradients and swift flows, and they carry large sediment loads in their upper reaches. Near the coast, a more mature profile develops. The river gradients decrease, and they begin to drop their sediment loads. These rivers have wide, rocky channels near the shore. Saint Thomas has a mean annual rainfall of 2,288 millimeters (90 inches).[142] However, this rainfall is seasonally distributed. Therefore, the rivers may be little more than a trickle in dry seasons, sinking into their rocky channels, but they may become raging torrents during moderate rainfall. Fresh water is scarce or lacking near the salt ponds and the Great Morass at Morant Point, as depicted by map unit 9. The salt ponds, located on the southern boundary of Saint Thomas, contain saline water. The Great Morass is a large mangrove swamp that contains mainly brackish to saline water. However, fresh water may also be found in the swamp. There are three streams that run through the morass originating from blue holes. This water may be fresh, but there is probably significant seawater mixing near the coast. The rest of the parish has fresh water seasonally available from small or intermittent streams, as depicted by map unit 5.

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and the alluvial aquifers. The limestone aquifers are in the south and east in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. Map unit 2 depicts the alluvial aquifers in sediment-filled valleys of the Yallahs, Morant, and Plantain Garden Rivers in the south. Very small to very large quantities of water are available from map unit 2. Wells provide 70 percent of the water supply to this parish. Depth to water varies, but is generally less than 100 meters. Depth to water may be greater in the mountainous areas to the north. These areas may be suitable for hand pump wells, but successful wells in the limestone may depend upon encountering water-bearing fractures. Springs are scattered throughout the foothills.

Unsuitable to small quantities of fresh water are available from less karstified, fine-grained, chalky limestone depicted in map unit 4. The parish capital Morant Bay is in map unit 4. The limestone in map unit 4 is less fractured and more permeable than the limestone in map unit 1. Depth to water varies, but is generally less than 100 meters. Successful wells may be drilled in these areas, although yields will be significantly less than those drilled in the fracture zones of map unit 1.

Most of the parish is composed of volcanic and metamorphic basement rock depicted in map unit 6. Ground water exploration is not recommended in this map unit during military exercises without site-specific reconnaissance. Springs may flow from fractures during the wet season.

Two sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

Trelawny

Area: 874.6 square kilometers (8 percent of the country)

Estimated Population (1998): 72,600 (2.8 percent of the population)

Population Density: 83 people per square kilometer

Parish Capital: Falmouth

Location: In northwestern Jamaica, with the Caribbean Sea forming the northern boundary. The western boundary borders Saint James Parish, and part of the southern boundary follows the Hectors River, which divides Trelawny from Manchester Parish. Part of the southern boundary also borders Saint Elizabeth Parish. The eastern boundary follows the Rio Bueno for a few kilometers, which divides Trelawny from Saint Ann Parish.

Surface Water:

Fresh water is perennially available from the major streams in this parish. Small to moderate amounts are available from the Rio Bueno and from the middle and lower reaches of the Martha Brae River, as depicted by map unit 1. Very small to small amounts of water are available from the upper reaches of the Martha Brae River and from a tributary, the Roaring River, as depicted by map unit 3. The Mouth and Hectors Rivers also have very small to small quantities of fresh water, as depicted by map unit 3. Significant water may also be found immediately northwest of Clarks Town, in Clarks Town Pond. This source was once used as a public water supply for Clarks Town, but the town has now switched to other sources. This pond has a surface area of 0.01 square kilometer (2.5 acres) and a maximum depth of 4.8 meters (15 feet). This water is moderately hard, with 108 milligrams per liter of dissolved calcium carbonate. Another significant pond is the Wakefield Pond. This pond has a surface area of 0.04 square kilometer (10.7 acres) and a maximum depth of 6.1 meters (20 feet). This water is soft, with 30 milligrams per liter of calcium carbonate.[143] Near the coast, there are numerous small or intermittent streams that carry fresh water seasonally. The Quashies River also has meager to very small quantities of fresh water seasonally available. Farther inland, fresh water is scarce or lacking due to karstic limestone, as depicted by map unit 8. Water in this area quickly disappears into the subsurface. The topography in this area is very rugged. The terrain may be very difficult to pass due to its high peaks, steep hills, ravines, gullies, and sinkholes. The natural outlets for the Hectors, Quashies, and Mouth Rivers are sinkholes. In addition, the Rio Bueno and the Martha Brae River have a higher sustained base flow than some of the rivers in the eastern part of the country. Therefore, they do not have such a dramatic change in flow during wet and dry seasons, but flow remains more constant. This is due to the base flow supplied by the interior limestone aquifer. The mean annual rainfall for the parish of Trelawny is 1,606 millimeters (63 inches).[144]

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers and alluvial aquifers covering about one-third of the parish. The limestone aquifers are depicted in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The limestone is generally thickest toward the coast and overlies basement rock. Access is generally good near Duanvale. Map unit 2 depicts the alluvial aquifers in the sediment-filled interior valleys of the west. Very small to very large quantities of water are available from these areas. Access is generally good in these flat alluvial valleys. Queen of Spains Valley is the largest and most accessible of these valleys. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures. Ground water may be obtained from boreholes in interior valleys such as Lluidas Vale.

Unsuitable to small quantities of fresh water are available in the north from fine-grained, chalky limestone depicted by map unit 4. Successful wells may depend upon encountering water-bearing fractures. A large fault near Duanvale may provide good areas for ground water exploration, although fault scarps in the area may locally hinder access. Very small to large quantities of water may be available from the aquifer beneath the Quashies River. Meager to very small amounts of water are seasonally available from this river while it flows at the surface; however, below the surface, the river perennially saturates the ground along the southern border of the parish. In the southern part of the parish, known as Cockpit Country, very small to large quantities of fresh water are available from the lower capacity, fractured, and karstified limestone depicted in map unit 3. Cockpit Country is known for its rough terrain, which is covered by alternating steep conical hills and pit-like valleys. Aquifer thickness here is highly variable, usually thinnest in valleys and thickest on hilltops. Isolated patches of alluvial sediments deposited within the valleys may yield limited amounts of ground water.

Ground water exploration in most areas in the rest of the parish is not recommended during military exercises without site-specific reconnaissance. Very small to very large quantities of brackish to saline water are available from alluvial aquifers near the parish capital Falmouth in map unit 7-2. Unsuitable to small quantities of brackish to saline water are available from relatively impermeable soft marls and lower capacity limestone along the coast in map unit 7-4. Chlorine concentrations may be as high as 1,000 milligrams per liter, and generally increase with depth due to upconing of salty seawater that has invaded local aquifers. Unsuitable to very small quantities of fresh water may be available from volcanic and metamorphic basement rock in the southeast in map unit 6. Springs are common along fault zones in the basement rock.

One sewage treatment plant exists in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Dunder contamination in the Martha Brae River Basin causes discoloration, odor, high turbidity, and high coliform bacteria counts.

Westmoreland

Area:	807 square kilometers (7.3 percent of the country)
Estimated Population (1998):	139,000 (5.4 percent of the population)
Population Density:	172 people per square kilometer
Parish Capital:	Savanna la Mar
Location:	In southwestern Jamaica, with the Caribbean Sea forming the western and southern boundaries. Following an irregular boundary, Westmoreland borders the parish of Hanover to the north. The eastern border follows the Great River for part of its length, separating Westmoreland with the parish of Saint James. The rest of the eastern boundary is an irregular line separating Westmoreland from Saint Elizabeth.

Surface Water:

Fresh water is perennially available from major streams in this parish. The Great River has small to moderate quantities of fresh water, as depicted by map unit 1. Very small to moderate quantities are available from the Roaring River, a tributary of the Cabarita River, as depicted by map unit 2. Very small to small quantities are available from the Cabarita River, as depicted by map unit 3. In addition, there are numerous small ponds located near Little London that may contain fresh water. Fresh water is seasonally available from the Orange and South Negril Rivers and numerous intermittent streams, as depicted by map unit 5. Fresh water is scarce or lacking in the eastern part of the parish due to the karstic nature of the underlying limestone, as depicted by map unit 8. In the Negril Great Morass and the morass located near the mouth of the Cabarita River, fresh water is scarce or lacking, as depicted by map unit 9. The Negril Great Morass covers 22.9 square kilometers (5, 657 acres), which is one-fifth of all the wetlands in Jamaica.[145] It is separated from the sea by a narrow sandy spit. Water in this morass may range from brackish to saline. However, some fresh water may be found during the wet seasons due to the presence of numerous dykes and levees in the morass that may effectively channel water. The swamp, located near the mouth of the Cabarita River, has three main water channels running through it. Generally, while this water is probably brackish to saline, during times of moderate rains, fresh water may be found. From 1951 to 1980, the mean annual rainfall in this parish was 2,216 millimeters (87 inches).[146]

Ground Water:

The best areas for ground water exploration are the karstified limestone aquifers that cover most of the parish. These areas are in map unit 1, where large to enormous quantities of fresh ground water are available from fractures and solution cavities. The parish capital Savanna-La-Mar is in map unit 1. The limestone is generally thickest near the coast and overlies basement rock. Depth to water varies, but is generally less than 100 meters. These areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures. An alluvium and peat aquiclude overlies the lowlands in the vicinity of the Cabarita River. Depth to water may be greater in the mountainous areas to the east.

Unsuitable to small quantities of fresh water are available from the less karstified, fine-grained, chalky limestone depicted by map unit 4 along the southwest coast and north of the Cabarita River. Limestone in this area is less fractured and more permeable than the limestone in map unit 1. Successful wells may be drilled in these areas, although yields will be significantly less than those drilled in the fracture zones in map unit 1. Depth to water varies, but is generally less than 100 meters.

The rest of the parish, depicted in map units 5 and 6, is composed of coastal and interior valley clays and shales, volcanic and metamorphic basement rock, and impermeable limestone. Ground water exploration is not recommended in these map units during military exercises without site-specific reconnaissance.

Two sewage treatment plants exist in this parish. However, the primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.

VI. Recommendations

Many of the agencies and individuals that were interviewed during the country visit expressed interest in technical assistance and training, watershed management and protection, improved sewage treatment and disposal technology transfer, advanced technological methods and updated equipment. Research is needed on effective wastewater systems and alternative forms of sanitation, since only a portion of the households are located in areas served by central collection and treatment systems. The passage of the Ministry of Water (MOW) Water Sector Policy Paper and the Watershed Policy Paper will be beneficial.

A. Technical Training and Assistance

Government officials recognize the need to further develop their technical capabilities in many areas. These areas include updating methods for the following: hydrological data collecting; monitoring and analysis; wastewater treatment plant operations; incinerator efficiency; operations and maintenance; sewage treatment and disposal; water treatment methods and applications; GIS use; and irrigation. Many plants operate with a lack of trained personnel.

B. Watershed Protection and Management

A draft watershed policy is in review now. It has been in draft form since 1999. The policy document states the essential elements of a national watershed management initiative. It supercedes the Watershed Protection Act of 1963, which is considered outdated. The watershed degradations caused by deforestation, sewage and agricultural contamination (seepage pits), and limited institutional capabilities may be overcome by the implementation of this watershed policy.

C. Troop Exercise Opportunities

U.S. Southern Command currently provides assistance to the Caribbean countries through its Humanitarian Civic Assistance exercises, which can include water well drilling. Wells are sometimes drilled and used as water supply for troops during these exercises. Upon completion of an exercise, any successful wells are appropriately fitted and turned over to the local communities for use as a water supply. Small surface impoundments could also be constructed by U.S. troops during troop engineering exercises, if conditions warrant. However, small surface impoundments should be constructed only in areas where no surface water contamination exists.

1. Well Exercises

Jamaica depends heavily on ground water for water supply. Overall, the quality of ground water is good throughout the country. Small hand pumps are in demand, particularly in rural areas. Installing small hand pump wells, especially in rural areas, as part of U.S. troop engineering exercises, could be of benefit. These wells could be a source of safe water for populations without access to safe water. The WRA would be an excellent source of information to determine rural areas with the greatest need for water.

2. Small Surface Impoundments

In certain areas of the country, the construction of small impoundments for capturing water for water supply may be considered. Mountain ranges and hilly terrain cover much of the land surface. In mountainous areas, depth to aquifers may be too great for troop exercises, and accessibility may be difficult. Other areas where small impoundments should be considered are areas where ground water exploration may be too difficult for troop exercises or potential well depths too great. Surface impoundments may also be beneficial for decreasing surface runoff and erosion and may aid aquifer recharge. Extreme caution should be exercised in site selection because of the potential for water contamination. Most of the water quality problems in the country are associated with surface water as opposed to ground water. These impoundments should be considered only in areas where the surface water is not heavily polluted, such as upstream from populated places, away from untreated domestic wastewater discharge, and away from industrial sites and major cities. The impoundments should be sited where water contamination would not be a problem. Design of these impoundments will not be difficult, and construction techniques will be very similar to local construction techniques. The other main factors are selecting a suitable site, sizing the embankment, and designing the outlet structures. The construction of these sites can be accomplished by U.S. troops.

D. Water Quality and Supply Improvement

Overall, the water quality of the water supply is good. More problems with water quality are associated with surface water as opposed to ground water, and most of the water supply of the country is from ground water sources. Many water wells in the Liguanea Plain in Kingston have been shut down due to excessive nitrates, caused by improper sewage disposal. Saline intrusion has contaminated ground water supplies in Clarendon and Saint Catherine Parishes, due to poor siting and overpumping of production wells in the southern plains. The disposal of waste from the bauxite-alumina and rum distillery industries has impacted ground water in Clarendon, Saint Catherine, Saint Elizabeth, and Saint Ann. Poor attention to wastewater services, generally coupled with under-funding of the sector, has largely been responsible for poor operations and maintenance practices. A result has been the discharge of poor-quality effluent to the nation's waterways. Many wastewater treatment plants fail to meet discharge standards. Improved wastewater treatment and a decrease in the use of soak-away pits should improve water quality. The improvement of water resources management is fundamental to the future control of water pollution.

Most urban residents have access to safe piped water. About 39 percent of rural households have piped water, but the quality is lower than that in urban areas. The distribution system in Kingston is very old and in great disrepair. It is estimated that about half the water is 'lost' in the distribution system. The two reservoirs that supply water to Kingston, Mona, and Hermitage have reduced capacities of about 2 and 20 percent respectively, due to siltation. More efforts to curb siltation of the reservoirs are needed to extend the usefulness of the reservoirs. The Kingston distribution system is in dire need of repair to save half of the water supply it is currently using.

Most of the water supply is used for irrigation, and irrigation efficiencies are low. Therefore, increased implementation of more efficient irrigation systems, such as drip irrigation, is greatly needed to prevent the waste of much of the water supply.

VII. Summary

Water resources and water supplies are the responsibilities of many agencies. The uneven seasonal distribution of water causes problems. Water quality in some areas is compromised by excessive nitrate levels due to saltwater intrusion. The intrusion is caused by overpumping in many wells, particularly near densely populated areas where the ground water may already be affected by improper or inadequate sewage disposal and wastewater treatment. Some factors contributing to the problems associated with water resources and supply are as follows:

- uneven rainfall distribution;
- degradation of the watersheds caused by deforestation, erosion of the karst terrain, and poor agricultural practices;
- rapid growth in urban areas, increasing demand beyond system capacity;
- poor distribution network in Kingston;
- dated technology for proper analysis;
- inefficient irrigation methods;
- improper sewage disposal and inadequate wastewater treatment;
- inadequate engineering structures to control flooding, erosion, drainage; and
- pollution of ground water from the bauxite-alumina industry, improper sewage disposal, and saline intrusion due to overpumping.

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APPENDIX A

Lists of Officials Consulted

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

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APPENDIX B

Glossary

Glossary

alluvial	Pertaining to processes or materials associated with transportation or deposition by running water.
alumina	Any of several forms of aluminum oxide, Al_2O_3, occurring naturally as corundum, in a hydrated form in bauxite with many impurities.
aquiclude	A porous rock formation capable of absorbing water, but not capable of transmitting it fast enough to supply sufficient amounts to a well.
aquifer	A geologic 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.
artesian conditions	Conditions when pressure in an aquifer is strong enough to raise the water level in a well above the height of the water table.
base flow	Sustained or fair-weather runoff. In most streams, base flow is composed largely of ground water discharge.
basement rock	The crust of the Earth below sedimentary rocks, including limestone. Composed of volcanic and metamorphic rocks, including Cretaceous lavas, tuffs, limestones, shales, and conglomerates with low permeability.
basin	A low area toward which streams flow from adjacent hills. Ordinarily, a basin opens either toward the sea or toward a downstream outlet; but in an arid region without an outlet, a basin can be surrounded by higher land.
bauxite	Hydrated alumina; the principal ore of aluminum.
bicarbonate	A compound containing a metal, generally Ca, Mg, K, and/or Na, and the radical HCO_3, such as Ca $(HCO_3)_2$.
biochemical oxygen demand (BOD)	The amount of oxygen consumed by microorganisms, mainly bacteria.
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.
brackish water	Water that contains more that 1,000 milligrams per liter but not more that 15,000 milligrams per liter of total dissolved solids.
calcium carbonate ($CaCO_3$)	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 or dolomite, that consists mostly of carbonate minerals.
chalk	A soft, pure, earthy, fine-textured, usually white to light-gray limestone of marine origin, consisting almost wholly of calcite. Normally very porous but impermeable, and considered a confining bed.

chalky limestone	Limestone containing chalk, a soft, pure, earthy, fine-textured limestone of marine origin, consisting almost wholly of calcite. Normally very porous but not very permeable.
chert	A compact, microcrystalline, glassy, hard, variously colored, siliceous sedimentary rock composed of chalcedonic silica. Chert occurs as lenses, nodules, or thin beds.
chloride (Cl)	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.
clay-sized particle	A mineral particle having a diameter less than 0.004 millimeter.
cockpit	A star-shaped depression with a cone-shaped, concave floor surrounded by steep, convex hill slopes.
confluence	The point where two streams meet.
conglomerate	Gravel-size or larger, consolidated, rounded to semirounded rock fragments in a finer grained material.
conveyance capability	The ability of a stream to move water and sediment downstream.
deforestation	The removal or clearing away of the trees or forest.
dendritic	This term refers to a branching, tree-like pattern that a stream and its tributaries form due to the geology of the area.
dissolved oxygen (DO)	The amount of oxygen, in parts per million by weight, dissolved in water, now generally expressed in milligrams per liter. It is a critical factor for fish and other aquatic life and for self-purification of a surface water body after inflow of oxygen-consuming pollutants.
drawdown	The change in surface elevation of a body of water as a result of withdrawing water. Drawdown in wells is detected by measuring an increase in the depth to water in the pumped well, or nearby wells, after withdrawing water from the well.
dolomitized	Referring to carbonate rock which has been transformed over time, so it has higher magnesium content and more pore spaces within the rock matrix than it had when it originally formed.
dunder	Effluent from sugar and rum industrial processing. Ground water contaminated by dunder has a bad taste and odor, high turbidity, high coliform counts, and traces of clarification residue and reducing sugars.
dyke	An embankment built to prevent floods.
effluent	An outflow of waste.
Eocene	A division of geologic time between 38 and 55 million years ago. Falls chronologically after the Paleocene and before the Oligocene. Included in the Tertiary.

fault	A fracture or fracture zone of the Earth with displacement of one side relative to the other.
fault zone	An area of numerous faults.
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 found per milliliter of water) when testing the sanitary quality of water.
fine-grained (rock)	(1) Describes igneous rock and its texture, whose particles have an average diameter less than 1 millimeter. (2) Describes sedimentary rock and its texture, in which the particles have an average diameter less than 0.06 millimeter (silt size or smaller).
fissure	A fracture or crack in a rock along which there is a distinct separation.
flash flood	Flood of short duration with a relatively high peak rate of flow, usually resulting from a high-intensity rainfall over a small area.
formation	A body of rock strata that consists dominantly of a certain lithologic type or combination of types.
fracture	A break in a rock with no significant displacement across the break.
fresh water	Water that contains 600 milligrams per liter or less of chlorides, 300 milligrams per liter or less of sulfates, and 1,000 milligrams per liter or less of total dissolved solids.
gaging station	A location on a stream where water levels are measured to record discharge and other parameters.
gravel-sized particles	An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than 2 millimeters.
halogenated hydrocarbons	Contaminant that is often leached into ground water from landfills containing spray bottles, refrigerants, and cleaning detergents.
hard rock	Rock that is relatively resistant to erosion; a firm, solid, or compact rock that does not yield easily to pressure.
hard water	A measurement of the amount of calcium carbonate ($CaCO_3$) in the water, which can form an insoluble residue.
heavy metals	A class of contaminants including arsenic, barium, chromium, mercury, nickel, lead, copper, zinc, cobalt, bismuth, gold, silver, manganese, and others, which in very small amounts may be harmful to human health.
herbicide	A substance that is used to kill plants.
hydroelectric	A facility that produces electrical energy by means of a generator coupled to a turbine through which water passes.
hydrogen-ion concentration (pH)	An expression of the intensity of the basic or acid condition of a liquid. Values range from 0 to 14, where 0 is the most acidic, 14 is the most basic, and 7 is neutral. Natural waters usually have values between 6.5 and 8.5.

igneous	A class of rock formed by the solidification of molten material. If the material is erupted onto the Earth's surface, the rock is called an extrusive or volcanic rock; if the material solidifies within the Earth, the rock is called an intrusive or plutonic rock.
intermittent stream	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 in a rock formation along which there is no evidence of displacement. Represents various stresses that the rocks have experienced. Ground water can percolate freely through connected joints, and soils can develop deeply along joints.
karst	A terrain, generally underlain by limestone, in which the topography is mainly formed by dissolving of rock. Common karst features include fissures, sinkholes, underground streams, and caverns.
lava	Molten rock which issues from a volcano or a fissure in the Earth's surface. Lava is also the same material solidified by cooling.
leaching	The removal of soluble substances by water that percolates through waste material and into the surrounding soil and rock.
levee	An embankment, usually composed of earth or concrete, that is used to prevent a river from overflowing.
limestone	(1) A heterogeneous mix of calcareous rocks ranging from rubbly and marly to hard, recrystallized, dolomitized types. White limestone is the most common aquifer material in Jamaica. The three most common types are: (a) well-fractured, rubbly limestone, which provides the best aquifer material; (b) deep-water, chalky, marly limestone with chert, which does not fracture as easily but is prone to forming solution cavities that provide poor to moderate aquifer material; and (c) partially fractured, dolomitized, recrystallized limestone, which provides poor aquifer material except in locally well-fractured areas.
	(2) For military purposes, the rock types which refer to all carbonate rocks.
	(3) Soft to moderately hard rock composed of calcium carbonate mainly in the form of shells, crystals, grains, or cementing material. Colors range from white-yellow to gray-black. Commonly thick bedded, jointed, and containing fossils. Limestone is often highly fractured and soluble.
mangrove	A group of plants that grows in a tropical or subtropical marine swamp. A marine swamp dominated by a community of these plants.
maritime tropical	A type of warm, wet air mass originating at low latitudes over ocean areas.
marl	A sedimentary rock composed primarily of clay and calcium carbonate. Marl is usually interbedded with shale and limestone. It is not normally good aquifer material, and often acts as a confining bed.
marsh	A shallow lake, usually stagnant, filled with rushes, reeds, sedges, and trees.

mature topography	Land where erosion is not actively taking place and processes are at equilibrium. Streams have broadened their floors and have developed alluvial deposits along their channels.
meandering stream	A stream with a tortuous or winding stream channel.
metamorphic	Any rock, such as schist or gneiss, that was formed from a pre-existing rock through heat, pressure, the effect of superheated fluids, or any combination of these.
morass	Ground that is soggy and low lying.
most probable number (MPN)	The likely number of bacteria found in water samples. This number cannot be directly counted, but must be estimated based on statistical methods.
norther	Wind storm that generally blows for 3 to 4 days and brings cold air and rain from North America.
open channel flow	The behavior of water flowing through a conduit in which water flows with a free surface.
outcrop	A mass of bedrock that is exposed at the surface of the Earth.
perched aquifer	A water-bearing unit of rock, which is separated from an underlying saturated layer by an unsaturated layer.
permeability	The property that enables rock to transmit water.
pH	Hydrogen-ion concentration: a measure of the acidity or basicity of a solution.
pipe flow	The behavior of water flowing through a conduit in which water does not flow with a free surface, rather it is enclosed in the conduit.
pit latrine	A method of waste disposal where biological wastes are deposited in a hole in the ground and covered with topsoil.
porosity	The ratio of the volume of the openings (voids, pores) in a rock or soil to its total volume. Porosity is usually stated as a percentage.
Quaternary Period	A period of geologic time from the end of the Tertiary Period to the present time during which rocks were formed.
rain shadow	A dry region on the lee (or sheltered) side of a topographical obstacle, usually a mountain range, where the rainfall is noticeably less than on the windward side.
recharge	Addition of water to the zone of saturation from precipitation, infiltration from surface streams, and other sources.
red mud ponds	Large surface impoundments of alkaline mud formed in sinkholes and other topographic depressions used to dispose of waste from bauxite alumina mining. Ground water in the vicinity of red mud ponds usually has high hydrogen-ion concentration and high levels of sodium.
reef	A chain of rock or coral along a shoreline and elevated above the surrounding bottom of the sea.
runoff	Rainfall not absorbed by the soil.
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion	Displacement of fresh surface or ground water by the advance of saltwater due to its greater density. Saltwater intrusion usually occurs

	in coastal and estuarine areas where it contaminates fresh water wells.
sand-sized particles	A term used for sedimentary rocks whose particles have an average diameter range greater than 0.6 millimeter to less than 2 millimeters.
scarp	An escarpment, cliff, or steep slope of some extent along a margin of a plateau, mesa, terrace, or beach.
shale	A soft to moderately hard, compacted, massive to laminated sedimentary rock composed of very fine-grained particles. Shale often weathers or breaks into very thin platy pieces or flakes.
silt-sized particles	A detrital particle commonly in the range of 0.06 to 0.002 millimeter.
sinkhole	A funnel-shaped depression in the Earth's surface formed by water in a soluble rock such as limestone.
soak-away pit	An open, unlined hole dug in the ground for the purpose of human waste disposal. Raw waste from soak-away pits often contaminates ground and surface water sources.
soft limestone	Limestone that is partially or mildly crystallized.
solution cavity	A hole created in a soluble rock by water that has dissolved a portion of the rock material.
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.
spit	A narrow embankment of land, commonly consisting of sand or gravel, deposited by ocean currents.
spring	A place where ground water flows naturally from a rock or the soil onto the land surface or into a body of surface water.
swamp	An area of moist or wet land with water standing on or just below the surface of the ground. Usually covered with a heavy and dense growth of vegetation.
Tertiary Period	A period of geologic time, 29 to 65 million years ago, during which rocks were formed. This is the first period of the Cenozoic Era during which high mountains were formed.
total dissolved solids (TDS)	The sum of all dissolved solids in water or wastewater.
total suspended solids (TSS)	The sum of insoluble solids that either float on the surface or are suspended in water, wastewater, or other liquids.
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.
transmissivity	The rate at which water passes through an aquifer.
tributary	Stream or other body of water, surface or underground, which contributes its water to another larger stream or body of water.

tuff	A fine-grained, mostly light-colored, soft, porous rock. Tuff is composed of small volcanic rock fragments and ash that are moderately compacted to form a texture more characteristic of sedimentary rocks.
turbidity	The cloudy appearance of water caused by the presence of suspended and colloidal matter. Turbidity is an indication of the clarity of water.
upconing	The cone-shaped rise of saltwater beneath fresh water in an aquifer as fresh water is produced from a well.
vegetal	A general term used for plants.
water table	The depth or level below which the ground is saturated with water.
white limestone	Limestone with limited amounts of terrestrial sediments, i.e. sand and clay-sized particles, eroded from the mainland of Jamaica. Formed during the Middle and Lower Eocene in deeper marine environments. It is often found at the surface or under recent sedimentary formations. White limestone may have chalk, flint, or chert beds, and occasionally softer beds of a more rubbly nature. It varies from pure, hard, recrystallized dolomitized types that have poor permeability and are resistant to weathering to soft, marly, chalky types with chert that have good permeability. This rock type forms the cap of the great limestone plateau of Jamaica, and is prone to forming cockpit topography with solution cavities and caverns below the Earth’s surface.
yellow limestone	Impure limestone interbedded with considerable amounts of tuffs, shales, and fine-grained sedimentary deposits, and may be flaggy, chalky or nodular. Formed during the Middle Eocene in a shallow marine environment. It is usually located below the white limestone and overlies the basement complex.
yield	The volume in liters per second of water produced from a well.
youthful topography	Sharp landforms with steep and irregular slopes. Erosion is actively taking place, and streams are cutting downwards.

APPENDIX C

Surface Water and Ground Water Resources

Tables and Figures

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Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh Water perennially available	Major perennial streams throughout the country. **Blue Mountain South Basin (I)** (1757N07628W)[3]: Plantain Garden River (1757N07613W). **Rio Cobre Basin (III)** (1805N07700W): Rio Cobre (1759N07652W). **Black River Basin (V)** (1806N07744W): Black River (1801N07751W). **Great River Basin (VII)** (1824N07756W): Great River (1827N07759W). **Martha Brae River Basin (VIII)** (1823N07740W): Martha Brae River (1829N07738W). **Dry Harbour Mountains Basin (IX)** (1820N07717W): Rio Bueno (1828N07728W), Laughlands Great River (1828N07716W), White River (1825N07704W). **Blue Mountain North Basin (X)** (1810N07642W): Rio Grande (1812N07630W), Swift River (1812N07634W), Wag Water River (1816N07647W).	Small to moderate quantities of water are available year-round. Moderate quantities are available during the high flow periods, which generally occur around October and to a lesser extent around May. Selected stream gaging stations and average flows are listed below. **Blue Mountain South Basin (I):** **1** Plantain Garden River, measured at a gaging station (1757N07616W) from 1983 to 1992, had an average flow from 2.61 to 13.76 m^3/s and a mean annual flow of 5.09 m^3/s. **Rio Cobre Basin (III):** **2** Rio Cobre, measured near Bog Walk (1805N07700W) from 1971 to 1973 and from 1986 to 1989, had an average flow from 6.03 to 17.07 m^3/s and a mean annual flow of 10.95 m^3/s. **3** Rio Cobre, measured near Spanish Town (1802N07659W) from 1954 to 1996, had an average flow from 1.39 to 12.37 m^3/s and a mean annual flow of 5.59 m^3/s. Between 1969 and 1979, the flows ranged from 0.10 m^3/s, during a very dry period, to 61.0 m^3/s, during a rainy, wet season. **Black River Basin (V):** **4** Black River, measured near Appleton (1810N07744W) from 1955 to 1995, had an average flow from 4.64 to 20.05 m^3/s and a mean annual flow of 11.15 m^3/s. **5** Black River, measured near Newton (1808N07745W) from 1966 to 1995, had an average flow from 4.69 to 22.59 m^3/s and a mean annual flow of 12.07 m^3/s. However, in October of 1973, there was a major flood that had a peak discharge of 117 m^3/s. This flood has a recurrence level of 12 years. The lowest flow observed was in March of 1977 and measured [illegible]	Water is fresh and generally very hard. On average the water hardness is about 320 mg/L. Exceptions are in the Blue Mountain North and Blue Mountain South. The water in these areas may not be as hard, due to the low carbonate nature of the bedrock. Average quality measurements for surface water are within this category: pH 7.2 to 8.2 TDS 200 mg/L coliform 2,400 mpn/100 mL. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use and farming on steep slopes, and deforestation have increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are in the Rio Cobre and in the Blue Mountain North Basins. Throughout the country, agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Rio Cobre Basin (III):** The Rio Cobre, measured in August and September of 1972, averaged: Below the confluence (1805N07700W) of Thomas River and Rio Pedro DO 7.2 mg/L BOD 4.8 mg/L TSS 70 mg/L.	Topography, transportation network, and vegetation may limit access and development of water points. In the **Dry Harbour Mountains Basin**, elevations for the White River may range from sea level to 305 m (1,000 ft). The White River is located in a deep trench-like valley. In the **Great River Basin**, the tributaries to the Great River are very fast moving, cutting steep ravines into the limestone topography. In the **Blue Mountain North Basin**, the middle to upper reaches of the Rio Grande, Wag Water, and Swift River have very rugged, mountainous topography with sharp ridges and deep valleys. In the **Black River Basin**, access to the river may be hindered along most of its length by low swampy ground.	In the **Blue Mountain North and South Basins**, but also in other areas, the effects of deforestation and improper land use may clog drainage systems with sediment and vegetal debris. Also, the practice of building on the flood plain may reduce the conveyance of the river, and the flood plain, raising flood levels. In the **Blue Mountain South Basin**, the course of the Plantain Garden River follows a fault. In the **Blue Mountain North and Blue Mountain South Basins**, rivers are characterized as being steep and rapid in their upper reaches. Flash flooding is common during the wet seasons. Due to the "flashy" nature of flow, these rivers may carry a large amount of sediment. In the **Great River Basin**, the course of the Great River follows a fault. In the **Rio Cobre Basin**, parts of the Rio Cobre River may disappear into the limestone and then rise again farther downstream during the dry season. This is likely to occur below the town of Bog Walk (1805N07700W). This may also happen with the Rio Pedro (1806N07700W).

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh Water perennially available (continued)		2.09 m^3/s. **6** Black River, measured near Lacovia (1804N07746W) in selected years from 1963 to 1995, had an average flow from 10.42 to 32.71 m^3/s and a mean annual flow of 19.82 m^3/s. Between 1964 and 1979, the lowest recorded flow was 5.24 m^3/s. **Great River Basin (VII):** **7** Great River, measured near Lethe (1824N07758W) from 1969 to 1979, ranged from 1.44 to 40.00 m^3/s and averaged 13.02 m^3/s. **Martha Brae River Basin (VIII):** **8** Martha Brae River, measured near Friendship (1824N07742W) in selected years from 1951 to 1995, had an average flow from 1.65 to 18.81 m^3/s and a mean annual flow of 8.28 m^3/s. **9** Martha Brae River, measured near Martha Brae (1828N07740W) in 1973, had a range of flow from 4.9 to 62 m^3/s. However, in selected years from 1955 to 1995 the Martha Brae River had an average flow from 6.51 to 24.21 m^3/s and a mean annual flow of 13.84 m^3/s. **Dry Harbour Mountains Basin (IX):** **10** Rio Bueno, measured near Rio Bueno (1828N07728W) in selected years from 1951 to 1995, had an average flow from 5.97 to 12.86 m^3/s and a mean annual flow of 8.58 m^3/s. **11** Laughlands Great River, measured at a gaging station (1827N07716W) from 1972 to 1994, had an average flow from 2.21 to 5.27 m^3/s and a mean annual flow of 3.41 m^3/s. **12** White River, measured at Exchange (1824N07704W) from 1989 to 1994, had an average flow from 3.03 to 3.59 m^3/s and a mean annual flow of 3.23 m^3/s. **Blue Mountain North Basin**	Near Central Village (1759N07655W) DO 8.8 mg/L BOD 6.0 mg/L TSS 45.5 mg/L. Pollution occurs south of Bog Walk (1806N07701W) mainly from the coffee, sugar, milk, and citrus industry. South of Spanish Town (1759N07657W), major polluters are sugar factories. These organic wastes produce turbidity, offensive odors, and give the water an unpleasant taste. **Black River Basin (V):** The Black River, measured in October 1972: Near Windsor (1810N07743W) DO 8.6 mg/L BOD 1.6 mg/L TSS 25 mg/L. Near Newton (1807N07745W) DO 8.6 mg/L BOD 4.8 mg/L TSS 35 mg/L. This station near Newton is downstream from a bauxite-alumina plant. Water being released from this location may contain a high amount of sodium and high pH. Near Black River (1801N07751W) DO 3.8 mg/L BOD 15.0 mg/L TSS 80 mg/L. Near Appleton (1810N07744W) is a sugar and a rum factory. This organic-rich waste may produce turbidity, offensive odors, and give the water an unpleasant taste. **Martha Brae River Basin (VIII):** Martha Brae River, measured near Falmouth (1830N07739W) in November 1972: DO 8.0 mg/L BOD 6.0 mg/L		In the Black River Basin, small vessels can navigate the Black River for 28 km (17 mi) upstream from the mouth of the river. This is the largest river in Jamaica. In the **Dry Harbour Mountains Basin (IX)**, the White River, as well as most of the rivers on the north coast, has a sustained base flow from the interior limestone aquifer. Parts of the upper reaches of the river may disappear into the ground and then resurface a few kilometers downstream, when flowing through karstic limestone areas. One of the principal sources of water for the White River is the Mount Plenty Spring (1820N07703W). This spring is thought to originate from the Moneague Blue Hole (1816N07706W), which has recently been contaminated. This pollution is believed to have come from lakes of bauxite waste, called red mud pits. This waste has a high sodium effluent. In the **Dry Harbour Mountains Basin**, two sources feeding the Rio Bueno are the Cave River (1812N07721W) and Quashies River (1817N07732W). Water from these two rivers sinks

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh Water perennially available (continued)		**(X):** **13** Rio Grande, measured at Fellowship (1808N07628W) from 1969 to 1979, had an average flow from 9.75 to 45.36 m^3/s and a mean annual flow of 24.06 m^3/s. Flows ranged from 2.05 to 108.00 m^3/s. **14** Wag Water River, measured at Devon Point (1812N07649W) in selected years from 1977 to 1990, had an average flow from 1.65 to 8.12 m^3/s and a mean annual flow of 5.53 m^3/s. **15** Swift River, measured near Chelsea (1808N07635W) in selected years from 1957 to 1995, had an average flow from 1.18 to 8.92 m^3/s and a mean annual flow of 4.79 m^3/s.	TSS 33 mg/L. Note: Two sugar factories that are located along the Martha Brae were not in operation when this measurement was taken. Sugar factories may cause high turbidity, offensive odors, and an unpleasant taste to the water due to the high organic content of the wastewater. **Dry Harbour Mountains Basin (IX):** Rio Bueno, measured near the mouth of the river during August, October, and December 1972, had an average fecal coliform concentration of 1,572 mpn/100 mL. White River, measured near the mouth of the river during August, October, and December 1972, had an average fecal coliform concentration of 953 mpn/100 mL. Laughlands Great River, measured near the mouth of the river during August, October, and December 1972, had an average fecal coliform concentration of 25,531 mpn/100 mL. **Blue Mountain North (X):** The Wag Water River may become contaminated with insecticides after spraying banana crops.		into the limestone aquifer and then rises to form the headwaters of the Rio Bueno (1824N07727W).

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water perennially available	Major perennial streams throughout the country. **Rio Minho Basin (IV)** (1801N07720W): Rio Minho (1747N07717W). **Black River Basin (V)** (1806N07744W): Y.S. River (1803N07750W). **Cabarita River Basin (VI)** (1818N07807W): Roaring River (1818N07804W). **Blue Mountain North Basin (X)** (1810N07642W): Buff Bay River (1814N07640W), Spanish River (1814N07637W).	Very small to moderate quantities of water are available year-round. Moderate quantities are available during the high flow periods, which generally occur around October and to a lesser extent around May. Selected stream gaging stations and average flows are listed below. **Rio Minho Basin (IV):** **16** Rio Minho, measured near Danks (1806N07716W) from 1967 to 1995, had an average flow from 0.91 to 7.56 m^3/s and a mean annual flow of 3.66 m^3/s. **Black River Basin (V):** **17** Y.S. River, measured near Middle Quarters (1806N07750W) from 1955 to 1995, had an average flow from 1.05 to 9.74 m^3/s and a mean annual flow of 4.97 m^3/s. **Cabarita River Basin (VI):** **18** Roaring River, measured near Petersfield (1817N07803W) from 1965 to 1995, had an average flow from 1.76 to 7.87 m^3/s and a mean annual flow of 4.71 m^3/s. The minimum flow that occurred between 1965 and 1976 was 0.44 m^3/s. **Blue Mountain North Basin (X):** **19** Buff Bay River, measured near Tranquility (1811N07641W) in 1963, had a maximum daily discharge of 156 m^3/s and a minimum daily discharge of 0.79 m^3/s. However, in selected years from 1955 to 1995, Buff Bay River had an average flow from 0.97 to 7.31 m^3/s and a mean annual flow of 3.56 m^3/s. **20** Spanish River, measured at Chepstowe (1810N07638W) in selected years from 1957 to 1995, had an average flow from 0.87 to 8.69 m^3/s and a mean annual flow of 4.16 m^3/s.	Water is fresh and generally very hard. On average the water hardness is about 320 mg/L. An exception is in the Blue Mountain North Basin. The water in this area may not be as hard, due to the low carbonate nature of the bedrock. Average measurements for surface water in this category: pH 7.2 to 8.2 TDS 200 mg/L. coliform 2,400 mpn/100 mL. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use, farming on steep slopes, and deforestation, has increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are in the Blue Mountain North Basin. Throughout the country, agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Rio Minho Basin (IV):** Rio Minho, measured in August 1972, averaged: Near Danks (1806N07717W) DO 7.0 mg/L BOD 13.2 mg/L TSS 93 mg/L. Near Sevens (1758N07713W) DO 6.4 mg/L BOD 27.5 mg/L	Topography, transportation network, and vegetation may limit access and development of water points. In the **Rio Minho Basin**, the topography above the confluence of the Rio Minho and the Pindars River is mountainous with knife-like ridges and gorge-like river valleys. Slopes are generally between 20 and 30 degrees. Below the confluence, the topography becomes gentler as it slopes down to the ocean. In the **Blue Mountain North Basin**, the middle to upper reaches of the Spanish and Buff Bay River have a very rugged, mountainous topography with sharp ridges and deep valleys.	Especially in the Blue Mountain North Basin, but also in other areas, the effects of deforestation and improper land use may clog drainage systems with sediment and vegetal debris. Also, the practice of building on the flood plain may reduce the conveyance of the river, and the flood plain, raising flood levels. In the **Rio Minho Basin**, the Rio Minho is very unreliable in its flow south of the confluence with the Pindars River. Very often parts of the Rio Minho will disappear into the alluvium or limestone aquifers during the dry season. In the **Blue Mountain North Basin**, rivers are characterized as being steep and rapid in their upper reaches. Flash flooding is common during the wet seasons. Due to the "flashy" nature of flow, these rivers may carry large amounts of sediment.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water perennially available (continued)			TSS 452 mg/L (Sugar Factory). Near Alley (1748N07716W) DO 11.4 mg/L BOD 17.6 mg/L TSS 66 mg/L (Sugar and Bauxite Factory). The major source of pollution on the Rio Minho is from industries such as sugar, citrus, paper, and bauxite processing. Bauxite processing waste may cause the water to have high sodium content. The other industries may cause a high turbidity, offensive odor, and unpleasant taste due to the high organic matter. Soils above the confluence with the Pindars River erode easily and improper land use has increased the problem.		
3 Fresh water perennially available	Major perennial streams and reservoirs throughout the country. **Blue Mountain South Basin (I)** (1757N07628W): Morant River (1753N07625W), Negro River (1754N07627W), Yallahs River (1752N07636W). **Kingston Basin (II)** (1802N07647W): Hope River (1757N07643W), Mona Reservoir (1800N07645W). **Rio Cobre Basin (III)** (1805N07700W): The upper reaches of the Rio Cobre (1759N07652W), Rio Pedro (1806N07700W). **Rio Minho Basin (IV)** (1801N07720W): Milk River (1750N07722W), Pindars River (1805N07714W).	Very small to small quantities of water are available year-round. Small quantities are available during the high flow periods, which occur around October to December and to a lesser extent around May. Selected stream gaging stations and average flows are listed below. **Blue Mountain South Basin (I):** Morant River (gaging station location unknown) has an average annual flow of 7.1 m^3/s; it has a flow of at least 1.2 m^3/s 90 percent of the time. **21** Yallahs River, measured near Llandewey (1758N07636W) from 1990 to 1995, had an average flow from 0.41 to 4.86 m^3/s and a mean annual flow of 2.32 m^3/s. **Kingston Basin (II):** **22** Hope River, measured near Gordon Town (1802N07644W) from 1955 to 1995, had an average flow from 0.36 to 1.39 m^3/s and a mean annual flow of	Water is fresh and generally very hard. On average the water hardness is about 320 mg/L. Exceptions are in the Blue Mountain North, Blue Mountain South, and Kingston Basins. The water in these areas may not be as hard, due to the nature of the bedrock. Average measurements for surface water in this category: pH 7.2 to 8.2 TDS 200 mg/L coliform 2,400 mpn/100 mL. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use and farming on steep slopes, and deforestation, has increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee,	Topography, transportation network, and vegetation may limit access and development of water points. In the **Kingston and Blue Mountain South Basin**, 81percent of the area that the Hope River drains has slopes greater than 25 degrees. In the Rio Minho Basin, the topography above the confluence of the Rio Minho and the Pindars River is mountainous with knife-like ridges and gorge-like river valleys. Slopes will generally be between 20 and 30 degrees. Below the confluence the topography becomes gentler as it slopes down to the ocean. In the Blue Mountain North Basin, the	Especially in the **Blue Mountain North, South, and Kingston Basins**, but also in other areas, the effects of deforestation and improper land use may clog drainage systems with sediment and vegetal debris. Also, the practice of building on the flood plain may reduce the conveyance of the river and the flood plain, raising flood levels. In the **Kingston and Blue Mountain North Basin**, the Mona and the Hermitage Reservoirs are not large in size, but are important because they help supply the city of Kingston with water. The Hope, Yallahs, and Morant Rivers may all have dry, gravelly, or

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)	**Black River Basin (V)** (1806N07744W): Hectors River (1814N07738W), South Elim River (1807N07742W). **Cabarita River Basin (VI)** (1818N07807W): Cabarita River (1813N07810W). **Great River Basin (VII)** (1824N07756W): Montego River (1828N07756W). **Martha Brae River Basin (VIII)** (1823N07740W): The upper reaches of the Martha Brae River (1829N07738W, Roaring River (1823N07742W), Mouth River (1818N07734W). **Dry Harbour Mountains Basin (IX)** (1820N07717W): Cave River (1812N07721W), Pear Tree Bottom River (1828N07722W), Roaring River (1824N07709W). **Blue Mountain North (X)** (1810N07642W): Hermitage Reservoir (1805N07646W).	0.69 m^3/s. Note: South of the diversion to the Mona Reservoir (1801N07644W), much of the water may be lost to the alluvium aquifer. In dry seasons, the lower reaches of the Hope River may become intermittent. Mona Reservoir has a storage capacity of 3.03 Mm^3. Supplies the City of Kingston with a flow of 0.20 m^3/s. **Rio Cobre Basin (III):** **23** Rio Cobre, measured near Linstead (1809N07703W) in selected years from 1973 to 1995, had an average flow from 0.14 to 4.42 m^3/s and a mean annual flow of 1.64 m^3/s. **24** Rio Pedro, measured near Harkers Hall (1807N07657W) from 1954 to 1995, ranged from 0.56 to 3.88 m^3/s and averaged 1.64 m^3/s. **Rio Minho Basin (IV):** **25** Milk River, measured near Rest (1752N07721W) in selected years from 1968 to 1993, had an average flow of 0.71 to 2.78 m^3/s and a mean annual flow of 1.47 m^3/s. **26** Pindars River, measured near the confluence with the Rio Minho (1805N07714W) from 1967 to 1995, had an average flow from 0.35 to 2.54 m^3/s and a mean annual flow of 1.16 m^3/s. **Black River Basin (V):** **27** Hectors River, measured at Troy (1815N07737W) in selected years from 1966 to 1985, had an average flow from 0.23 to 1.75 m^3/s and a mean annual flow of 0.75 m^3/s. **28** South Elim River, measured near Elim (1807N07741W) in selected years from 1967 to 1995, had an average flow from 0.48 to 1.08 m^3/s and a mean annual flow of 0.73 m^3/s. **Cabarita River Basin (VI):** **29** Cabarita River, measured near Grange (1819N07804W) in selected years from 1968 to 1995, had an average flow from 0.42 to	pesticide contamination may occur with moderate rain. Possible areas of concern are located in the Kingston, Rio Cobre, and the Blue Mountain North Basins. Throughout the country, agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Blue Mountain South Basin (I):** The Yallahs and Morant Rivers are subject to heavy sediment loads. Deforestation has increased the problem and has also caused unpredictable river flows and flooding. **Kingston Basin (II):** Hope River, measured near Gordon Town (1802N07644W) from 1989 to 1990: pH 7.6 to 8.8 TDS (average) 354.3 mg/L. Nitrates: Range 0.006 to 0.618 mg/L Average 0.27 mg/L Phosphate (average) 0.039 mg/L. Suspended sediment concentration at the maximum discharge measured is 3,461 mg/L. The Salt River (1802N07643W), a tributary that joins the Hope River near Gordon Town, may range from fresh to brackish water. Other tributaries, due to land use, may have higher amounts of nitrates and phosphates. The Hog Hole River (1802N07643W), a tributary of the Hope River, usually displays high concentrations of nitrate and phosphate ions, compared with other tributaries of the Hope River. **Rio Minho Basin (IV):** Soils above the confluence of the Rio Minho and Pindars River erode easily, and improper land use has	Hermitage Reservoir and its tributaries are surrounded by rugged terrain with high, narrow ridges and deep, narrow valleys. The Hermitage Reservoir is at an elevation of 529 m (1,740 ft).	boulder-strewn beds near the mouths of the rivers. During dry seasons, water in these rivers may disappear into the deep gravel beds in their lower courses. In the **Blue Mountain South Basin**, below Llandewey on the Yallahs River, there is a diversion of water to the Kingston Basin of about 26.5 Mm^3/yr (0.84 m^3/s). This may reduce the southern part of the Yallahs River to an intermittent stream during dry seasons. In the **Kingston Basin**, the Hope River supplies 11 percent of the total water supply to the city of Kingston. The Mona Reservoir has had its capacity reduced by 2 percent, due to sedimentation, since its completion in 1957. The Mona Reservoir has silted up much less than the Hermitage Reservoir because of the presence of sediment and flow-control gates on the diversion channel. In the **Rio Cobre Basin**, parts of the Rio Cobre River may disappear into the limestone and then rise again farther downstream during the dry season. In the **Rio Minho Basin**, the course of the Milk River follows a fault. The Milk River is

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)		3.28 m^3/s and a mean annual flow of 1.73 m^3/s. **Great River Basin (VII):** **30** Montego River, measured near Montego Bay (1828N07755W) in selected years from 1968 to 1995, had an average flow from 0.83 to 4.25 m^3/s and a mean annual flow of 2.04 m^3/s. During the wet season, moderate flows can occur. **Martha Brae River Basin (VIII):** **31** Martha Brae River, measured near Pantrepant (1823N07741W) from 1966 to 1995, had an average flow from 0.95 to 6.91 m^3/s and mean annual flow of 3.11 m^3/s. **32** Roaring River, measured near Bunkers Hill (1823N07742W) in selected years from 1966 to 1994, had an average flow from 0.51 to 5.61 m^3/s and a mean annual flow of 2.43 m^3/s. **33** Mouth River, measured near Rock Spring (1818N07734W) in selected years from 1966 to 1994, had an average flow from 0.19 to 2.41 m^3/s and a mean annual flow of 0.82 m^3/s. **Dry Harbour Mountains Basin (IX):** **34** Cave River, measured near Borro Bridge (1812N07725W) in selected years from 1970 to 1995, had an average flow from 0.33 to 2.25 m^3/s and a mean annual flow of 1.02 m^3/s. In June 1986, the peak flow at this location was 7.80 m^3/s. Water from this river sinks into the karstic limestone and flows underground to the Rio Bueno. Flow rates range from 0.017 to 0.035 m^3/s. **35** Pear Tree Bottom River, measured at a gaging station (1826N07722W) from 1971 to 1972, had an average daily flow of 1.23 m^3/s. **36** Roaring River, measured near Ocho Rios (1824N07709W) from 1955	increased the problem. Milk River, measured in August and November 1972, averaged: Near Scotts Pass (1800N07723W) DO 7.9 mg/L BOD 3.0 mg/L TSS 38 mg/L; Near Rest (1753N07722W) DO 5.9 mg/L BOD 2.8 mg/L TSS 18.5 mg/L. There were no major sources of pollution at the time of the 1973 study. **Martha Brae River Basin (VIII):** Martha Brae River, measured north of Bunkers Hill (1823N07741W) in November 1972: DO 9.8 mg/L BOD 8.2 mg/L TSS 69.0 mg/L. The sugar factories located along this river were not in operation during this sampling. Sugar factories may cause high turbidity, offensive odors, and an unpleasant taste to the water due to the high organic content of the waste. Roaring River, measured near the mouth of the river in August, October, and December 1972, averaged a fecal coliform concentration of 298 mpn/100 mg/L. **Dry Harbour Mountains Basin (IX):** Pear Tree Bottom River, measured near the mouth of the river in August, October, and December 1972, had an average fecal coliform value of 158 mpn/100 mg/L. **Blue Mountain North Basin (X):** Hermitage Reservoir has a large problem with sedimentation, especially after heavy rain. Since its		navigable for 3 km (2 mi) from the mouth of the river for small vessels. South of Scott Pass, parts of the river may sink into the limestone aquifer and then rise again farther downstream. In the **Martha Brae River Basin**, the Mouth River has a sinkhole as its natural outlet. Water from this river is believed to flow underground and supply the Fontabelle Spring (1824N07741W), located near the Martha Brae River. Parts of the Mouth River may sink into the limestone aquifer and reappear farther downstream. In the **Dry Harbour Mountains Basin**, parts of the Cave River may sink into the underlying limestone aquifer and reappear farther downstream.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)		(1824N07709W) from 1955 to 1971, had an average daily discharge of 2.3 m^3/s and the lowest flow during this period was 1.6 m^3/s. **Blue Mountain North Basin (X):** Hermitage Reservoir (1805N07646W) has a storage capacity of 1.49 Mm^3, and yields 0.54 m^3/s to the City of Kingston. Before sedimentation, the reservoir had a storage capacity of 1.89 Mm^3.	completion in 1927, the capacity of the reservoir has been reduced by about 21 percent.		
4 Fresh water seasonally available	Major perennial streams and ponds throughout the country. **Rio Cobre Basin (III)** (1805N07700W): Rio Doro (1806N07700W), Indian River (1813N07658W), Pedro River (1811N07714W), Rio Magno Gully (1808N07702W). **Black River Basin (V)** (1806N07744W): Wallywash Pond (1758N07748W). **Great River Basin (VII)** (1824N07756W): Lucea East River (1826N07809W). **Dry Harbour Mountains Basin (IX)** (1820N07717W): Quashies River (1817N07732W).	Meager to very small quantities are available. Very small quantities are available during the high flow periods, which generally occur around October and to a lesser extent around May. Flows may occasionally stop during dry seasons. Selected stream gaging stations and average flows are listed below. **Rio Cobre Basin (III):** **37** Rio Doro, measured near Williamsfield (1810N07657W) in selected years from 1970 to 1995, had an average flow from 0.15 to 0.76 m^3/s and a mean annual flow of 0.41 m^3/s. **38** Indian River, measured at Rio Magno Gully (1813N07658W) in selected years from 1971 to 1995, had an average flow from 0.13 to 0.53 m^3/s and a mean annual flow of 0.31 m^3/s. **39** Pedro River, measured near Kellits (1811N07713W) from 1970 to 1995, had an average flow from 0.08 to 0.63 m^3/s and a mean annual flow of 0.26 m^3/s. **Black River Basin (V):** Wallywash Pond (1758N07748W) is probably fed by three springs at an approximate rate of 0.04 m^3/s. Note: The pond is 4.9 m (16 ft) deep at the lowest point. **Great River Basin (VII):** Lucea East River (1826N07809W), measured between 1971 and 1975 at	Water is fresh and generally very hard. On average, the water hardness is about 320 mg/L. Typical data for surface water in this category: pH 7.2 to 8.2 TDS 200 mL coliform 2,400 mpn/100 mL. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use and farming on steep slopes, and deforestation has increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are in the Rio Cobre Basin. Throughout the country, agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes.	Rugged topography, poor transportation network, and thick vegetation may limit access and development of water points.	The effects of deforestation and improper land use may clog drainage systems with sediment and vegetal debris. Also, the practice of building on the flood plain may reduce the conveyance of the river and the flood plain, raising flood levels. In the **Black River Basin**, the Wallywash Pond is located in a low-lying area that was formed by the down faulting of the Earth's crust between two roughly parallel faults. In the **Dry Harbour Mountains Basin**, parts of the Quashies River may disappear into the underlying limestone aquifer and reappear farther downstream.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water seasonally available (continued)		between 1971 and 1975 at an unknown location, had a mean daily flow of 0.56 m^3/s. **Dry Harbour Mountains Basin (IX):** **40** Quashies River, measured near Freemans Hall (1817N07732W) in selected years from 1966 to 1988, had an average flow from 0.08 to 0.59 m^3/s and a mean annual flow of 0.21 m^3/s. Water from this river sinks into the karstic limestone and flows underground to the Rio Bueno. Flow rates range from 0.017 to 0.035 m/s.			
5 Fresh water seasonally available	Numerous intermittent streams. **Rio Minho Basin (IV)** (1801N07720W): Upper Reaches of the Milk River (1750N07722W). **Cabarita River Basin (VI)** (1818N07807W): Orange River (1822N07819W), South Negril River (1816N07821W).	Meager to moderate amounts of fresh water are available during the high flow periods, which generally occur around October and to a less extent around May. In the Blue Mountain North Basin, there are many intermittent streams that may have moderate flows after rain. Selected stream gaging stations and average flows are listed below. **Rio Minho Basin (IV):** **41** Milk River, measured near Scott Pass (1800N07723W) from 1970 to 1995, had an average flow from 0.21 to 1.12 m^3/s and a mean annual flow of 0.59 m^3/s. **Cabarita River Basin (VI):** **42** Orange River, measured near Logwood (1821N07818W) from 1971 to 1995, had an average flow from 0.13 to 1.26 m^3/s and a mean annual flow of 0.67 m^3/s. South Negril River, measured from 1971 to 1972 at an unknown location, had a low flow value of 0.04 m^3/s in February 1972.	Water is fresh and generally very hard. On average, the water hardness is about 320 mg/L. Exceptions are in the **Blue Mountain North, Blue Mountain South, and Kingston Basins**. The water in these areas may not be as hard, due to the nature of the bedrock. Typical data for surface water in this category: pH 7.2 to 8.2 TDS 200 mg/L coliform 2,400 mpn/100 mL. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use and farming on steep slopes, and deforestation, has increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are located in the Kingston, the Rio Cobre, and the Blue Mountain North Basins. Throughout the country, agricultural runoff may	The poor transportation network, low swampy ground, and thick vegetation limit access to and development of water points. The **Cabarita River Basin** access may be hindered by swampy terrain, especially near the mouth of the river.	Especially in the **Blue Mountain North, South, and Kingston Basins**, but also in other areas, the effects of deforestation and improper land use may clog drainage systems. Also, the practice of building on the flood plain may reduce the conveyance of the river and the flood plain, raising flood levels. In the **Rio Minho Basin**, the course of the Milk River follows a fault. Milk River is navigable for 3 km (2 mi) for small vessels. South of Scott Pass (1800N07723W), parts of the river may sink into the limestone aquifer and then rise again farther downstream. In the **Cabarita River Basin**, the Orange River is meandering and has a mature profile.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water seasonally available (continued)			contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Cabarita River Basin (VI):** The South Negril River may have high nitrates, phosphates, and fecal coliform levels.		
6 Fresh water seasonally available	Fresh to brackish streams and gullies. **Rio Cobre Basin (III)** (1805N07700W): Coleburns Gully (1754N07704W), Fresh River (1801N07652W), Lower reaches of the Rio Cobre River (1759N07652W), Salt Island Creek (1754N07702W). **Rio Minho Basin (IV)** (1801N07720W): Rhymesbury Gully (1753N07721W), Saint Anne's Gully (1755N07720W), Main Savanna Gully (1754N07719W), Hilliards River (1751N07721W), Breadnut Gully (1751N07710W), The lower reaches of the Rio Minho (1747N07717W).	Meager to moderate quantities of fresh water are available during the high flow periods, which generally occur around October and to a lesser extent around May. Water may become brackish during dry periods. **Rio Cobre Basin (III):** Fresh River, measured at an unknown location, has an average flow of 0.63 m^3/s. Coleburns Gully flows at an approximate rate of 0.25 m^3/s. **Rio Minho Basin (IV):** Rhymesbury, Saint Anne's, and Main Savanna Gullies, and the Hilliards River were once dry for 6 months of the year. However, now they all carry water throughout the year due to irrigation and flow into the Milk River. Changes in irrigation may cause changes in the amount of flow in these streams. Breadnut Gully only flows when rain has fallen and is typically dry for 9 months of the year. The lower reaches of the Rio Minho may lose much of its water to a limestone aquifer. During dry seasons, the river may become intermittent.	Water is generally fresh and generally very hard. On average, the water hardness is about 320 mg/L. These rivers and gullies may become brackish during the low flow period due to evaporation or saltwater intrusion. Biological contamination is a major problem around and downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. Soil erosion, due to improper land use and farming on steep slopes, and deforestation has increased the volume of sediment carried by streams in most basins. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are located in the Kingston, Rio Cobre, and the Blue Mountain North Basins. Throughout the country, agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Rio Cobre Basin (III):** The Fresh River ranges from 600 to 1,200 mg/L of Cl. Fecal coliform levels may be high due to runoff from stockyards or cattle pens. The Rio Cobre may range from fresh to brackish in its lower reaches due to saline intrusion, agricultural runoff, and evaporation. **Rio Minho Basin (IV):** The Rhymesbury, Saint Anne's, and Main Savanna	The poor transportation network, low swampy ground, and thick vegetation limit access to and development of water points.	The effects of deforestation and improper land use may clog drainage systems with sediment and vegetal debris. Also, the practice of building on the flood plain may reduce the conveyance of the river and the flood plain, raising flood levels. In the **Rio Cobre Basin**, plans are being developed to use the Fresh River as a water supply for Kingston.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
6 Fresh water seasonally available (continued)			Gullies and Hilliards River may contain fresh to brackish water due to the intrusion of saline water into coastal aquifers. The water in the aquifers is used for irrigation, and the runoff supplies the gullies.		
7 Fresh water scarce or lacking	Fresh to brackish swamps and streams that flow through the swamps. **Black River Basin (V)** (1806N07744W): The upper Black River Morass (1806N07743W), Part of the lower Black River Morass (1801N07750W), Broad River (1802N07751W), Lower reach of the Black River (1803N07750W) Lower reach of the Y.S. River (1807N07750W).	Meager to moderate amounts of fresh to brackish water may be found. **Black River Basin (V):** Broad River, measured at an unknown location, had a range of flow from 1.4 to 12.4 m^3/s.	Water is fresh to brackish. During high flows, due to numerous streams that flow through the swamp, fresh water may be found. However, due to evaporation, these swamps may become brackish during dry periods. These swamps are downstream from a bauxite and aluminum plant, located near Newton (1807N07745W), and from a sugar and rum factory near Appleton (1810N07744W). Effluent from the bauxite and aluminum plant may contain a high amount of sodium and have a low pH. Organic-rich wastes are produced from the sugar and rum factory. These wastes may produce turbidity and offensive odors; and they may give the water an unpleasant taste. **Black River Basin (V):** The water quality of the Broad River is influenced by the tides. During high tides, the amount of flow to the sea can be retarded or even reversed. During low tides, the flow may be very high. In addition, seawater intrudes at least 3 km (2 mi) upstream from the mouth of the river. During high flows, the water in this stream may be fresh, especially in the upper reaches of the river.	The poor transportation network, low swampy ground, and thick vegetation limit access to and development of water points.	
8 Fresh water scarce or lacking	Fresh water that is quickly absorbed or channeled into the subsurface limestone aquifer. Sources are in areas of the following locations: **Rio Cobre (III)** (1805N07700W), **Rio Minho (IV)** (1801N07720W), **Black River (V)** (1806N07744W),	A large area in the west-central part of the country that is underlain by karstic limestone. In this area, there is little to no surface drainage. Any rain that falls may temporarily flow on the surface, but is quickly absorbed or channeled into the subsurface through gullies, sinkholes, and caves.	Water is generally fresh and generally very hard. On average, the water hardness is about 320 mg/L.	The Cockpit Country is very rough and rugged terrain. It has high peaks, steep hills, collapse structures, sinkholes, ravines, and gullies. These features limit access to and development of water points.	

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
8 Fresh water scarce or lacking	**Cabarita River (VI)** (1818N07807W), **Great River (VII)** (1824N07756W), **Martha Brae River (VIII)** (1823N07740W), **Dry Harbour Mountains Basin (IX)** (1820N07717W), The Cockpit Country (1818N07743W).				
9 Fresh water scarce or lacking	Brackish to saline ponds, swamps, and streams. **Blue Mountain South Basin (I)** (1757N07628W): The Salt Ponds (1751N07633W). **Rio Cobre Basin (III)** (1805N07700W): The Great Salt Pond (1755N07653W). **Black River Basin (V)** (1806N07744W): Broad River (1802N07751W), Parottee Great Salt Pond (1759N07750W). Saltwater marshes, tidal flats, mangroves, and coastal lagoons. **Blue Mountain South Basin (I)** (1757N07628W): The Great Morass at Morant Point (1755N07612W). **Black River Basin (V)** (1806N07744W): Lower reach of the Black River (1803N07750W), Part of the lower Black River Morass (1801N07750W). **Cabarita River Basin (VI)** (1818N07807W): The Negril Great Morass	Meager to moderate amounts of brackish to saline water available year-round. Mangrove swamps and marshy areas occur along the coast. They are more likely to occur along the south coast, but they also occur to the north. **Blue Mountain South Basin (I):** Two salt ponds are in this basin (1751N07633W). The larger pond has a maximum depth of 4.3 m (14 ft), and the smaller pond has a maximum depth of 1.2 m (4 ft). **Black River Basin (V):** Broad River, measured at an unknown location, had a range of flow from 1.4 to 12.4 m^3/s.	Water is brackish to saline. The salinity of all of the ponds and the Negril Great Morass is dependent on the amount of fresh water runoff. During high flows, the water is brackish or possibly fresh in some areas. Water is brackish to saline during the low flow periods. Biological contamination may be a problem when these features are located around or downstream from populated areas due to lack of sewage treatment. Jamaica soils are enriched in heavy metals compared with the world average. Higher levels of As, Cd, Hg, and Pb may be found near bauxite deposits and could contaminate water. After spraying crops such as bananas and coffee, pesticide contamination may occur with moderate rain. Possible areas of concern are in the Kingston, Rio Cobre, and Blue Mountain North Basins. Agricultural runoff may contaminate surface water with pesticides, herbicides, and fecal coliform from animal and human wastes. **Black River Basin (V):** The water quality of the Broad River is influenced by the tides. During high tides, the amount of flow to the sea can be retarded or even reversed. During low tides, the flow may be very high. In addition, seawater intrudes at least 3 km (2 mi) upstream from the mouth of	The transportation network, low swampy ground, and thick vegetation limit access to and development of water points. In the **Cabarita River Basin**, the Negril Great Morass was once drained. As a result, there are canals throughout the morass. Some ponding may occur behind levees, and dry ground may be found on slight elevations.	Most of the ponds and morass are influenced by tides, and parts of the morass may dry up. In the **Blue Mountain South Basin**, the salt ponds are now connected to each other and to the sea by a manmade channel. In the **Cabarita River Basin**, the Negril Great Morass is separated from the ocean by a narrow stretch of land that is developed as a resort and beach area.

Table C-1. Surface Water Resources (Continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
9 Fresh water scarce or lacking (continued)	(1819N07820W).		the river. During high flows, the water in this stream may be fresh, especially in the upper reaches of the river. **Blue Mountain South Basin (I):** The larger salt pond is 10 times more saline than the sea. The smaller pond is less saline than the sea on the surface, but equally as saline as the sea 0.9 m (3 ft) below the surface. Sometimes the ponds are a bright red color, which is caused by bacteria that thrive during times of drought. **Cabarita River Basin (VI):** In the southern section of the Negril Great Morass, near the South Negril River, there may be high fecal coliform levels due to development of settlements along the South Negril River. River and seawater exchange is significant. Therefore, the water near the coast is generally saline, grading into brackish and even into small amounts of fresh water where streams enter the Negril Great Morass (1819N07820W). A solid waste dump may contaminate the water near Orange Bay (1822N07819W).		

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

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

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

Conversion Chart:

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

Table C-1. Surface Water Resources (Continued)

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

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

Blue Mountain South Basin…….1757N07628W

Geographic coordinates for the Blue Mountain South Basin that are given as 1757N07628W equal 17°57' N 76°28' W and can be written as a latitude of 17 degrees and 57 minutes north and a longitude of 76 degrees and 28 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country scale map. Geographic coordinates for rivers are generally at the river mouth.

Note:

As	= arsenic	m/s	= meters per second
BOD	= biological oxygen demand	m^3/s	= cubic meters per second
$CaCO_3$	= calcium carbonate	mg/L	= milligrams per liter
Cd	= cadmium	mL	= milliliters
Cl	= chlorine	Mm^3	= million cubic meters
DO	= dissolved oxygen	Mm^3/yr	= million cubic meters per year
ft^3/s	= cubic feet per second	mpn	= most probable number
gal/min	= gallons per minute	Pb	= lead
Hg	= mercury	TDS	= total dissolved solids
km^2	= square kilometers	TSS	= total suspended solids
L/min	= liters per minute		

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful	Aquifers consist of a highly fractured and karstified, hard, Tertiary white limestone underlain by a hard, less permeable yellow limestone. The white limestone was formed during the Middle and Lower Eocene in deep marine environments. It has limited amounts of sand and clay-sized particles eroded from the mainland of Jamaica. The yellow limestone was formed during the Middle Eocene in a shallow marine environment, and is interbedded with considerable amounts of tuffs, chert, shales, and fine-grained sedimentary deposits. Limestone aquifers can overlie the basement complex. White and yellow limestones are found within every parish in Jamaica.	Large to enormous quantities of fresh water generally available from fractures and solution cavities in the limestone. Yields average 80 L/s. Yields up to 125 L/s are common with negligible drawdown. Yields up to 315 L/s have been obtained. Aquifer transmissivity averages 5,000 m^2/d. Specific yield averages 0.03. The following is a list of well yields: Two wells at Morant Bay (1753N07625W)[3]: 53 L/s and 75 L/s. Pedro Plains (1756N07747W): 155 L/s. Porus (1802N07725W): 87 L/s. Two wells at Malvern Well (1757N07744W): 35 L/s and 44 L/s. Near the Martha Brae River (1823N07742W): ≤63 L/s. Yields from springs bordering alluvial areas near the Martha Brae River range between 28 and 3,000 L/s. Yields from wells and springs may be lower during the dry season when recharge to aquifers from precipitation and surface streams is low.	Water is fresh. TDS are generally 250 to 450 mg/L. Average pH is between 7.0 and 7.2. Water is very hard with high levels of calcium bicarbonate, and generally exhibits high turbidity. Turbidity generally increases as well yield increases. Turbidity in springs increases during spring when flows are high. Wells at Caymanas (1801N07654W) have Cl levels between 44 and 176 mg/L; Na levels between 25 and 80 mg/L. Springs are generally fresh. Springs forming the Gut River (1751N07728W) and Fresh River (1801N07652W) have high Cl levels. Mineral springs near the Plantain Garden River (1755N07617W), the Milk River (1750N07722W), and the Black River (1801N07751W) may be brackish to saline. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Red mud ponds from bauxite mining contaminate ground water near the northern part of the Rio Cobre Basin (1805N07700W), causing high Na and low pH. Red mud ponds are generally located in ground water recharge areas in upper elevations. Dunder contamination in the Rio Cobre Basin (1805N07700W) and the Martha Brae River Basin (1823N07742W) causes discoloration, odor, high turbidity, and high coliform bacteria counts. Solid waste disposal in	Well depths range between 3 and 500 m. Existing wells are commonly <100 m. Well depths in the southern part of the Rio Cobre Basin (1805N07700W) range between 15 and 275 m, averaging between 30 and 60 m. Depth to water near Moneague (1816N07707W) ranges between 200 and 300 m. Well depths in Westmoreland (1814N07809W) and Hanover (1825N07808W) Parishes range between 5 and 90 m. Well depths in the Pedro Plains (1756N07747W) and near the Black River (1801N07751W) range between 5 and 325 m, averaging between 15 and 110 m. Well depths near the Rio Minho (1747N07717W) range between 8 and 290 m, averaging between 30 and 90 m. Well depths near the Hope River (1757N07643W) and Liguanea Plain (1801N07648W) range between 10 and 85 m, averaging between 24 and 85 m. Well depths near the Martha Brae River (1829N07738W) range between 3 and 305 m, averaging between 20 and 60 m. Depth to water is ≤15 m. Ground water table in the coastal plain and near riverbeds is commonly <30 m below the surface. Ground water is close	Ground water flows through hard limestone in a combination of ways: pipe flow, open channel flow, and flow through a porous medium. Water frequently flows underground through well-defined channels in faults, caves, and solution cavities in the limestone. Depressions on the surface often indicate channel flow beneath the surface. Springs and caves are common throughout limestone areas. Limestone is most karstified in the Dry Harbour Mountains (1819N07724W) and John Crow Mountains (1805N07624W). Surface streams fed by precipitation seep into the limestone and recharge ground water. Likewise, springs fed by aquifers emerge from the ground and flow into surface streams. Recharge is greatest after heavy rain. Ground water levels may rise almost immediately after heavy rain, and then decline rapidly as ground water drains through subsurface channels. Successful wells in these areas depend upon encountering water-bearing fractures or solution cavities. Using remote sensing techniques to identify potential fracture zones before drilling should improve chances for successful wells. If

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful (continued)			sinkholes may contribute a wide variety of contaminants such as heavy metals and halogenated hydrocarbons. NO_3 levels in Kingston (1800N07648W) area can be up to 30 mg/L. Contaminants in limestone can spread quickly through underground streams, solution cavities, and fractures. Water quality can be worse shortly after rain when surface water carrying contaminants from settlements and agricultural activities seeps into permeable limestone aquifers.	to sea level in coastal areas, deeper in mountainous areas. Rugged topography generally indicates a deep ground water table. Gently sloping topography generally indicates a shallow ground water table. The ground water table is closest to the surface in December, lowest in March and April. The water table is at or near the surface in swampy areas along the southern coast west of the Milk River (1750N07722W). Aquifer thickness is up to 1,000 m, and generally thickest toward the coast. Flowing artesian conditions may exist in Clarendon (1759N07718W), Saint Catherine (1804N07701W), Liguanea Plain (1801N07648W), and valleys where clayey alluvium overlies the limestone. Access varies with location. Rugged terrain in hilly and mountainous areas makes access difficult. Access near the coast is generally good.	possible, wells should be sited on fracture intersections. Limestone is generally well jointed and fractured. Faults are commonly oriented north-south and east-west. Thick vegetation cover may make fractures difficult to locate. Yields from fractures may have seasonal variability and depend on rainfall recharge.
2 Fresh water generally plentiful	Less extensive aquifers composed of Quaternary alluvial sediments and sandstones located in river basins and along the coast. Sediments consist of interbedded gravels, sands, and clays. Alluvial aquifers can overlie limestone aquifers.	Very small to very large quantities of fresh water available. Yields from alluvial aquifers are generally 32 L/s but may be as high as 125 L/s with negligible drawdown. Aquifer transmissivity averages 1,500 to 7,000 m^2/d. Specific yield averages 0.14. Yield near Raymonds (1751N07714W) is 88 L/s. Yields near the Annotto Bay (1816N07646W) average 65 L/s.	Water is fresh. TDS are generally 250 to 500 mg/L. Average pH is between 7.0 and 7.2. Water is very hard with high levels of $CaCO_3$. High NO_3 levels in Kingston (1800N07648W) area generally range between 8 and 80 mg/L. Cl levels range between 8 and 600 mg/L. Cl levels in densely populated areas may reach 800 mg/L for brief periods.	Well depths range between 1 and 100 m, averaging 30 m. Aquifer thickness is between 30 and 600 m, and is generally thickest along the southern coast. Ground water is typically found in layers of sand and gravel that are separated by layers of silt and clay. Well depths in the Rio Cobre Basin (1805N07700W) range between 7 and	Surface streams fed by precipitation recharge ground water. Ground water also supplies water for surface streams. Springs commonly emerge from sediments at the base of mountain slopes.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water generally plentiful (continued)		Yields may be lower during the dry season when recharge to aquifers from precipitation and surface streams is low.	The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Solid waste disposal in sinkholes may contribute a wide variety of contaminants such as heavy metals and halogenated hydrocarbons. Dunder contamination in the Martha Brae River Basin (1823N07740W) and Rio Minho Basin (1801N07720W) causes discoloration, odor, turbidity, and high coliform bacteria counts.	460 m, averaging between 15 and 45 m. Well depths in the Rio Minho Basin (1801N07720W) range between 5 and 140 m, averaging between 5 and 30 m. Well depths near Liguanea (1801N07646W) range between 30 and 213 m, averaging between 30 and 90 m. Well depths near Queenhythe (1826N07725W) are ≤210 m. Well depths near Annotto Bay (1816N07646W) average 30 m. Access is generally good. Access may be difficult in swampy areas and in mountain valleys.	
3 Fresh water locally plentiful	Isolated and extensive aquifers composed of lower capacity Tertiary yellow limestone, which frequently contains layers of sands, clays, and volcanic tuffs.	Very small to large quantities of fresh water available from fractures and solution cavities. Very small quantities of water may be available from sub-surface alluvial aquifers south of Troy (1815N07737W) and east of Albert Town (1817N07733W) in sediments deposited by underground rivers. The Quashies (1817N07733W) and Hectors Rivers (1814N07738W) deposit alluvium beneath the surface as they flow through the limestone aquifers. Yields may be lower during the dry season in March and April when recharge to aquifers from precipitation and surface streams is low.	Water is fresh. Water is very hard with high levels of $CaCO_3$. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Solid waste disposal in sinkholes may contribute a wide variety of contaminants such as heavy metals and halogenated hydrocarbons. Dunder contamination in the Martha Brae River Basin (1823N07740W) causes discoloration, odor, high turbidity, and high fecal coliform bacteria counts. Contaminants in limestone can spread quickly through underground streams, solution cavities, and fractures. Water quality can be worse shortly after rain when surface	Aquifer thickness averages 500 m. Water table may be several hundred feet below the surface in the southern and central parts of the Cockpit Country (1818N07743W). Well depths in the northern part of the Rio Cobre Basin (1805N07700W) range between 18 and 340 m, averaging between 60 and 120 m. Well depths in the Rio Minho Basin (1801N07720W) range between 8 and 290 m, averaging between 30 and 90 m. Ground water is close to the surface near Bog Walk (1806N07701W). Access is generally difficult due to mountainous terrain.	Ground water flows through hard limestone in a combination of ways: pipe flow, open channel flow, and flow through a porous medium. Water frequently flows underground through well-defined channels in faults, caves, and cavities in the limestone. Depressions on the surface often indicate channel flow beneath the surface. Successful wells in these areas depend upon encountering water-bearing fractures or solution cavities. Using remote-sensing techniques to identify potential fracture zones before drilling should improve chances for successful wells. If possible, wells

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful (continued)			water carrying contaminants from settlements and agricultural activities seeps into permeable limestone aquifers.	Access is especially difficult in the steep conical hills and depressions of the Cockpit Country (1818N07743W). Limestone in hilly and mountainous areas often contains less ground water. Fracture trace and lineament analysis is recommended. Limestone is most karstified in the north in the Cockpit Country. The Cockpit Country is noted for its closely spaced, steep, cone-shaped hills interspersed with steep-sided depressions about 100 m deep.	should be sited on fracture intersections. Thick vegetation cover may make fractures difficult to locate. Surface streams fed by precipitation recharge the ground water by seeping into the limestone. Springs fed by aquifers emerge from the ground and flow into surface streams. Recharge is greatest after heavy rain. Ground water levels may rise almost immediately after heavy rain, and then decline rapidly as ground water drains through subsurface channels.
4 Fresh water locally plentiful	Isolated soft limestone and alluvial aquifers composed of carbonate rocks, reefs, soft marls, clays, and coastal formations, including fine-grained chalk. Generally, alluvial aquifers along the coast transition to limestone aquifers farther inland.	Unsuitable to small quantities of fresh water available. Up to very large yields may be available from the white limestone aquifers below the softer limestone and alluvial aquifers. Yields from chalky limestone are smaller, but suitable spots are easier to locate. Chalky limestone exists north of the Cockpit Country (1818N07743W) in northern Trelawny Parish (1823N07738W). Yields may be lower during the dry season in March and April when recharge to aquifers from precipitation and surface streams is low.	Water is generally fresh. Water is very hard with high levels of $CaCO_3$. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels. Solid waste disposal in sinkholes may contribute a wide variety of contaminants such as heavy metals and halogenated hydrocarbons. Dunder contamination in the Martha Brae River Basin (1823N07742W) causes discoloration, odor, high turbidity, and high coliform bacteria counts.	Aquifer thickness is between 300 and 1,000 m. Depth to water in these limestone regions is less than depth to water in other limestone aquifers, although smaller quantities of water are available. Well depths in Westmoreland (1814N07809W) and Hanover (1825N07808W) Parishes range between 5 and 90 m in limestone material; between 3 and 23 m in alluvial material. Well depths in Saint Ann's Parish are $\leq$150 m. Access is generally good. Access may be difficult because of hilly and mountainous terrain. Access near Duanvale (1824N07736W) may be hindered by the east-west oriented fault zone, with scarps up to 100 m high.	Chalky limestone is generally more permeable and less fractured than the common white and yellow limestone, although well yields are generally lower. Ground water generally flows through the pore spaces of the limestone. Surface streams fed by precipitation recharge the ground water by seeping into the limestone. Springs fed by aquifers emerge from the ground and flow into surface streams. Recharge is greatest after heavy rain. Ground water levels may rise almost immediately after heavy rain, and then decline rapidly as ground water drains through subsurface channels.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
5 Fresh water scarce or lacking	Isolated aquifers composed of clays and shales in interior valleys and along the coast. These aquifers overlie limestone or the basement complex.	Unsuitable to very small quantities of fresh water available from isolated aquifers. Yields may be lower during the dry season in March and April when recharge to aquifers from precipitation and surface streams is low.	Water is generally fresh. Water is very hard with high levels of $CaCO_3$. Dunder contamination in the Black River Basin (1806N07744W) causes discoloration, odor, turbidity, and high fecal coliform bacteria counts. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits and landfills may have high fecal coliform levels, heavy metals, and halogenated hydrocarbons.	Aquifer thickness is <30 m. Well depths in Westmoreland (1814N07809W) and Hanover (1825N07808W) Parishes range between 3 and 23 m. Well depths in the Pedro Plains (1756N07747W) and Black River Basin (1806N07744W) range between 5 and 25 m. The water table is at or near the surface in swampy areas near Negril (1816N07821W) and Black River (1801N07751W). Access may be difficult in swampy areas and in mountain valleys.	Surface streams fed by precipitation recharge the ground water by seeping into the sediments. Recharge is greatest after heavy rain. Perched aquifers may exist within clay sediments.
6 Fresh water scarce or lacking	Isolated aquifers in the basement rock composed of Cretaceous lavas, tuffs, limestones, shales, and conglomerates with low permeability.	Unsuitable to very small quantities available from fractures. Springs may yield higher quantities of water. Yields may be lower during the dry season in March and April when recharge to aquifers from precipitation and surface streams is low.	Water is generally fresh. Spring near Bath (1757N07621W) may be brackish to saline with high concentrations of sulfur. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.	Depth to water in mountainous areas may be too great for economical use. Access is generally difficult due to mountainous terrain. Rock outcrops are common and may hinder access.	Surface streams fed by precipitation recharge the ground water by seeping into cracks and fractures in the basement rock. Recharge is greatest after heavy rain. Successful wells in these areas depend upon encountering water-bearing fractures. Using remote-sensing techniques to identify potential fracture zones before drilling should improve chances for successful wells. If possible, wells should be sited on fracture intersections.
7-1 Fresh water scarce or lacking	Aquifers consist of brackish to saline water in the highly fractured and karstified, hard, Tertiary white limestone, underlain by the hard, less permeable yellow limestone. See map unit 1 for additional aquifer characteristics	Large to enormous quantities of brackish to saline water generally available.	Overpumping from aquifers has caused salt-water intrusion from the Caribbean Sea (1500N07500W). Contaminated water usually has high amounts of Na, Ca, Cl, and HCO_3. The Cl concentrations generally increase with	Fresh water may exist near the coast in isolated aquifers near the surface. Well depths range between 3 and 500 m. Existing wells are commonly <100 m. Ground water table in the	Fresh water may be available in isolated areas where well pumping management plans are controlling saltwater intrusion.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
7-1 Fresh water scarce or lacking (continued)	characteristics.		generally increase with depth as a result of upconing of saltwater pumped by wells dug or drilled below sea level. Cl may be as high as 1,000 mg/L. Contamination is widespread, but some wells may yield fresh water depending on the extent of the aquifer and whether or not pumping rates have been restricted to prevent saltwater upconing. Water quality generally improves when pumping rates decrease. Ground water sources near Nain (1758N07736W) and Moneague (1816N07707W) have high Na and low pH due to contamination from bauxite mining operations. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.	coastal plain and near riverbeds is commonly <30 m below the surface. Ground water levels are close to sea level in coastal areas. Aquifer thickness may be as thick as 1,000 m. Access is generally good. Access may be difficult in mountainous areas. The water table is at or near the surface in swampy areas along the coast east of Lionel Town (1748N07714W).	
7-2 Fresh water scarce or lacking	Less extensive brackish to saline aquifers composed of Quaternary alluvial sediments and sandstones located in river basins and along coast. Sediments consist of interbedded gravels, sands, and clays. Alluvial aquifers can overlie limestone aquifers. See map unit 2 for additional aquifer characteristics.	Very small to very large quantities of brackish to saline water available. Yields from alluvial aquifers are generally 32 L/s, but may be as high as 125 L/s with negligible drawdown.	Overpumping from aquifers has caused saltwater intrusion from the Caribbean Sea (1500N07500W). Contaminated water usually has high amounts of Na, Ca, Cl, and HCO_3. The Cl concentrations generally increase with depth due to upconing of saltwater pumped by wells dug or drilled below sea level. Cl exceeds 600 mg/L below 50 m in wells along coast near the Martha Brae River (1829N07738W). Cl may be as high as 1,000 mg/L. Contamination is widespread, but some wells may yield fresh water depending on the extent of the aquifer and whether or not pumping rates have been restricted to prevent saltwater upconing. Water	Fresh water may exist near the coast in isolated aquifers near the surface. Well depths range between 1 and 100 m, averaging 30 m. Aquifer thickness is between 30 and 600 m, and generally the thickest along the southern coast. Ground water is typically found in layers of sand and gravel that are separated by layers of silt and clay. The water table is at or near the surface in swampy areas near Falmouth (1830N07739W) and along the coast east of Lionel Town (1748N07714W). Ground water levels are close to sea level	Fresh water may be available in isolated areas where well pumping management plans are controlling saltwater intrusion.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
7-2 Fresh water scarce or lacking (continued)			quality generally improves when pumping rates decrease. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.	in coastal areas, including Spanish Town (1759N07657W).	
7-4 Fresh water scarce or lacking	Isolated soft limestone and alluvial brackish to saline aquifers composed of carbonate rocks, reefs, soft marls, clays, and coastal formations, including fine-grained chalk. Generally, alluvial aquifers along the coast transition to limestone aquifers farther inland. See map unit 4 for additional aquifer characteristics.	Unsuitable to small quantities of brackish to saline water available. Up to very large yields may be available from the white limestone aquifers below the softer limestone and alluvial aquifers. Yields from chalky limestone are less, but suitable well sites are easier to locate. Chalky limestone is north of the Cockpit Country (1818N07743W) in northern Trelawny Parish (1823N07738W).	Overpumping from aquifers has caused saltwater intrusion from the Caribbean Sea (1500N07500W). Contaminated water usually has high amounts of Na, Ca, Cl, and HCO_3. The Cl concentrations generally increase with depth due to upconing of saltwater pumped by wells dug or drilled below sea level. Cl exceeds 600 mg/L below 50 m in wells along coast near the Martha Brae River (1829N07738W). Fresh water may exist near the coast in isolated aquifers near the surface. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.	Fresh water may exist near the coast in isolated aquifers near the surface. Aquifer thickness is between 300 and 1,000 m. Depth to water in these limestone regions is less than depth to water in other limestone aquifers, although smaller quantities of water are available. Ground water levels are close to sea level in coastal areas.	Fresh water may be available in isolated areas where well pumping management plans are controlling saltwater intrusion.
7-5 Fresh water scarce or lacking	Isolated brackish to saline aquifers composed of clays and shales in interior valleys. These aquifers overlie limestone or the basement complex. See map unit 5 for additional aquifer characteristics.	Unsuitable to very small quantities of fresh water available from isolated aquifers.	Overpumping from aquifers has caused saltwater intrusion from the Caribbean Sea (1500N07500W). Contaminated water usually has high amounts of Na, Ca, Cl, and HCO_3. The Cl concentrations generally increase with depth due to upconing of saltwater pumped by wells dug or drilled below sea level. Cl may be as high as 1,000 mg/L. Fresh water may exist near the coast in isolated aquifers near the surface. The primary method of	Fresh water may exist near the coast in isolated aquifers near the surface. Aquifer thickness is less than 30 m. Ground water levels are close to sea level in coastal areas. Access is generally good.	Fresh water may be available in isolated areas where well pumping management plans are controlling saltwater intrusion.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
7-5 Fresh water scarce or lacking			sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.		
7-6 Fresh water scarce or lacking	Isolated brackish to saline aquifers located in the basement rock. See map unit 6 for additional aquifer characteristics.	Unsuitable to very small quantities available from fractures. Springs may yield higher quantities of water.	Overpumping from aquifers has caused saltwater intrusion from the Caribbean Sea (1500N07500W). Contaminated water usually has high amounts of Na, Ca, Cl, and HCO_3. The Cl concentrations generally increase with depth due to upconing of saltwater pumped by wells dug or drilled below sea level. Cl may be as high as 1,000 mg/L. Fresh water may exist near the coast in isolated aquifers near the surface. The primary method of sewage disposal is the use of hand-dug soak-away pits. Ground water near soak-away pits may have high fecal coliform levels.	Fresh water may exist near the coast in isolated aquifers near the surface. Ground water levels are close to sea level in coastal areas. Access is generally good.	Fresh water may be available in isolated areas where well pumping management plans are controlling saltwater intrusion.

[1]Quantitative Terms:
Enormous = >100 L/s (1,600 gal/min)
Very large = >50 to 100 L/s (800 to 1,600 gal/min)
Large = >25 to 50 L/s (400 to 800 gal/min)
Moderate = >10 to 25 L/s (160 to 400 gal/min)
Small = >4 to 10 L/s (64 to 160 gal/min)
Very small = >1 to 4 L/s (16 to 64 gal/min)
Meager = >0.25 to 1 L/s (4 to 16 gal/min)
Unsuitable = $\leq$0.25 L/s (4 gal/min)

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

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

[3]Geographic coordinates for place names and primary features are in degrees and minutes of latitude and longitude. 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:

Morant Bay…….1753N07625W

Geographic coordinates for Morant Bay that are given as 1753N07625W equal 17°53' N 76°25' W and can be written as latitude of 17 degrees and 53 minutes north and a longitude of 76 degrees and 25 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country scale map. Geographic coordinates for rivers are generally at the river mouth.

Table C-2. Ground Water Resources (Continued)

Note:

Ca	=	calcium
$CaCO_3$	=	calcium carbonate
Cl	=	chloride
gal/min	=	gallons per minute
HCO_3	=	bicarbonate
L/min	=	liters per minute
L/s	=	liters per second
m	=	meters
m^2/d	=	square meters per day
mg/L	=	milligrams per liter
Na	=	sodium
NO_3	=	nitrate
pH	=	hydrogen-ion concentration
TDS	=	total dissolved solids

Conversion Chart:

To Convert	Multiply By	To Obtain
liters per second	15.840	gallons per minute
liters per second	60.000	liters per minute
liters per second	950.000	gallons per hour
gallons per minute	0.063	liters per second
gallons per minute	3.780	liters per minute