WATER RESOURCES ASSESSMENT OF HAITI

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Executive Summary

Haiti is one of the most densely populated countries in the world and one of the poorest in the Western Hemisphere. The population has already outstripped domestic food production, and it is estimated that the population will be 8 million by the year 2000. One-third of the population lives in the Département de l'Ouest where Port-au-Prince is located. Heavy migration from rural areas to towns and cities occurring over the past decade has adversely affected the distribution of the water supply. Access to water and sanitation facilities is inadequate, contributing to poor living conditions, disease, and a high mortality rate. In 1990 only 39 percent of the 5.9 million residents had adequate access to water and only 24 percent to sanitation. The lack of potable water for basic human needs is one of the most critical problems in the country.

Given the rainfall and abundant water resources, there is adequate water to meet the water demands, but proper management to develop and maintain the water supply requirements is lacking. However, the water supply sector is undergoing complete transformation. Although currently there is no comprehensive water policy, progress is being made towards establishing a national water resources management policy. Numerous agencies and non-government organizations (NGO's) are working to provide water, many of which conduct their missions with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources. The Reform Unit for Potable Water (URSEP) is a special agency created recently to help organize the efforts of the various agencies in the water sector.

Pollution of the water resources is a significant problem. Contamination of surface water and shallow ground water aquifers are prevalent throughout the country. Domestic wastewater and agricultural runoff cause biological contamination of water near and downstream of populated places. Currently there is no public system for the collection and treatment of wastewater. Indications are that contamination is increasing rapidly, especially for surface water. The amount of water pollution is important because much of the population still uses surface water and ground water from shallow aquifers for their water supply.

Deforestation, with its devastating environmental consequences, is a serious problem in Haiti. Lac de Peligre, the only major reservoir in the country, has lost 30 percent of its storage capacity due to sedimentation caused by deforestation. Deforestation accelerates soil erosion, decreases the amount of recharge to aquifers by increasing surface runoff, damages barrier reefs and ecosystems, increases turbidity which affects mangroves, decreases agricultural production, and causes problems and increased maintenance of water systems and impoundments. Hydrologic data is lacking also. As of April 1998, only 3 of the 35 gaging stations and 25 percent of the hydrometeorological gages were functional. The technical information obtained from such a network is critical for effective water resources management.

If the recommendations for watershed management are adopted, if progress is made toward reducing the untreated waste entering the nation's waterways, and if a national water resources management policy is implemented, positive, immediate, and long-term benefits 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 Haiti. 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 Haiti to maximize the use of these resources. The other objective is to provide Haiti 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 1998.

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Contents

Executive Summary i
Preface iii
Contents iv
List of Acronyms and Abbreviations vii
List of Place Names ix

I. Introduction 1

II. Country Profile 2
A. Geography 2
B. Population and Social Impacts 2
C. Economy 3
D. Flood Control 3
E. Legislative Framework 4

III. Current Uses of Water Resources 4
A. Water Supply 4
1. Domestic Uses and Needs 6
2. Industrial/Commercial Uses and Needs 9
3. Agricultural Uses and Needs 9
B. Hydropower 10
C. Stream Gage Network 10
D. Waterway Transportation 11
A. Surface Water Resources 11
1. Precipitation and Climate 11
2. Rivers and Basins 12
3. Lakes and Swamps 13
4. Deforestation Effects 14
B. Ground Water Resources 14
1. Aquifer Definition and Characteristics 15
2. Haiti Hydrogeology 16
C. Water Quality 17
1. Surface Water 17
2. Ground Water 18
3. Domestic Waste Disposal 18
A. Introduction 18
B. Water Conditions by Map Unit 19
C. Water Conditions by Department 20

Contents, continued

Département de l'Artibonite 21

Département du Centre 22

Département de la Grand'Anse 23

Département du Nord 24

Département du Nord-Est 25

Département du Nord-Ouest 26

Département de l'Ouest 27

Département du Sud 29

Département du Sud-Est 30

VI. Recommendations 31

A. General 31

B. Watershed Protection and Management 31

C. Troop Exercise Opportunities 31

D. Water Quality and Supply Improvement 32

VII. Summary 32

Endnotes 33

Bibliography 36

Tables
Table 1. Population Distribution 2
Table 2. Water Consumption by Hydrogeographic Region (Mm3/yr) 4
Table 3. Water Supply in Port-au-Prince 7
Table 4. Water Supply in Secondary Villages 8
Table 5. Irrigation by Hydrogeographic Region 10
Table 6. Hydropower Plants, 1996 10
Table 7. Major Drainage Basins 13

Figures
Figure 1. County Map xiv
Figure 2. Vicinity Map 2
Figure 3. Hydrographic Regions 5

Appendix A. List of Officials Consulted and List of Agencies Contacted
List of Officials Consulted A-1
List of Agencies Contacted A-2

Appendix B. Glossary
Glossary B-1

Contents, continued

Appendix C. Surface Water and Ground Water Resources
Tables
Table C-1. Surface Water Resources C-1
Table C-2. Ground Water Resources C-8

Figures
Figure C-1. Surface Water Resources C-17
Figure C-2. Ground Water Resources C-19

List of Acronyms and Abbreviations

Acronyms

ASSODLO	Association Haitienne pour la Maîtrise de l'Eau en Milieu Rural (Haitian Association for Water Control in Rural Areas)
CAMEP	Centrale Autonome Metropolitaine d'Eau Potable (Independent Metropolitan Water Company)
CARE	Cooperative for American Relief to Everywhere
CREPA	Centre Regional pour l'Eau Potable et l'Assainissement (Regional Center for Potable Water and Sanitation)
ED'H	Electricité d'Haiti (Haitian Electricity Company)
GDP	Gross domestic product
GNP	Gross national product
IDB	Inter-American Development Bank
IHSI	Institut Haitien de Statistiques et d'Informatique (Haitian Institute for Statistics and Information Technology)
MARNDR	Ministère de l'Agriculture, des Ressources Naturelles et du Développement Rural (Ministry of Agriculture, Natural Resources, and Rural Development)
MDE	Ministère de l'Environnement (Ministry of the Environment)
MSPP	Ministère de la Santé Publique et de la Population (Ministry of Public Health and Population)
MTPTC	Ministère des Travaux Publiques, Transports et Communications (Ministry of Public Works, Transportation, and Communication)
NGO	Non-government organization
PAHO	Pan American Health Organization
PNUD (also UNDP)	Programme des Nations Unies pour le Développement (United Nations Development Program)
POCHEP	Poste Communautaire d'Hygiene et d'Eau Potable (Community Water Supply and Sanitation Post)
SBC	Southern Baptist Convention
SNEP	Service National d'Eau Potable (National Water Supply Service)
SNRE	Service National de Ressources en Eau (National Service for Water Resources)
UMEPA	National Office for Drinking Water and Sanitation (French name not available)
UNDP (also PNUD)	United Nations Development Program (Programme des Nations Unies pour le Développement)
UNICEF	United Nations Children's Fund
URSEP	Unité de Reformé du Secteur en Eau Potable (Reform Unit for Potable Water) under the Ministry of Public Works
USACE	U.S. Army Corps of Engineers (referred to in text as *Corps*)
USAID	U.S. Agency for International Development
USSOUTHCOM	United States Southern Command
WHO	World Health Organization

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
Ca	calcium
$CaCO_3$	calcium carbonate
Cl	chloride
Fe	iron
gal/min	gallons per minute
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	potential of hydrogen
PVC	polyvinyl chloride
SO_4	sulfate
TDS	total dissolved solids
TSS	total suspended solids

List of Place Names

Place Name	Geographic Coordinates
Acul, Baie de l'	1944N07220W
Acul, Rivière de l'	1807N07351W
Amont Barrage	1828N07233W
Amont Bassin General	1830N07212W
Anse à Galets	1850N07252W
Anse-à-Pitres	1803N07145W
Anse Rouge Rivière	1939N07303W
Artibonite Basin	1905N07200W
Artibonite, Département de l'	1920N07230W
Artibonite estuary	1915N07247W
Artibonite, Plaine de l'	1915N07235W
Artibonite, Rivière de l'	1915N07247W
Artibonite, Rivière de l' (delta)	1915N07247W
Artibonite, Rivière de l' (middle and upper reaches)	1850N07206W
Aufilier	1928N07239W
Bainet, Rivière de	1811N07245W
Baradères, Rivière des	1830N07340W
Barres, Rivière des	1956N07242W
Blanche, Rivière	1939N07227W
Bois Pin	1852N07153W
Bombardopolis, Plateau de	1945N07320W
Bombardopolis-Gonaïves Zone	1940N07300W
Bouyaha, Rivière	1910N07204W
Brodequin, Rivière	1815N07325W
Brossard, Rivière	1830N07321W
Caïman, Trou	1840N07209W
Camp Perrin	1819N07352W
Canot, Rivière	1910N07204W
Cap-Haïtien Zone	1945N07212W
Castel	1819N07235W
Cavaillon	1818N07339W
Cavaillon Basin	1820N07340W
Cavaillon, Rivière de	1814N07341W
Cayes-Jacmel-Anse à Pitres Zone	1817N07205W
Cayes, Plaine des	1814N07346W
Cayes Zone	1814N07350W
Centre, Département du	1900N07200W
Chaîne des Matheux	1855N07230W

List of Place Names, continued

Place Name	Geographic Coordinates
Charpentier	1813N07345W
Colombier, Rivière	1934N07256W
Corail-Anse à Veau Zone	1830N07345W
Côtes de Fer	1811N07300W
Côtes de Fer-Bainet Zone	1815N07250W
Côtes de Fer, Rivière des	1811N07300W
Coupe à l'Inde	1917N07231W
Cul-de-Sac, Plaine du	1836N07210W
Cul-de-Sac Zone	1836N07210W
Dame Marie, Rivière de	1834N07425W
Dieubonne, Source	1924N07205W
Duclos	1917N07239W
Estère Basin	1915N07230W
Estère, Rivière de l'	1924N07242W
Fer à Cheval, Rivière de	1850N07206W
Fond Pomme	1947N07320W
Fond Verrettes Zone	1853N07153W
Fort Libertè	1940N07150W
Galois (Haut de Cap), Rivière	1945N07213W
Gauche, Rivière	1815N07233W
Gôave, Grand Rivière	1826N07246W
Gonaïves	1927N07241W
Gonaïves, Plaine du	1930N07240W
Gonâve, Golfe de la	1900N07330W
Gonâve, Île de la	1851N07303W
Gonave Island Zone	1851N07303W
Grand'Anse Basin	1830N07415W
Grand'Anse, Département de la	1830N07340W
Grand'Anse, Rivière	1838N07406W
Grande Cayemite	1837N07345W
Grande Rivière de Jacmel Basin	1820N07235W
Grande Rivière de Nippes Basin	1829N07318W
Grande Rivière du Nord Basin	1930N07207W
Grise, Rivière (Grande Rivière du Cul-de-Sac)	1838N07221W
Guayamouc, Rivière	1859N07152W
Hinche	1909N07201W
Islet, Rivière de l'	1811N07344W
Jacmel	1814N07232W

List of Place Names, continued

Place Name	Geographic Coordinates
Jacmel, Grande Rivière de	1814N07233W
Jean Rabel, Rivière de	1954N07312W
Jeanton	1904N07243W
Jérémie	1839N07407W
Jérémie-Les Irois Zone	1840N07415W
Jet d'Eau, Source	1817N07224W
La Gorge	1830N07207W
Lamartinière	1836N07212W
La Quinte Basin	1930N07230W
La Quinte, Rivière	1924N07241W
La Rue	1943N07211W
Léogâne-Carrefour Zone	1830N07230W
Les Cayes	1812N07345W
Les Trois Rivières	1957N07252W
Les Trois Rivières (middle reaches)	1939N07239W
Les Trois Rivières (upper reaches)	1936N07228W
Limbé Basin	1940N07225W
Limbé, Rivière du	1948N07224W
Limonade-Ouanaminthe Zone	1940N07150W
Lociane, Rivière	1915N07250W
Loma de Cabrere, Batholite	1930N07200W
Maissade	1910N07208W
Mami, Source	1823N07321W
Marigot, Rivière	1814N07218W
Marion, Rivière	1940N07150W
Massacre, Rivière du (or Rio Dajabon)	1943N07146W
Miel Source	1823N07155W
Miragoâne, de Étang	1824N07303W
Mirebalais	1850N07206W
Môle Saint Nicolas-Moustiques Zone	1950N07308W
Momance, Rivière	1834N07234W
Mombin Rivière	1815N07336W
Monnery	1830N07332W
Montagnes Noires, Massif des	1855N07205W
Montrouis, Rivière	1857N07243W
Moustiques, Rivière	1955N07257W
Nan Ruche	1945N07301W
Nan Tinte	1950N07306W

List of Place Names, continued

Place Name	Geographic Coordinates
Nippes, Grande Rivière de	1829N07318W
Nord, Département du	1936N07218W
Nord-Est, Département du	1932N07142W
Nord, Grande Rivière du	1945N07209W
Nord-Ouest, Département du	1945N07305W
Nord, Plaine du	1940N07210W
Ouanaminthe	1933N07144W
Ouest, Département de l’	1840N07220W
Passe Ranja	1836N07408W
Passe Laraque	1836N07405W
Paulin Lacoine	1956N07256W
Pédernales, Rivière	1802N07144W
Péligre, Lac de (Lake Peligre)	1852N07156W
Pérédo	1815N07218W
Pétion	1847N07202W
Petit Rivière de Nippes-Grand Gôave Zone	1924N07303W
Petit Bourg du Borgne	1949N07234W
Phaéton	1941N07154W
Pition Remard	1818N07255W
Plaisance	1936N07228W
Plateau Centrale	1915N07200W
Pont de l'Estère	1919N07237W
Pont Gros Morne	1939N07239W
Pont Sondé	1909N07237W
Pont Parois	1928N07200W
Port Margot, Rivière de	1949N07226W
Port-au-Prince	1832N07220W
Port-de-Paix	1957N07250W
Port-de-Paix-Port Margot Zone	1950N07235W
Quartier Morin	1942N07209W
Roche à l’Inde	1939N07225W
Roseaux, Rivière des	1836N07402W
Roseaux-Voldrogue Zone	1830N07405W
Rouffer Quinte	1922N07231W
Saint Louis du Sud-Aquin Zone	1820N07320W
Saint-Marc-Duvalierville Zone	1850N07230W
Saint-Marc, Rivière de	1907N07242W
Saint-Raphaël	1926N07212W

List of Place Names, continued

Place Name	Geographic Coordinates
Saumâtre, Étang	1835N07200W
Saut d'Eau	1849N07212W
Selle, Massif de la	1821N07217W
Soliette, Rivière	1830N07151W
Source Sable	1836N07204W
Sud, Département du	1815N07340W
Sud-Est, Département du	1818N07224W
Sud, Ravine du	1811N07345W
Tiburon, Rivière de	1820N07424W
Tiburon-St. Jean Zone	1815N07410W
Torbeck	1810N07349W
Torbeck, Rivière de	1810N07349W
Torcelle, Rivière	1843N07227W
Tortue, Île de la	2004N07249W
Tortue Island Zone	2004N07249W
Trois Rivières Basin	1945N07240W
Vache, Île à	1804N07338W
Voldrogue, Rivière de la	1837N07405W
Wallondry	1925N07213W

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:

Acul, Baie de l'..1944N07220W

Geographic coordinates for Baie de l'Acul that are given as 1944N07220W equal 19°44' N 72°20' W and can be written as a latitude of 19 degrees and 44 minutes north and a longitude of 72 degrees and 20 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.

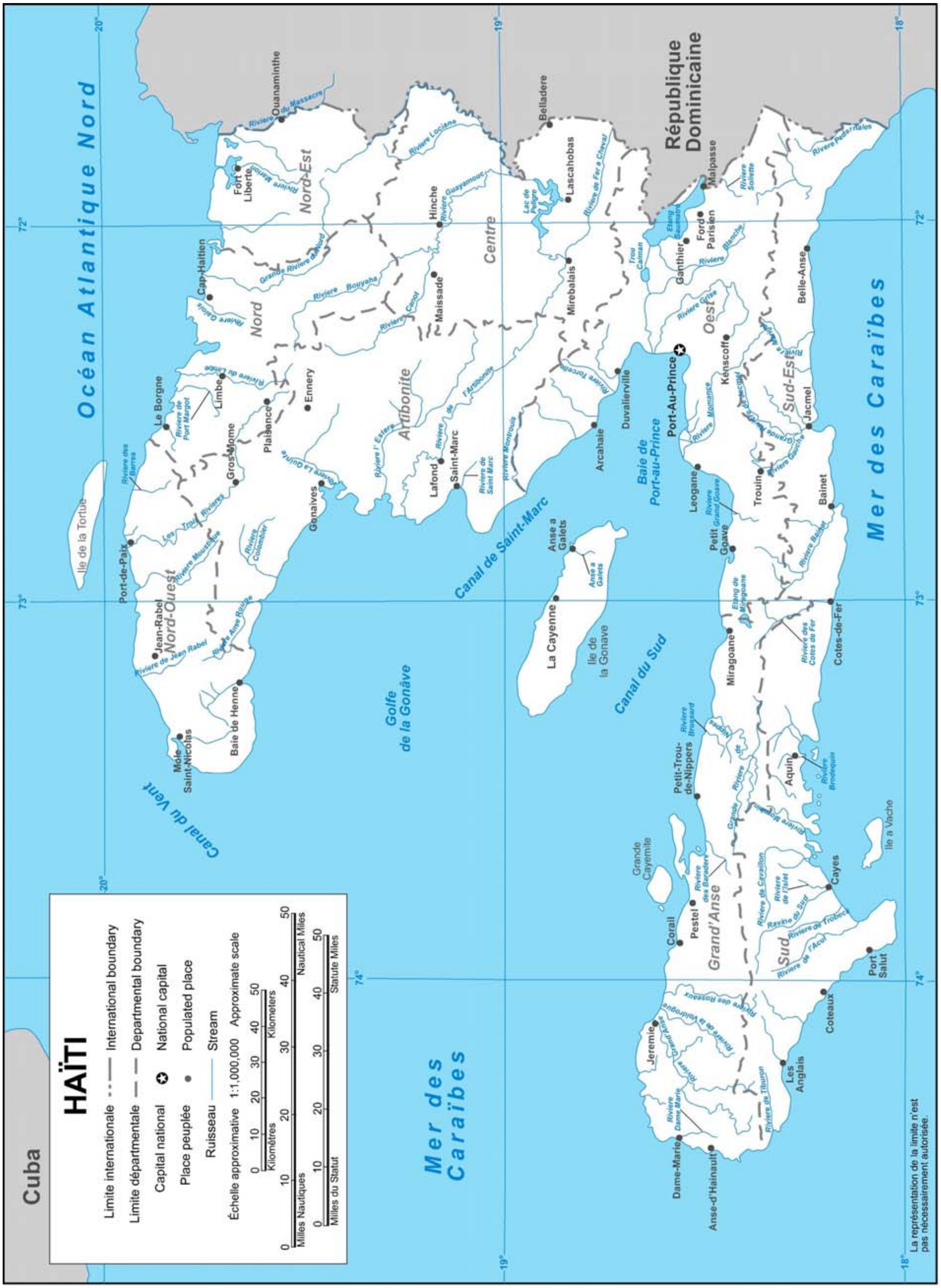

Figure 1. County Map

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.i 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.ii As well as being in abundant supply, the available water must have specific quality characteristics, such as the low concentration of total dissolved solids (TDS). The TDS concentration of water affects the domestic, industrial, commercial, and agricultural uses of water. The natural nontoxic constituents of water are not a major deterrent to domestic use until the TDS concentration exceeds 1,000 milligrams per liter. As TDS values increase over 1,000 milligrams per liter, the usefulness of water for commercial, industrial, and agricultural uses decreases. In addition to TDS concentrations, other quality factors affect water. These factors include the amount of disease-causing organisms, the presence of manufactured chemical compounds and trace metals, and certain types of natural ions that can be harmful at higher concentrations.

The purpose of this assessment is to document the general overall water resources situation in Haiti. This work involves describing the existing major water resources in the country, identifying special water resources needs and opportunities, documenting ongoing and planned water resources development activities, and suggesting practicable approaches to short- and long-term water resources development. This assessment resulted from an in-country information-gathering trip and from information obtained in the United States on the part of four water resources professionals. The scope was confined to a “professional opinion,” given the size of the country and the host of technical reports available on the various aspects of Haiti’s water resources.

This information can be used to support current and potential future investments in managing the country’s water resources and to assist military planners during troop engineering 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 population and the high mortality rate, the lack of wastewater treatment, the devastating effects of deforestation on the water resources, and the lack of hydrologic data. Watershed management plans should be enacted to control deforestation and to manage water resources.

Responsibility for overseeing the water resources of Haiti 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 with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources.

II. Country Profile

A. Geography

Haiti shares the island of Hispaniola, the second largest island in the Caribbean Sea, with the Dominican Republic. With its 27,700 square kilometers (10,714 square miles) of territory, Haiti is similar in size to the U.S. state of Maryland and includes the islands of Gonâve, Tortue, Vache, and Grande Cayemite.

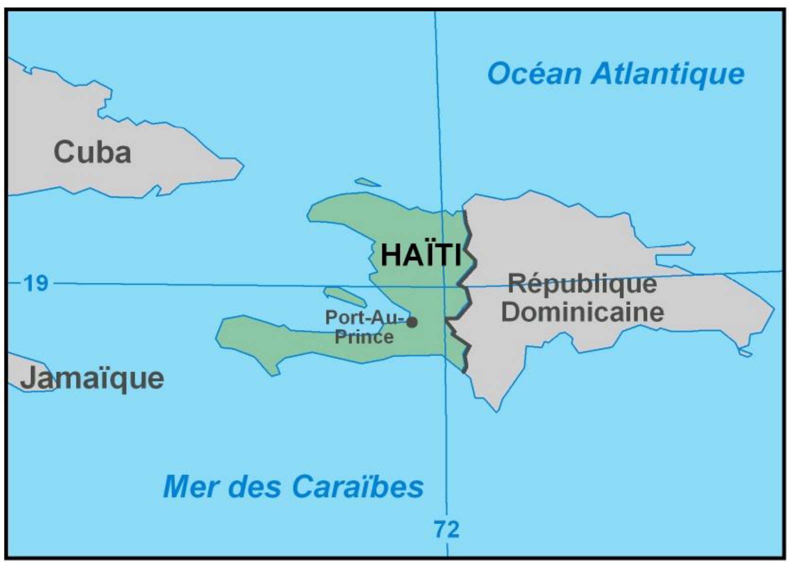

Figure 2. Vicinity Map

Five mountain ranges (Massif du Nord, Massif des Montagnes Noires, Chaîne des Matheux, Massif de la Hotte, and Massif de la Selle) cover 75 percent of the land surface. The highest peak, Morne de la Selle, rises to an elevation of 2,680 meters (8,790 feet). The remaining land area consists of four major flatlands: (1) the Plaine du Nord between the Atlantic Ocean and the Massif du Nord; (2) the Plaine de l'Artibonite to the north of Chaîne des Matheux; (3) the Plaine du Cul-de-Sac between the Chaîne des Matheux and the Massif de la Selle; and (4) the Plateau Centrale to the east of the Montagnes Noires. See figures 1 and 2 for general geographic information.

B. Population and Social Impacts

Haiti is the poorest country in the Western Hemisphere and is one of the most densely populated countries in the world. Deteriorating living conditions in rural areas have caused a population shift to the urban areas, accelerating urbanization. Over one-third of the total population (34.7 percent) lives in the Département de l'Ouest, where the nation's capital Port-au-Prince is located. Over 25 percent of the total population of Haiti is in Port-au-Prince, with a population of just less than 2 million. Despite a relatively low population growth rate, largely a consequence of widespread emigration, the population has outstripped domestic food production.[iii] In addition, rapid urbanization has adversely affected the distribution of the water supply.

The last census was conducted in 1982. Population projections, developed by the Institut Haitien de Statistiques et d'Informatique (IHSI), in conjunction with the Latin American Demographic Center, estimate the population at about 7,200,000 as of 1995. The population of the departments, based on the 1995 estimates, is provided in table 1. With an anticipated population growth rate of about 2 percent per year, projections indicate that the population will reach 8 million by the year 2000.

As of 1995, with an average of 260 inhabitants per square kilometer, Haiti has one of the highest population densities of all Latin American countries. The density of population per unit of cultivated area, figured at 885 inhabitants per square kilometer, dramatically underscores the heavy population pressure on land in the country.

Table 1. Population Distribution

Department	Population	Capital	Approximate Area (km^2)
Artibonite	1,013,779	Gonaïves	4,530
Centre	490,790	Hinche	3,700
Grand'Anse	641,399	Jeremie	3,335
Nord	759,318	Cap-Haïtien	2,045
Nord-Est	248,764	Fort-Liberté	1,750
Nord-Ouest	420,971	Port-de-Paix	2,525
Ouest	2,494,862	Port-au-Prince	4,650
Sud	653,398	Les Cayes	2,950
Sud-Est	457,013	Jacmel	2,215
Total	**7,180,294**		**27,700**

Source: IHSI estimates for 1995 and "Haiti en chiffres" (Haiti Statistics) IHSI, January 1996.

Over the past 10 years, heavy migration from rural areas to towns and cities has seriously affected the housing situation. This is particularly noticeable in the metropolitan area of Port-au-Prince where the rapid population increase within this limited geographical area has caused a decline in the living conditions of the poor. There has been a sizable increase in the household occupancy rate. The average size of the household unit is generally presumed to be five persons. However, this figure is clearly higher in the metropolitan area, where dwelling units in *Bidonvilles* or shantytowns are known for their cramped quarters. Such overcrowding is conducive to the transmission of airborne diseases such as influenza, tuberculosis, and meningitis.[iv]

Haiti has one of the highest mortality rates in the Western Hemisphere. This problem has increased due to the country's socioeconomic and political crises. A life expectancy of 55 years is relatively short when compared to that of 67 years for Latin America as a whole.[v]

Rapid urbanization has adversely affected the distribution of water supply. Access to water and sanitation facilities is generally inadequate. In 1990 only 39 percent of the 5.9 million residents had adequate access to water and only 24 percent to sanitation facilities. The lack of access to safe water supply contributes to poor health and hygiene. Infectious and parasitic diseases, often spread through unsafe water, are the leading causes of morbidity and mortality in Haiti.[vi]

In the northern part of the capital Port-au-Prince, where 300,000 people live in a 5-square-kilometer area, rainwater mixed with sewage frequently floods homes during the wet season. Epidemics including malaria, typhoid, chronic diarrhea, and intestinal infections are caused by water contaminated by rubbish and fecal matter. Infants are especially vulnerable to these diseases, accounting for the death of up to one-third of all children before the age of five.[vii] The Pan American Health Organization (PAHO) reported in 1980, that more than half of all recorded deaths were linked to gastrointestinal diseases that are primarily waterborne. In the arid northwest, the lack of safe water and the fact that people drink brackish water have dire health consequences. In this area, as many as three quarters of the population suffer from intestinal parasites and hypertension (high blood pressure) caused by excessive salt consumption.[viii]

C. Economy

The agricultural sector of the economy, consisting mainly of small-scale subsistence, employs about 66 percent of the labor force and accounts for about 35 percent of the gross domestic product (GDP) and about 27 percent of total exports. In 1990 the chief agricultural export products were coffee, rope fiber, sugar, and cocoa. The other primary sectors, along with the percentages of the labor force they employ, are the services industry (25 percent) and the manufacturing industry (9 percent). The services and manufacturing industries account for about 42 percent and 23 percent of the GDP, respectively.

About 75 percent of the population lives in abject poverty. Based on 1997 estimates, the unemployment rate in a work force of approximately 3.6 million is about 70 percent.[ix]

D. Flood Control

Most of the major cities are along the coast and are surrounded by steep, often barren, hills. The combination of scarce vegetation on surrounding hillsides and lack of storm water drainage systems produces serious flooding, often resulting in significant loss of human lives and serious property damage. Between 1992 and April 1998, there were 12 serious flood events which resulted in loss of life and severe loss of property (exact figures are unavailable). The only event during this time period for which data is available was tropical storm Gordon that struck in November 1994 destroying over 3,500 residences and killing over 800 people near Port-au-Prince and Jacmel.x In September 1998, Hurricane Georges struck Haiti. Preliminary reports indicate that the storm killed at least 173 people and left over 18,000 people homeless. Crop losses were estimated at 60 to 80 percent. Tens of thousands of cattle and other livestock were lost to the storm. These losses represent a staggering blow to a country where agriculture provides one-third of the gross national product (GNP). The loss of these crops and livestock will result in short-term food shortages. Flooding contaminated the water supply, and the lack of uncontaminated water is expected to produce deadly waterborne diseases, such as cholera and dengue fever. The storm severely damaged the country's fragile communication, transportation, and building infrastructures.xi

Within the Port-au-Prince area, uncontrolled housing construction to accommodate the growing population has resulted in the construction of large numbers of dwellings in flood plains. This situation, along with generally poor materials and construction techniques, exposes many residents to serious danger when floods occur. In addition, the overall lack of domestic waste disposal methods increases biological contamination of the waterways during flood events.

E. Legislative Framework

Haiti does not have a comprehensive water policy. Current laws that address water issues are fragmented, with authorities spread among various agencies. However, in recent years, the Ministère des Travaux Publiques, Transports et Communications (MTPTC) recognized the need for comprehensive national water management with the creation of the Unité de Reformé du Secteur en Eau Potable (URSEP). URSEP is currently working with the Inter-American Development Bank (IDB) to establish a new drinking water policy. Upon completion of this effort, plans call for the development of a national sanitation policy to include new laws and the creation of a regulatory agency.

III. Current Uses of Water Resources

A. Water Supply

Water supply is a very serious problem, although the country has an average annual rainfall of 1,400 millimeters. The uneven distribution of rainfall and population, along with poor overall management of the available water resources, are the major causes of the water supply problem.[xii] Annually, some areas receive only 400 millimeters of rainfall, and others receive as much as 3,600 millimeters. Only about 10 percent of the total available water in the country is used, and of this, 90 percent is used for irrigation and 10 percent for domestic purposes.[xiii] Water consumption by region is shown in table 2.

Table 2. Water Consumption by Hydrogeographic Region (Mm3/yr)

Region (see Fig. 3)	Water Supply	Irrigation	Other	Total Consumed	Total Available
Centre-Nord	8.0	410.0	-	418.0	3,800
Centre-Sud	80.0	333.5	4.0	417.5	1,100
Nord	5.0	8.4	0.4	13.8	1,000
Nord-Ouest	11.0	161.0	-	172.0	1,200
Sud-Est	1.5	69.0	-	70.5	800
Sud-Ouest	5.5	187.0	.25	192.75	4,700
Total	111.0	1,168.9	4.65	1,284.55	12,600

Source: Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé, Comité National Interministeriel, *Analyse du Secteur Eau Potable et Assainissement*, Agenda 21, May 1996, p. 83.

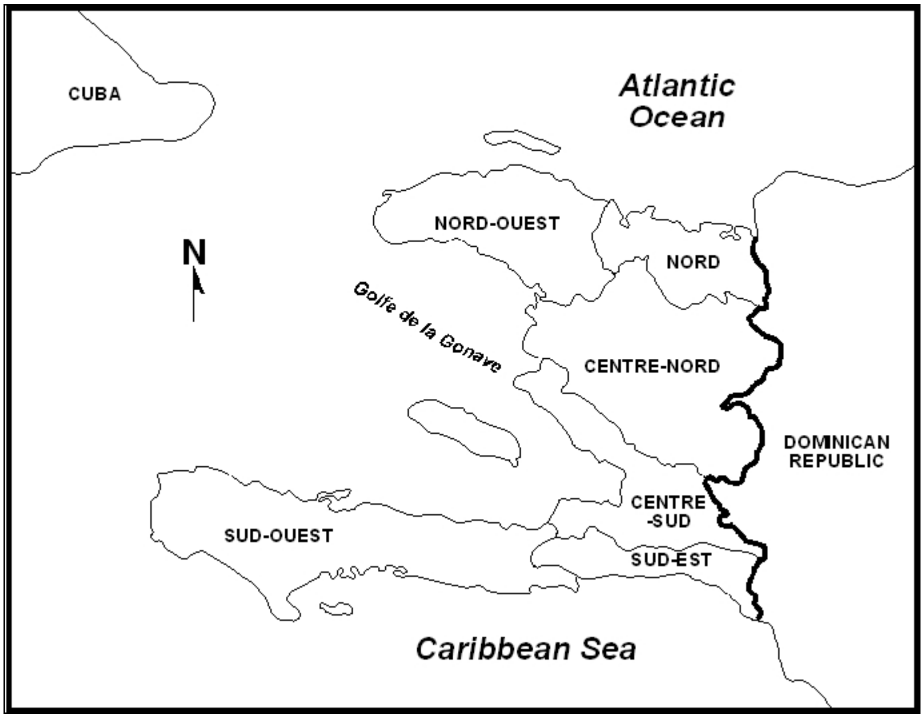

Figure 3. Hydrographic Regions

Water supply is provided by three Government agencies, several non-government organizations (NGO's), along with various private and religious relief groups. The two leading Government agencies, the Centrale Autonome Metropolitaine d'Eau Potable (CAMEP) and the Service National d'Eau Potable (SNEP) are within MTPTC. The third agency, the Poste Communautaire d'Hygiene et d'Eau Potable (POCHEP), is within the Ministère de la Santé Publique et de la Population (MSPP). CAMEP is responsible for water supply to Port-au-Prince and surrounding areas. SNEP is responsible for water supply to the smaller cities and rural areas, while POCHEP concentrates on rural areas with populations of less than 2,000.

In 1996 the MTPTC created a unit, URSEP, to reform the water supply sector. Issues under consideration by URSEP include decentralization of the water services and privatization of some water supply sectors. Most of the funding for this initiative is provided by the IDB. Under the current system, development of water supply systems is accomplished by several agencies with very little coordination. However, the need for adequate potable water is of such great magnitude that development opportunities are available for all agencies and organizations. The limiting factor is the lack of financial resources, and the need to avoid duplication of effort is essential in maximizing the return of these limited resources.

Many organizations are working in-country to provide water to the urban and rural populations. These organizations range from international donor agencies such as the Cooperative for American Relief to Everywhere (CARE) and the United Nations Development Program (UNDP) to smaller private organizations like the U.S.-based Southern Baptist Convention (SBC). The international organizations work primarily through Haitian agencies, while most of the smaller organizations work independently to meet basic water needs in rural areas.

The types of projects constructed by these NGO's include the construction of small irrigation systems, the drilling of wells and the capturing of springs in rural areas, and storm drainage projects in Port-au-Prince. Small relief organizations generally drill wells or capture springs to supply potable water in the rural areas.

Theft of water and vandalism of the water distribution system are serious problems. For example, in Jeremie, the water distribution lines that lie on the ground surface are broken in many locations, with water running out of the lines, and people stealing the water instead of using the fountains that are occasionally installed on the lines. The system is gravity fed, so the breaking of the distribution lines deprives the population at the end of the line of water. Another problem in Jeremie is the customers refuse to pay for water service, depriving the local water system of working capital to repair and lay new lines.

1. Domestic Uses and Needs

Much of the surface water is contaminated or saline; however, it is used for domestic purposes by much of the population with little or no treatment. The Government and NGO's are trying to supply potable water to the population from water wells. About 40 percent of the population obtains water supplied by Government- and NGO-constructed water supply systems or wells.

The 1996 estimated percentages of populations with access to either a water-supply system or a well are as follows: 35 percent of Port-au-Prince, including the surrounding areas of Pétion-Ville, Carrefour, and Delmas; (2) 43 percent of the secondary villages (populations over 5,000); and (3) 39 percent of the rural villages (populations less than 5,000).[xiv] The following sections present a breakdown of the water supply situation for the three sectors.

Port-au-Prince. Water supply for Port-au-Prince is poor. In 1995 only about 35 percent of the nearly 2 million inhabitants had access to the water system.[xv] Most of the metropolitan areas receive water service only part of the time. Some areas receive water service daily, but most receive water only twice a week. The lack of service is attributed to (1) system losses associated with the age of the distribution system and theft of service, estimated at 60 percent; (2) interruptions in the power supply to the wells and pumps; and (3) contamination of water sources.

About 75 percent of the water for the municipal system is obtained from 18 springs located near the Massif de la Selle mountains and the remainder from 5 old water wells and 6 new ones (as of mid-1998). The municipal water system does not use surface water as a source. A 1996 report estimated production from springs and wells to be 40,000,000 cubic meters per year.[xvi] Most of the distribution is accomplished by a gravity-fed system of 16 municipal storage tanks that provides a total volume capacity of more than 45,000 cubic meters. See table 3 for the population served by the various types of service.

Table 3. Water Supply in Port-au-Prince	
Type of service	Total Population Served
Distribution systems	520,800
Public fountains	60,000
Private wells	3,400
Supply to shantytowns	15,600
Source other than CAMEP	36,500
Total	636,300

Source: Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé, Comité National Interministeriel, *Analyse du Secteur Eau Potable et Assainissement*, Agenda 21, May 1996, p. 147.

CAMEP has five wells in the vicinity of the airport with each capable of producing 200 cubic meters per hour from electric-powered vertical turbine pumps. The wells are approximately 100 meters deep and 12 to 16 inches in diameter. Not coincidentally, this area near the airport receives the most consistent water service. Six new wells have been drilled along Rivière Grise to supplement the existing wells. All wells pump 24 hours a day, and all have secondary generators to provide electricity during power outages. Frequent interruptions to service are caused by shortages of generator fuel. Water distribution in the capital is via 24-inch water mains and 8-inch polyvinyl chloride (PVC) pipes. The network, built in the 1970's, is outdated and in poor condition.

Chlorine disinfectant is injected at all wells and springs. CAMEP is the only agency with a water-testing laboratory. About 25 samples from different sites are tested daily for coliform bacteria. When samples fail the coliform test, the results are relayed to the citizens via the public radio system. Contamination of the distribution lines by domestic waste from latrines and cesspools located too close to inhabited areas is a common problem.

The sources of water for Port-au-Prince are facing several major problems that are decreasing the quality and quantity. One problem is contamination. All the springs are reported to be contaminated by biological contamination from human and solid wastes. A couple of the springs are too polluted to be used. Human sewage, agricultural runoff, and industrial wastes are also threatening the wells. A second major problem is decreasing yields from the springs. Deforestation, urbanization, and drought are greatly diminishing the amount of water infiltrating into the ground to recharge the aquifers, with the result of decreasing flow from the springs.

For many of the inhabitants, especially the poor, the only source of water is surface water from Rivière Grise, Rivière Blanche, smaller streams, irrigation ditches, and the city's storm water drains. The surface water near the city is severely polluted by human sewage, solid wastes, and industrial chemical contamination.

Secondary Villages. SNEP manages many water supply systems that serve the smaller secondary cities. Of 28 SNEP-managed systems, 5 are pumped, 3 are a combination of gravity-fed and pumped systems, and the remaining 20 are gravity-fed systems. If all residential connections and public fountains are considered, 260,000 people receive service from SNEP. UNICEF, the World Bank, IDP, the German Foundation for Technical Assistance, and the U.S. Agency for International Development (USAID) have provided assistance in the development of water supply projects to SNEP. Other agencies and organizations also provide water supply services to this sector. In 1995 about 43 percent of the population of secondary villages had access to water systems. Estimated water supply coverage in secondary villages is presented in table 4.

Table 4. Water Supply in Secondary Villages

Department	Population	Population Served	Percent Served
Artibonite	239,652	106,920	44.6
Centre	72,739	36,641	50.4
Grand'Anse	83,362	23,018	27.6
Nord	210,765	117,890	56.0
Nord-Est	63,798	15,293	24.0
Nord-Ouest	61,59	22,375	36.3
Ouest	78,545	25,474	32.4
Sud	94,383	41,242	43.7
Sud-Est	39,054	13,864	35.5
Total	943,891	402,717	43.0

Source: Système de Suivi du Secteur Eau Potable et Assainissement (WASAMS), *Actualisation des Taux de Couverture des Besoins en AEPA au 31 Décembre 1996*, OPS/OMS-UNICEF, December 1997, p. 8.

Rural Areas. Water supply coverage to the rural areas was estimated to be 39 percent in 1996.[xvii] A great need exists for water wells, as most of the rural population uses surface water which is often contaminated. Both SNEP and POCHEP work in this sector along with NGO's, various humanitarian relief organizations, as well as the Ministère de l'Agriculture des Ressources Naturelles et du Developpement Rural (MARNDR). Most of the small relief organizations concentrate their efforts within this sector.

Since its creation in 1981, POCHEP has installed about 90 water supply systems funded mostly by the IDB. The projects consist mainly of well installation and the capturing of springs. Many of the private relief organizations concentrate on the installation of basic hand pump wells. Many of POCHEP's systems, however, include public bathing areas and distribution networks. Several of these networks extend up to 17 kilometers from their source. POCHEP trains the local citizens in public health issues along with the proper operation and maintenance of the water systems, and they maintain a detailed database on their existing and proposed projects. In many cases, especially in the larger villages, once POCHEP completes a system, it is turned over to SNEP to manage.

The small relief organizations like the SBC, Water for Life, Free Methodist Mission, and the Blue Ridge Ministries play a significant role in the development of water supply for rural areas. Interviews with members of the SBC, who have been drilling wells in Haiti since 1964, provided the following information that can be considered somewhat typical of other small relief organizations. The SBC has one operational cable-tool drill rig that is used to drill about 25 to 35 wells per year. As of April 1998, a backlog of 10 wells existed. Hand pumps are installed on the wells.

As of April 1998, most of the SBC's efforts were concentrated in the Nord and Nord-Est departments, but they work throughout the country. Within the northern departments, most of the wells are drilled to a minimum depth of 100 feet, since many of the shallower 40- to 60-foot-deep wells risk going dry during the dry season. In the past, the SBC has also captured springs as water sources, but the cost to drill a well is about one-third that of capturing a spring. Consequently, all their current efforts center on well drilling and repairing existing systems. The

SBC also trains the local population in the operation and maintenance of their systems and performs annual checks on the conditions of the systems.

Many of the mountainous areas, particularly in the Département du Nord-Ouest, are experiencing water shortages due to aquifer drawdown. This is attributed to deforestation and overuse of aquifers. According to a report sponsored by the United Nations, one method of reducing the rate of decrease in water levels would be to construct small surface impoundments to serve as aquifer recharge areas, which retain rainwater. The depth to water in much of the mountainous areas is too great for pumping water by hand pumps, meaning electrical (submersible) pumps would have to be used. This is a problem too, as many of these areas do not have a functioning electrical system.

The overdevelopment of ground water resources on the Plaine du Cul-de-Sac (Cul-de-Sac Plain) for irrigation and water supply has created saltwater intrusion problems in wells, particularly in the coastal areas near Port-au-Prince.

2. Industrial/Commercial Uses and Needs

Annually, the food-processing industry (i.e., juice, carbonated drinks, beer) in the Plaine du Cul-de-Sac (Cul-de-Sac Plain) uses more than 4 million cubic meters of water. Ground water, obtained from about 800 wells, is the primary source of this water.[xviii] Information on other industrial uses and needs is unavailable.

3. Agricultural Uses and Needs

Surface water flows directly into a great number of irrigation systems. The most important agricultural areas in the country are the irrigated plains that include the Plaine du Nord (North Plain), the Fort-Liberté area, the Plaine du Cul-de-Sac (Cul-de-Sac Plain), the Plaine des Cayes (Cayes Plain) and the lower Rivière de l'Artibonite and Rivière de l'Estère valleys. The quantity of surface water available for irrigation is decreasing due to deforestation.[xix]

Although agriculture accounts for 66 percent of the employment, it generates only 35 percent of the GDP. This is partly because of the uneven distribution of rainfall, which forces farmers to rely on irrigation to meet their needs. About 80 percent of the total quantity of water utilized in the country is for irrigation. In 1996 an estimated 1,170 million cubic meters of water was used for irrigation (see table 5). A 1996 report listed the total number of irrigation projects at 128, serving a total area of about 70,000 hectares. However, because of system malfunctions and losses, only about 42,000 hectares are irrigated on a regular basis. The largest irrigation projects, which irrigate 25,000 hectares, are along the Rivière de l'Artibonite.[xx] MARNDR does not maintain current records on the amount of land irrigated or the amount of water used for irrigation purposes. Consequently, actual numbers on the amount of land irrigated are difficult to verify.

Table 5. Irrigation by Hydrogeographic Region	
Region	Consumption Mm^3/yr)
Centre-Nord	410.0
Centre-Sud	333.5
Nord	8.4
Nord-Ouest	161.0
Sud-Est	69.0
Sud-Ouest	187.0
Total	1168.9

Source: Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé, Comité National Interministeriel, *Analyse du Secteur Eau Potable et Assainissement*, Agenda 21, May 1996, p. 83.

B. Hydropower

The Electricité d'Haiti (ED'H) is responsible for the electrical energy system. Electrical power is concentrated in Port-au-Prince and limited to rotating-sector service during dry periods. System losses, attributed to theft, create additional stress on the system. Haiti has seven hydropower projects, of which the Peligre project with an installed capacity of more than 47 megawatts is by far the largest. The most serious problem facing the Peligre project is deforestation which causes erosion and sedimentation that is filling the reservoir.

Table 6. Hydropower Plants, 1996		
Project	River Name	Installed Capacity (MW)
Peligre	Rivière de l'Artibonite	47.1
Drouet	Rivière de l'Artibonite	2.5
Saut Mathirine	Rivière de Cavaillon	2.4
Grande Rivière du Nord	Rivière Caracol	0.9
Montrouis	Rivière Deluge	0.9
Jacmel	Rivière Gaillard	0.9
Belladere	Rivière Onde Verte	0.3
Total		55.0

Source: Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé, Comité National Interministeriel, *Analyse du Secteur Eau Potable et Assainissement*, Agenda 21, May 1996, p. 88.

C. Stream Gage Network

Most of the available water data is for the periods 1922 through 1940, the 1960's, and the late 1980's. The collected data was mainly for the development of specific water projects and programs.

The Service National de Ressources en Eau (SNRE) is the agency responsible for the collection of water data. However, budget problems in the past years have caused the deterioration of the data-gathering network. In 1994 a survey by SNRE and the Association Haitienne pour la Maîtrise de l'Eau en Milieu Rural (ASSODLO) determined that of the 183 hydrometeorological gages located, only 25 percent were functional. Based on interviews with SNRE officials in April 1998, only 3 of their 35 stream gaging stations were functioning. One of the biggest problems of the actual network is its altimetric distribution. About 63 percent of the network is located between zero and 200 meters altitude. This is largely due to the difficulties of accessing the mountainous areas. Deforestation is becoming critical in many of the mountainous areas of the northwest, making the need for accurate climatological information even more important. A great need exists to reestablish the national network of river and rain gages. The technical information obtained from such a network is critical for effective water resources management.

D. Waterway Transportation

Commercial navigation along the rivers is almost nonexistent. The Rivière de l'Artibonite, navigable only by small shallow draft vessels, is occasionally used by small boats that serve local transportation and commerce.

IV. Existing Water Resources

A. Surface Water Resources

More than 100 streams flow from the Haitian mountains into the Golfe de la Gonâve, the Atlantic Ocean, and the Caribbean Sea. No streams flow toward the Dominican Republic. In the highlands, streamflow is rapid and torrential, but in the lowlands, the same streams become slow and meander. Many streams have their flows dissipated by evaporation and infiltration and never reach the sea. Surface water flows directly into many irrigation systems, but the quantity of water available for irrigation is decreasing due to deforestation.[xxi]

1. Precipitation and Climate

The climate is considered to be tropical maritime. On the plains, the mean annual temperature is 27 degrees Celsius (81 degrees Fahrenheit), while in the mountains, the mean annual temperature is 16 degrees Celsius (61 degrees Fahrenheit). Seasonal temperature variation is only 4 to 5 degrees Celsius (8 to 10 degrees Fahrenheit). Frost frequently occurs at elevations above 400 meters (1,312 feet) during winter.

The quantity and regional distribution of rainfall is extremely variable because of the orientation of the mountain chains and intervening lowlands with respect to rain-bearing northeast trade winds. Haiti lies in the rain shadow of the Dominican Republic. Rainfall produced by trade winds is stopped by the mountain ridge dividing the two countries. Northern and windward slopes of mountainous areas commonly receive two to three times as much precipitation as leeward slopes. Average annual precipitation in mountainous areas commonly exceeds 1,200 millimeters (42 inches) and can be as much as 2,700 millimeters (106 inches). The average annual precipitation in lowland areas is usually less than 1,200 millimeters (42 inches) and can be as little as 550 millimeters (22 inches).[xxii] The Plaine du Gonaïves and the eastern part of the Plaine du Cul-de-Sac are the driest areas in the country. The Plaine du Gonaïves averages 550 millimeters (22 inches) of precipitation annually, and the eastern part of the Plaine du Cul-de-Sac averages 850 millimeters (33 inches).[xxiii] The country also experiences a high rate of evaporation.

April through November is generally the wet season, though many areas will have a lull between June and August. In these areas, the first wet season is from April to June and the second from September to November. The lull is not a dry period, but there is a marked decrease in precipitation. At Port-au-Prince, the wettest period is from May to November, while at Gonaïves, the wettest period is from June to September. Tropical storms, hurricanes, droughts, and floods are frequent.[xxiv] Hurricane season is from June through October. Flash flooding occurs often during the wet season, but flooding can occur at any time of the year. During periods of rainfall, flows in most streams are torrential but of short duration.[xxv]

2. Rivers and Basins

There are 30 hydrographic basins and zones in the country, which drain from the mountains to the coastal waters. Table 7 provides information on the major drainage basins within the country. Many streams have a branching network of tributaries. In many areas, fast-flowing streams converge with shallower, slower-moving meandering streams, causing a decrease in velocity, which in turn causes an increase in the average depth, increased sedimentation, less mixing, and greater in-channel retention times. This may lead to significant water quality variations, especially in total suspended solids, dissolved oxygen content, turbidity, and related constituents.[xxvi]

Most of the streams are relatively small and less than 100 kilometers long. The Rivière de l'Artibonite, which rises in the Dominican Republic and drains westward to the Golfe de la Gonâve, is the largest stream. The Rivière de l'Artibonite has a length of about 280 kilometers and a catchment area of about 9,500 square kilometers.[xxvii] It is shallow, as are most other streams in the country, but has average flows ten times that of any of the other streams. Other large streams include Les Trois Rivières, Rivière Grand'Anse, and Rivière du Massacre (or Rio Dajabon), and Rivière Pédernales. The Trois Rivières is the second longest stream and discharges into the Atlantic at Port-de-Paix. The Rivière Grand'Anse has the second highest discharge and reaches the coast near Jérémie on the southern peninsula. The Rivière du Massacre and the Rivière Pédernales begin in the Dominican Republic and form parts of Haiti's border with the Dominican Republic before flowing into the Atlantic Ocean and Caribbean Sea, respectively.[xxviii]

Many perennial streams begin on the rainy windward mountain slopes, but disappear, in whole or in part in the drier lowland plains. For example, Rivière Grise and Rivière Blanche begin on the northern slopes of the Massif de la Selle, disappear on the Plaine du Cul-de Sac during low flow, but reach the sea during floods.[xxix]

Table 7. Major Drainage Basins					
Basin Number (see Fig. C-1)	River Name	Drainage Area in Haiti (km^2)	Maximum Daily Flow (m^3/s)	Minimum Daily Flow (m^3/s)	Annual Discharge (Mean Daily Flow) (m^3/s)
III	Les Trois Rivières	897	1,500	0.3	13.13
VI	Rivière du Limbé	312	485	0.3	4.29
VIII	Grande Rivière du Nord	663	390	0.02	7.66
X	Rivière de l'Estère	834	95.3	1.85	18.76
XI	Rivière de l'Artibonite	6,862	2,500	8.4	101.4
XIII	Rivière Grise (Grande Rivière du Cul-de-Sac)	290	475	0.31	3.97
XVI	Rivière Momance	330	420	0.6	5.88
XVII	Grande Rivière de Jacmel	560	800	0.12	4.67
XXII	Rivière de Cavaillon	380	1,035	0.7	9.42
XXIV	Ravine du Sud	330	350	0.28	4.86
XXVI	Grand'Anse Rivière	541	850	0.7	26.85

Sources: M. Ehrlich et al., June 1985. Organization of American States, 1972. Organisation Panaméricaine de la Santé/ Organisation Mondiale de la Santé, 1996. United Nations Development Program, Department of Technical Cooperation for Development, 1991.

3. Lakes and Swamps

The largest natural lake in the country is Étang Saumâtre at the eastern end of the Plaine du Cul-de-Sac. It covers an area of about 181 square kilometers, has no outlet, and contains brackish water. Values for total dissolved solids (TDS) vary between 7,500 and 10,650 milligrams per liter.xxx The water level of the lake fluctuates from 12 to 20 meters above mean sea level.[xxxi] The Étang Saumâtre is the habitat of many exotic species of tropical wildlife. Many of the smaller natural lakes that exist throughout the country contain brackish water. Numerous ponds and lakes occupy sinkholes in limestone terrain. Some of these lakes are permanent while others are intermittent. The Lac de Péligre (Lake Peligre) is a manmade reservoir on the upper Rivière de l'Artibonite at the convergence of Massif des Montagnes Noires and Chaîne des Matheux. Completion of the dam formed a massive reservoir and allowed some control over the flow of the Rivière de l'Artibonite, which had previously fluctuated between a raging torrent and an uncertain trickle. The Lac de Péligre, which covers an area of about 30 square kilometers, has lost about 30 percent of its storage capacity (see Chapter IV, A, 4).[xxxii]

Along the coast, brackish surface water occurs in mangrove swamps that are backed by marshy areas. Just south of Gonaïves is the most extensive area which is 32 kilometers long and up to 5 kilometers wide. An inland marsh area surrounds Étang Saumâtre. Significant mangrove forests occur on the north coast between Baie de l'Acul and Fort-Liberté, in the Rivière de l'Artibonite estuary, in the Grande Cayemite area along the northern coast of the southern peninsula, and in the Les Cayes region including the Île à Vache. Important mangrove swamps are also found on the Île à la Gonâve, primarily on the northern coast but also fringing much of the rest of the island.[xxxiii] Many of these areas are not depicted in figure C-1 due to the map scale.

4. Deforestation Effects

A major environmental problem that is adversely affecting the surface water resources is the rapid deforestation that is occurring. The removal of trees and vegetation allow for increased and faster runoff of rainfall. The faster runoff causes a rapid increase in the amount of water entering the stream, resulting in water levels that rise faster with larger peak discharges. It also causes less rainwater to infiltrate into the soil to recharge the aquifers. Deforestation has also been associated with changes in rainfall patterns.

Deforestation, combined with the heavy agricultural pressure on marginal farmlands, accelerates soil erosion, which increases the volume of sediment carried by the streams and degrades the water quality of the upland and downstream areas. All streams have high sediment loads due to erosion in the upper parts of the basins. Soil from eroded slopes clogs streams, drainage channels, impoundments, and water systems, resulting in higher operation and maintenance costs. Inland deforestation is causing increased sedimentation in the rivers discharging to the coast which is damaging the barrier reef and associated fragile ecosystems. Increased turbidity is adversely affecting mangroves, coral reefs, and seagrass beds.[xxxiv] Estimates of the total volume of soil loss annually due to erosion are as high as 20,000 tons.[xxxv] As erosion increases, the river regime will become steeper, which increases the amount of runoff and decreases the amount of infiltration. The flow regime and total river discharge may be permanently altered. Rate, volume, and sediment loads may complicate forestry, agriculture, and downstream activities. With each passing year, the rivers and streams flow more like torrents and less like stable permanent rivers. Therefore, surface water use as a water supply for the increasing population is continuously decreasing, and less water is available when it is needed during the dry season.[xxxvi]

The active deforestation in the headwater areas of the Ravine du Sud river basin is already resulting in decreased agricultural potential in the downstream lowlands. Due to deforestation, Lac de Péligre, which receives its water from the upper Rivière de l’Artibonite, has lost 30 percent of its storage capacity due to sedimentation. By the year 2010, it is estimated that only river basins in the extreme southeast will have some forest cover. For all areas, current discharge values are probably larger than historical data, since evapotranspiration losses are less with lower vegetation density resulting in higher runoff.[xxxvii]

During the period from 1992 to 1994, the increased demand for charcoal brought on by fuel and propane shortages caused an increase in the rate of deforestation. Fuel shortages, coupled with high unemployment within the agricultural sector, forced many farm families to sell charcoal as a means to survive.

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. The continued access to and the development of safe and reliable supplies of ground water are important issues that the Government of Haiti and many international and private organizations are working on.

Ground water is generally plentiful throughout the plains and valleys of the country, but in the mountainous areas, the availability of fresh ground water varies considerably, from locally plentiful to scarce. Alluvial plains and valleys (see appendix C, figure C-2, map units 1 and 6) make up approximately 17 percent of the country but contain about 84 percent of the available ground water reserves. The mountainous areas contain many types of aquifers, including karstic, fractured, low permeability, and igneous aquifers. Areas containing karstic and highly fractured aquifers (map unit 2) make up approximately 15 percent of the country and contain about 2 percent of the available ground water reserves. Areas containing less fractured and discontinuous aquifers (map unit 3) make up approximately 25 percent of the country and contain about 12 percent of the available ground water reserves. The poor permeability and igneous aquifers (map units 4 and 5) make up approximately 42 percent of the country but contain less than 1 percent of the available ground water reserves.xxxviii

Deforestation has a negative impact on the ground water resources of the country. Deforestation reduces the amount of water that recharges the aquifers, resulting in lower ground water levels. In many areas, this drop is causing wells to 'dry up' or the water level to be too low to economically produce water. Most hand pumps cannot produce water from depths greater than 300 feet.

Although ground water is generally safer than untreated surface water supplies, many shallow aquifers are becoming biologically contaminated, primarily due to improper waste disposal.

1. Aquifer Definition and Characteristics

To understand how ground water hydrogeology works and where the most likely sources of water may be located, a short aquifer definition 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 the borehole, at any one location. It exists in many types of geologic environments, such as intergrain pores in unconsolidated sand and gravel, cooling fractures in basalts, solution cavities in limestone, and systematic joints and fractures in metamorphic and igneous rock, to name a few. Unfortunately, rock masses are rarely homogeneous, and adjacent rock types may vary significantly in their ability to hold water. In certain rock masses, such as some types of consolidated sediments and volcanic rock, water cannot flow, for the most part, through the mass; the only water flow sufficient to produce usable quantities of water may be through 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. On the other hand, 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 consisting 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. Haiti Hydrogeology

Variations in the geological structures, geomorphology, rock types, and precipitation contribute to the varying ground water conditions in different parts of the country. The primary aquifer systems are alluvial aquifers (map units 1 and 6); reef and karstic or highly fractured limestones (map unit 2); and fractured sedimentary rocks (map unit 3). Other aquifers are within low permeability deposits (map unit 4) and igneous rocks (map unit 5). These aquifer systems are described in table C-2 and depicted on figure C-2. Descriptions are based upon the interpretation of the most recent hydrogeological information available.

In the plains and river valleys, depth to water is generally less than 150 meters. In the mountains, depth to water may be greater than 200 meters. In many areas, the depth to water may be too great for economical use.xxxix Seasonal fluctuation of the water table can be more than 15 meters. In most parts of the country, deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation. Aquifers in the mountains are generally locally recharged by rainfall, while those in the lowlands are primarily recharged from the mountains.

Access to well sites 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. Only in the plains and major river valleys is access generally unhindered. The easiest access is in the Plaine du Cul-de-Sac.

a. Alluvial Aquifers (map units 1 and 6)

Fresh water is generally plentiful from productive aquifers in alluvium in the northern coastal plain, and most river valleys and other coastal plains (map unit 1). Near the city of Jacmel, and in parts of the Plaine du Cul-de-Sac, these aquifers include extremely porous and permeable reef deposits. Ground water in the alluvial deposits is typically found in 1- to 8-meter-thick layers of sand and gravel that are separated by layers of silt and clay. The alluvial deposits are widely tapped for domestic supply and locally by irrigation wells.xl

Brackish or saline water, due to saltwater intrusion, is generally plentiful from alluvial aquifers near the coast and in the Plaine du Cul-de-Sac (map unit 6). The exception is near Étang Saumâtre, which has no outlet. Here the ground water is brackish to saline because of the highly mineralized soil.

b. Reef and Limestone Aquifers (map unit 2)

Fresh water is locally plentiful from reef deposits and karstic or highly fractured limestones. The reef deposits are primarily found in the Plateau de Bombardopolis on the islands of Gonâve and Tortue and locally along the coast. The natural porosity and permeability of the reef deposits has been increased by fractures and solution cavities. The limestone aquifers receive large amounts of recharge and store and transmit water through extensive systems of fractures and solution cavities. Springs of varying yields are very common. 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.

c. Other Aquifers (map units 3, 4, and 5)

Fresh water is locally plentiful from fractured limestones, sandstones, conglomerates, and schist aquifers that are generally interbedded with shales, siltstones, marls, and chalks.[xli] Typically, these rocks have not been strongly deformed by folding and faulting, which results in an uneven distribution of fractures (map unit 3).[xlii]

Fresh water is scarce or lacking in areas containing low-permeability shales, consolidated conglomerates, sandstones, marls, chalks, and other rock types. Water yields are generally less than 5 liters per second. Locally, wells drilled into fracture zones may have higher yields (map unit 4).

Fresh water is scarce or lacking in areas containing igneous and metamorphic rocks. Aquifers are found in basalt, diabase, lavas, andesites, quartz diorites, quartzite, and other igneous rocks. These rocks may be interbedded with shales, limestones, tuffs, and weathered igneous rock (map unit 5).[xliii] Water yields are generally less than 5 liters per second. Locally, wells drilled into fractured zones may have higher yields.

C. Water Quality

The lack of access to a safe water supply (see chapter III) contributes to poor health and hygiene. Infectious and parasitic diseases, often spread through unsafe water, are the leading causes of morbidity and mortality. Of the three agencies responsible for water supply (CAMEP, SNEP, and POCHEP), only CAMEP has a laboratory and routinely monitors water quality. In the arid northwest, the lack of safe water causes people to consume brackish water, which has dire health effects. Overall, a great need for wastewater treatment exists, particularly in the area of Port-au-Prince. The first priority, however, must be the development of dependable water supply sources.

1. Surface Water

Surface water contamination from domestic and industrial sources occurs throughout the country, especially near heavily populated areas. Specific information on water quality is not available, but many sources indicate that surface water contamination has increased significantly in recent years. Domestic wastewater and agricultural runoff cause biological contamination of the surface water near and downriver of populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites.

2. Ground Water

Biological contamination of the shallow aquifers by human and animal wastes is a major problem. Chemical contamination is becoming a greater problem, especially near major towns. Deforestation and overuse are also lowering overall water quality. Near the coast and in many areas of the Plaine du Cul-de-Sac, overuse is causing increased saltwater intrusion, further lowering water quality.

3. Domestic Waste Disposal

There is no public system for the collection or treatment of domestic and industrial wastewater, and all existing sanitation systems are privately owned. Residential areas and larger cities with running water dispose of wastewater either into septic tanks or infiltration ditches. Some households divert their wastewater into rainwater channels without treatment. About 43 percent of the population is covered by systems for domestic wastes, including latrines and flush toilets. In rural areas, only 16 percent of the population has this service.

The collection and disposal of domestic solid waste poses a serious problem, particularly in Port-au-Prince and other large cities without adequate landfills.[xliv] The situation within the rural areas is similar although on a smaller scale. The lack of domestic waste disposal has resulted in bacteriological pollution of several of the 18 springs supplying Port-au-Prince.[xlv] The Metropolitan Solid Waste Collection Service is responsible for the collection of solid wastes in Port-au-Prince, but only 30 percent of the daily volume of solid wastes produced is collected. The overall waste collection in other cities is about 42 percent, while it is only 16 percent within rural areas.[xlvi] Service is more reliable in smaller cities where collection is ensured by local governments and local offices of the MTPTC and the MSPP.

Several initiatives are underway to improve the disposal of domestic waste within rural areas. Sponsored by UNICEF and other NGO's, a program to construct latrines in rural areas began in 1980. In 1995 it was estimated that about 155,000 single-family and community-type latrines served about 24 percent of the rural population.

V. Water Resources Departmental Summary

A. Introduction

This chapter summarizes the water resources information of Haiti, 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 6. 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 6. 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 nine departments.

B. Water Conditions by Map Unit

Figure C-1, Surface Water Resources, divides the country into six 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 very large quantities. Map units 4 and 5 depict areas, where fresh surface water is seasonally available in meager to very large quantities during high flows. Map unit 6 depicts areas, where fresh surface water is scarce or lacking and moderate to enormous quantities of brackish to saline water are perennially available. Figure C-1 also divides the country into 30 hydrographic basins and zones labeled I through XXX. Several river basin boundaries cross both departmental and international borders. The locations of selected river gaging stations are also depicted in figure C-1.

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

Surface water and ground water quantity and quality are described for each department 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 ≥1,000 milligrams per liter (mg/L); maximum chlorides ≥600 mg/L; maximum sulfates (SO_4) ≥300 mg/L
Brackish water = maximum TDS >1,000 mg/L, but ≥15,000 mg/L
Saline water = TDS >15,000 mg/L

C. Water Conditions by Department

The following information was compiled for each department from figures C-1 and C-2 and tables C-1 and C-2. The write-up for each department 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 department 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 department or region. Specific well information was 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.

Département de l'Artibonite

Area:	4,530 square kilometers (16.4 percent of the country)
Estimated Population (1995):	1,013,779 (14 percent of the population)
Population Density:	224 people per square kilometer
Departmental Capital:	Gonaïves
Location:	In north-central Haiti, with the Golfe de la Gonâve forming the western boundary.

Surface Water:

The largest and longest river in Haiti, the Rivière de l'Artibonite, lies in this department in map unit 1 and discharges into the Golfe de la Gonâve. Fresh water is perennially available in moderate to very large quantities from map unit 1, from the Rivière de l'Artibonite. Fresh water is perennially available in small to very large quantities from the Rivière de l'Estère, a major river, as depicted by map unit 2. Rivière La Quinte, Rivière de Saint Marc, and part of Les Trois Rivières lie in map unit 3 in the northern part of the department, where fresh water is perennially available in very small to very large quantities.

Most of the department lies within map unit 5, where fresh water is seasonally available in meager to very large quantities from May through October from intermittent streams, such as Rivière Anse Rouge and Rivière Colombier. The department capital of Gonaïves lies in this map unit near the mouth of the Rivière de l'Estère along the coast. Brackish to saline water is found in map unit 6, north of Rivière de l'Estère along the coast.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the stream valleys and the Plaine du Gonaïves, as depicted by map unit 1. Fresh ground water is generally available in small to enormous quantities in this map unit, which covers about one-fourth of the department. Depth to water is about 20 to 40 meters in the Rivière de l'Artibonite valley. These alluvial aquifers are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells.

About one-third of the department lies in map units 2 and 3 in scattered locations, where fresh ground water is locally plentiful from limestones, sandstones, conglomerates, and schists. Some areas may be suitable for hand pump wells, but successful wells in these areas may depend upon encountering water-bearing fractures.

The remainder of the department lies in areas where ground water exploration is not recommended during military exercises without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. The department capital of Gonaïves is located in map unit 6, where brackish to saline water exists in alluvial aquifers near the coast.

Département du Centre

Area: 3,700 square kilometers (13.4 percent of the country)

Estimated Population (1995): 490,790 (7 percent of the population)

Population Density: 133 people per square kilometer

The least densely populated department

Departmental Capital: Hinche

Location: In the east-central part of the country, with the border with the Dominican Republic forming the eastern boundary.

Surface Water:

Fresh surface water is perennially plentiful along the middle reach of Rivière de l'Artibonite, its major tributaries, and Lac de Péligre, as depicted by map unit 1. Lac de Péligre, which stores 395 million cubic meters and lies in the southern part of the department, was formed by a dam on Rivière de l'Artibonite at the convergence of Massif des Montagnes Noires and Chaîne des Matheux. The lake, which has lost 30 percent of its capacity due to sedimentation caused by deforestation, covers 30 square kilometers, and is used for flood control, irrigation, and hydroelectric power generation. The shoreline of the lake is rocky, steep, and irregular, so access may be difficult.

The Rivière Bouyaha and parts of the upper reach of Rivière de l'Artibonite lie in map unit 2, where fresh water is perennially available. Map unit 3 occupies the department along part of Rivière Canot, Rivière Guayamouc, Rivière Lociane, and Rivière de Fer a Cheval, where fresh water is perennially available in very small to very large quantities. The department capital of Hinche lies in map unit 3 near Rivière Guayamouc. The remainder of the department lies in map unit 5, where fresh surface water is seasonally available in meager to very large quantities from intermittent streams, with many streams being dry for part of the year.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Rivière de l'Artibonite valley and along its tributaries, as depicted by map unit 1. Map unit 1 occupies less than one-fourth of the department in the south, where fresh water is generally plentiful in small to enormous quantities at depths generally less than 50 meters. These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells.

About one-third of the department lies in map units 2 and 3, where fresh water is locally plentiful from limestones, sandstones, conglomerates, and schists. Karstic and highly fractured limestones can be found in map unit 2 areas in this department. Some areas may be suitable for hand pump wells, but successful wells in these areas may depend upon encountering water-bearing fractures.

More than half of the department lies in map units 4 and 5, where fresh ground water is scarce or lacking. Ground water exploration during military exercises is not recommended in these map units without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. The department capital Hinche lies in map unit 4.

Département de la Grand'Anse

Area:	3,335 square kilometers (12 percent of the country)
Estimated Population (1995):	641,399 (9 percent of the population)
Population Density:	192 people per square kilometer
Departmental Capital:	Jérémie
Location:	In the northwestern part of the southern peninsula, with the Golfe de la Gonâve forming the northern boundary.

Surface Water:

Fresh surface water is perennially available in very small to very large quantities along Rivière Grand'Anse, Rivière des Roseaux, and Rivière de la Voldrogue, as depicted by map unit 3. Rivière Grand'Anse has the second highest discharge in the country and reaches the coast of Golfe de la Gonâve near Jérémie. Most of the department lies in map units 4 and 5, where fresh surface water is seasonally available from streams and lakes, such as Rivière de Dame Marie, Rivière des Baradères, Grande Rivière de Nippes, and Rivière Brossard. Many streams are dry for part of the year. Rivière des Baradères disappears into a limestone depression. The department capital Jérémie is located near the mouth of Rivière Grand'Anse and lies in map unit 5.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the major stream valleys, such as Rivière de Dame Marie and the lower reach of Rivière Grand'Anse. These areas lie in map unit 1, which cover less than one-fourth of the department, where fresh ground water is generally plentiful in small to enormous quantities. These alluvial deposits are suitable for hand pump and tactical wells.

About half of the department lies in map units 2 and 3, where ground water is locally plentiful from limestones, sandstones, and conglomerates. Reef deposits of weathered and fractured limestone aquifers can be found in map unit 2 areas in this department. The department capital of Jérémie lies in map unit 3. Some areas may be suitable for hand pump wells, but successful wells in these areas may depend upon encountering water-bearing fractures.

Ground water exploration during military exercises is not recommended in the remainder of the department without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas.

Département du Nord

Area:	2,045 square kilometers (7.4 percent of the country)
Estimated Population (1995):	759,318 (11 percent of the population)
Population Density:	371 people per square kilometer
Departmental Capital:	Cap-Haïtien
Location:	In the north-central part of the country with the Atlantic Ocean forming the northern boundary.

Surface Water:

Fresh surface water is perennially available along Rivière Bouyaha and Rivière du Limbé. Rivière Bouyaha lies in map unit 2, where small to large quantities of fresh water are available. Rivière du Limbé lies in map unit 3, where very small to very large quantities of fresh water are available. Rivière du Limbé is well incised in deep narrow valleys separated by steep hills. The lowest part of the river basin is poorly drained and swampy.

Most of the department lies in map units 4 and 5, where fresh surface water is seasonally available from rivers such as Rivière Galois (Haut de Cap) and Grande Rivière du Nord. Many streams are dry for part of the year. The department capital Cap-Haïtien is located near the mouth of Rivière Galois and is in map unit 5. Along the department's northeast coast is a small area of map unit 6, where brackish to saline water is found.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Plaine du Nord and the stream valleys, which occupy less than one-fourth of the department mainly in the northern parts. These areas lie in map unit 1, where fresh ground water is generally plentiful in small to enormous quantities. These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells. Depth to water is usually 5 to 25 meters.

Less than one-fourth of the department lies in map units 2 and 3, where ground water is locally plentiful from limestones, sandstones, conglomerates, and schists. These areas are generally in the northern and southeastern parts of the department. Some areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

The remainder of the department lies in areas where ground water exploration is not recommended during military exercises without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. The department capital Cap-Haïtien is in this area, map unit 6, where brackish to saline ground water exists in alluvial aquifers of the Plaine du Nord.

Département du Nord-Est

Area:	1,750 square kilometers (6.4 percent of the country)
	The smallest department in Haiti
Estimated Population (1995):	248,764 (3 percent of the population)
	The least populated department in Haiti
Population Density:	142 people per square kilometer
Departmental Capital:	Fort-Liberté
Location:	In northeast Haiti, with the Atlantic Ocean forming the northern boundary and the Dominican Republic forming the eastern boundary.

Surface Water:

Fresh water is seasonally available throughout most of the department. Most of the department lies in map unit 5, where meager to very large quantities are available from intermittent streams such as the upper reach of the Grande Rivière du Nord. Meager to large quantities are available from streams such as Rivière Marion and Rivière du Massacre as depicted by map unit 4. The department capital Fort-Liberté is located at the mouth of Rivière Marion and is in map unit 4. Part of the northwest coastline lies within map unit 6, where brackish to saline water is perennially available.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Plaine du Nord, which is in the northern part of the department. This area lies in map unit 1 and occupies about one-third of the department, where fresh water is generally plentiful in small to enormous quantities. These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells. Depth to water is usually 5 to 25 meters. The department capital Fort-Liberté is located in map unit 1. Near the city are areas of map unit 6, where saltwater intrusion is a problem.

Ground water exploration during military exercises is not recommended in the remainder of the department without site-specific reconnaissance because fresh water is scarce or lacking. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. The entire coastal area lies within map unit 6, where brackish to saline ground water exists in alluvial aquifers.

Département du Nord-Ouest

Area:	2,525 square kilometers (9.1 percent of the country)
Estimated Population (1995):	420,971 (6 percent of the population)
Population Density:	167 people per square kilometer
Departmental Capital:	Port-de-Paix
Location:	On the western end of the northern peninsula. The Atlantic Ocean forms the northern and western boundary, while the Golfe de la Gonâve forms the southern boundary. Includes the Île de la Tortue.

Surface Water:

Fresh surface water is perennially available in the small part of the department that lies along Les Trois Rivières, as depicted by map unit 2 in the lower reach and map unit 3 in the middle reach. Access to the river may be difficult due to rugged terrain and deeply incised stream valleys. The department capital Port-de-Paix is located at the mouth of Les Trois Rivières and is in map unit 2. Les Trois Rivières is the second longest river in the country, discharging into the Atlantic at Port-de-Paix.

Nearly the entire department lies in map unit 5, where fresh surface water is seasonally available, in meager to very large quantities, from May to October, with most streams being dry for part of the year.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the stream valleys, such as Les Trois Rivières and Rivière des Barres, as depicted by map unit 1. Map unit 1 covers less than one-fourth of the department, where ground water is plentiful in small to enormous quantities. These alluvial deposits are suitable for hand pump and tactical wells. The department capital of Port-de-Paix is near the mouth of Les Trois Rivières and is partially located in map unit 1.

About half of the department lies in map unit 2 and 3, where ground water is locally plentiful from limestones, sandstones, conglomerates, and schists. These areas are scattered throughout the department and on the Île de la Tortue. Reef deposits of weathered and fractured limestone aquifers can be found in map unit 2 areas in this department. Some areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures. The department capital of Port-de-Paix is located partially in map unit 3.

The remainder of the department lies in map unit 4, where ground water exploration is not recommended during military exercises without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. Many of the mountainous locations within this area are experiencing water shortages due to aquifer drawdown.

Département de l'Ouest

Area:	4,650 square kilometers (16.8 percent of the country)
	The largest department in Haiti
Estimated Population (1995):	2,494,862 (35 percent of the population)
	The most populated department in Haiti
Population Density:	537 people per square kilometer
	The most densely populated department in Haiti
Departmental Capital:	Port-au-Prince
Location:	In south-central Haiti, with the Golfe de la Gonâve forming the western boundary and the Dominican Republic and the Étang Saumâtre forming the eastern boundary. Includes the national capital of Port-au-Prince and the Île de la Gonâve.

Surface Water:

Fresh surface water is perennially available from streams and lakes, as depicted by map unit 3. The major streams that include the Rivière Blanche and the Rivière Grise (Grande Rivière du Cul-de-Sac) along with their associated plains are in map unit 3. These two rivers begin on the northern slopes of the Massif de la Selle, but disappear in the Plaine du Cul-de-Sac during low flow, reaching the sea during floods.

Much of the department lies in map unit 5, where fresh surface water is seasonally available in meager to large quantities from May to October from intermittent streams, such as Rivière Grand Goâve and the upper reaches of Rivière Grise, Rivière Blanche, and Rivière Momance.

Port-au-Prince, the department and national capital, lies in the Plaine du Cul-de-Sac, south of the mouth of Rivière Grise (Grande Rivière du Cul-de-Sac). Most of the city lies in map unit 5, but the coastal areas near Port-au-Prince lie in map unit 6, where brackish to saline water exists. The municipal water system for Port-au-Prince does not use surface water for any of its water needs. However, for many of the inhabitants, the only source of water is surface water from the Rivière Grise, the Rivière Blanche, smaller streams, irrigation ditches, and the city's storm water drains. The surface water near the city is severely polluted by human sewage, solid wastes, and industrial chemical contamination.

Along the coast and surrounding the lakes Étang Saumâtre, Trou Caïman, and Étang de Miragoâne are areas that lie in map unit 6, where fresh surface water is scarce or lacking. In these areas, brackish to saline surface water is perennially available. Étang Saumâtre, located at the eastern end of the Plaine du Cul-de-Sac, covers an area of about 181 square kilometers. It is the largest natural lake in the country but has no outlet, allowing for the buildup of salts. TDS values range between 7,500 and 10,650 milligrams per liter. The water level of the lake fluctuates between 12 and 20 meters above sea level. The lake is the habitat of many exotic species of tropical wildlife.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Plaine du Cul-de-Sac, stream valleys, and coastal plains, covering about one-fourth of the department. These areas lie in map unit 1, where fresh ground water is generally plentiful in small to enormous quantities. These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells. Depth to water is usually 30 to 50 meters. In part of the Plaine du Cul-de-Sac, the aquifers include very porous and permeable reef and carbonate deposits, usually between 25 and 50 meters thick. The best access to potential well sites in the country is in the Plaine du Cul-de-Sac in this department. Two well fields in map unit 1, east of the international airport, provide water to the municipal water system of Port-au-Prince.

Over half of the department lies in map units 2 and 3, where ground water is locally plentiful from limestones, sandstones, and conglomerates. Reef deposits of weathered and fractured limestone aquifers can be found in map unit 2 areas in this department, including most of the Île de la Gonâve. Some areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

Ground water exploration during military exercises is not recommended in the remainder of the department without site-specific reconnaissance because fresh water is scarce or lacking. Specialized civilian technical expertise in water well drilling may have marginal success in these areas. Along the coast near Port-au-Prince, in the northern part of the Plaine du Cul-de-Sac, and near the Étang Saumâtre are areas of map unit 6, where brackish to saline water exists in alluvial aquifers. In the area of Étang Saumâtre, the ground water is brackish to saline because of the highly mineralized soil.

Port-au-Prince, the department and national capital, lies on alluvial aquifers of the Plaine du Cul-de-Sac, but falls within map unit 6 because the aquifers have been contaminated by saltwater intrusion. North and east of the center of the city is map unit 1, where fresh ground water is generally plentiful in small to enormous quantities from Quaternary alluvial aquifers at depths generally less than 50 meters. South of the city is map unit 3, where unsuitable to enormous quantities are available from karstic or fractured limestones at depths generally less than 200 meters.

The Port-au-Prince municipal water system supplies water to about one-third of the population. The main sources of water for the municipal water system are 18 springs in the hills south of the city in map unit 3 and 2 well fields east of the international airport that are in map unit 1. These sources provide approximately 36 million cubic meters of water per year. These sources are facing several major problems that are decreasing the quality and quantity of the water entering the municipal water system. All of the springs are reported to be contaminated by biological contamination from human and solid wastes with a couple of the springs being too polluted to be used. Human sewage, agricultural runoff, and industrial wastes are also threatening the wells. Water yields from the springs are also decreasing. Deforestation, urbanization, and drought are greatly diminishing the amount of water infiltrating into the ground to recharge the aquifers, reducing the amount of water produced by the springs.

Département du Sud

Area:	2,950 square kilometers (10.5 percent of the country)
Estimated Population (1995):	653,398 (9 percent of the population)
Population Density:	221 people per square kilometer
Departmental Capital:	Les Cayes
Location:	In the southwestern part of the southern peninsula, with the Caribbean Sea forming the southern boundary. Includes the Île à Vache and several other small islands.

Surface Water:

Fresh surface water is perennially available only in the part of the department along the Plaine des Cayes, as depicted by map unit 3. Fresh water is available in very small to very large quantities from rivers such as Rivière de Cavaillon, Rivière de l'Islet, Ravine du Sud, Rivière De Torbeck, and Rivière de l'Acul. Rivière de l'Islet and Rivière de Torbeck may disappear and reappear again before reaching the coast. The department capital Les Cayes is located at the mouth of the Ravine du Sud in map unit 3.

Most of the department lies in map units 4 and 5, where fresh surface water is seasonally available from streams such as the Rivière Brodequin, Rivière Mombin, and Rivière de Tiburon. Many streams are dry for part of the year. Many streams in the eastern part of the department are deeply incised and have torrential flows. Along the coast and on the Île à Vache are areas of map unit 6, where brackish to saline water is available year-round.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Plaine des Cayes and the major stream valleys, such as Rivière de Cavaillon, Ravine du Sud, Rivière de Torbeck, the lower and middle reaches of Rivière de l'Acul, and the lower reach of Rivière Brodequin, as depicted by map unit 1. In these areas, which cover about one-fourth of the department, fresh ground water is generally available in small to enormous quantities. Depth to water can be as deep as 150 meters. These alluvial deposits are tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells. The department capital of Les Cayes lies in map unit 1. Near the city, saltwater intrusion is a problem.

More than half of the department lies in map units 2 and 3, where ground water is locally plentiful from limestones, sandstones, and conglomerates. Reef deposits of weathered and fractured limestone aquifers can be found in map unit 2, located mainly in the east. Some areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

Ground water exploration during military exercises is not recommended in the remainder of the department without site-specific reconnaissance because fresh water is scarce or lacking. These areas are depicted by map units 5 and 6, which are in scattered locations throughout the department. Specialized civilian technical expertise in water well drilling may have marginal success in these areas.

Département du Sud-Est

Area: 2,215 square kilometers (8 percent of the country)

Estimated Population (1995): 457,013 (6 percent of the population)

Population Density: 206 people per square kilometer

Departmental Capital: Jacmel

Location: In the southeastern part of the southern peninsula, with the Caribbean Sea forming the southern boundary and the Dominican Republic forming the eastern boundary.

Surface Water:

Fresh surface water is perennially available along Grande Rivière de Jacmel and its tributary near Jacmel and along part of Rivière Gauche. These areas lie in map unit 3, where very small to very large quantities are available. The department capital Jacmel is located at the mouth of Grande Rivière de Jacmel and is in map unit 3.

The remainder of the department lies in map units 4 and 5, where fresh surface water is seasonally available from lakes and streams such as Rivière de Bainet, Rivière Marigot, and Rivière Pédernales. Rivière Pédernales forms part of the southernmost boundary with the Dominican Republic. Many streams are dry for part of the year.

Ground Water:

The best area for ground water exploration is the alluvial aquifers in the lower Grande Rivière de Jacmel valley. This area consists of map unit 1, occupying less than one-fourth of the department, where fresh ground water is generally plentiful in small to enormous quantities. These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells and are suitable for hand pump and tactical wells. The department capital of Jacmel is located in map unit 1. Near Jacmel, the aquifers include very porous and permeable reef and carbonate deposits, generally between 25 and 50 meters thick.

Most of the department lies in map units 2 and 3 in areas scattered throughout the department, where ground water is locally plentiful from limestones, sandstones, and conglomerates. Reef deposits of weathered and fractured limestones can be found in map unit 2. Some areas may be suitable for hand pump wells, but successful wells may depend upon encountering water-bearing fractures.

In small parts of the department, scattered throughout, fresh ground water is scarce or lacking as depicted by map unit 5. Ground water exploration during military exercises is not recommended in these areas without site-specific reconnaissance. Specialized civilian technical expertise in water well drilling may have marginal success in these areas.

VI. Recommendations

A. General

Haitian Government agencies and several NGO's are attempting to solve the country's water resources problems. The Corps assessment team was provided several comprehensive documents, each containing excellent recommendations for improving the situation with Haiti's water resources. The following needs are identified by the Corps assessment team and by Haitian Government officials.

B. Watershed Protection and Management

A common concern of most Government officials and technical experts is the impact of deforestation on the country's environment and on its water resources. Development of comprehensive watershed and basin management plans is needed to curb these impacts. The intent of a watershed management plan is to achieve a comprehensive view of water and land resource problems within a watershed and to identify opportunities and authorities to address such problems. Watershed planning is a systematic approach to (1) evaluating alternative uses of water and land resources, (2) identifying conflicts and trade-offs among competing uses, and (3) making contemplated changes through informed decisions.

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

C. Troop Exercise Opportunities

1. Well Exercises

Haiti depends heavily on ground water for its water supply. Overall, the quality of ground water is good throughout the country. Small hand pump wells are in great 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 great benefit. These wells could be a source of safe water replacing contaminated surface water supplies in certain areas of the country. An organization like POCHEP 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 should be considered. Mountain ranges cover about 75 percent of the land surface. In these 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 aquifer drawdown is associated with the impacts of deforestation and where ground water exploration may be too difficult for troop exercises. 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. 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

Much of the population lacks access to water supply and sanitation services, which directly impacts the quality of life. Wastewater treatment is also lacking throughout the country, with much effluent discharged into the nation’s waterways without treatment. Wastewater treatment is needed to improve the quality of the surface water resources of the country, as much of the population uses surface water for their water supply needs. The water supply sector is presently undergoing transformation, and it is recommended that work continue in this effort, to improve potable water access for the population.

VII. Summary

Water resources in Haiti are a major concern. The lack of adequate safe (potable) water supplies for basic human needs is a significant problem throughout Haiti, although surface and ground water resources are abundant. This situation leads to increased competition for limited resources. Several of the main reasons for this situation are:

- uneven rainfall distribution;
- degradation of the watersheds caused by deforestation;
- rapid growth in urban areas increasing demand beyond system capacity;
- poor distribution networks;
- poor water resources management;
- no single agency responsible for management of water resources;
- lack of adequate data needed to make informed decisions;
- poor irrigation supply network leading to underdevelopment of sector; and
- lack of wastewater collection and treatment and proper solid waste disposal.

The water supply sector is undergoing complete transformation, and consequently many of these issues will be addressed. URSEP is a special agency created to correct organizational problems of the water sector. When URSEP recommendations become law, two new organizations, UMEPA and CREPA, will be formed. UMEPA is the National Office for Drinking Water and Sanitation, and CREPA is the Regulatory Committee for Water Supply and Sanitation.

Critical issues are the lack of access to water and sanitation, high population density and high mortality rate, the extensive environmental damage caused by deforestation, and the lack of hydrologic data. The solution to these issues presents significant challenges to the managers of Haiti's water resources. Throughout our meetings with the managers, the recognition of the task before them and willingness to address the issues were evident.

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

Endnotes

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

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

[iii]M. Mendez, *Planning for Water and Sanitation Programs in the Caribbean–1991 Update,* Water and Sanitation for Health Project Field Report No. 335, Environmental Health Project, Washington, DC: U.S. Agency for International Development, February 1992, p. 69.

[iv]Pan American Health Organization/World Health Organization (PAHO/WHO), *Health Situation Analysis–Haiti 1996*, PAHO/WHO/AM/HAI/HST/96.01, Port-au-Prince: Ministry of Public Health and Population, June 1996, pp.14-16.

[v]PAHO/WHO, pp. 11-18.

[vi]M. Mendez, pp. 69-74.

[vii]C. Maternowska, *People & the Planet,* "Real Lives–Haiti," Vol. 3, No. 4, Planet 21, London, 1994, p. 2.

[viii]D. Kinely, *Waterlines,* "Haiti Adopts Low-Cost Solutions to Its Water Problems," Vol. 4, No. 3, London: Intermediate Technology Publications, Ltd., January 1986, p. 21.

[ix]PAHO/WHO, p. 10.

[x]Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé (OPS/OMS), Comité National Interministeriel, *Analyse du Secteur Eau Potable et Assainissement*, Agenda 21, May 1996, pp. 19 and 20.

[xi]Michele Turk, DisasterRelief.org, "Immortal Hurricane Georges Lives On in the Agony of the Victims," 9 October 1998, Internet: http://162.6.3.135:1020/Disasters/981008georges23, Accessed January 1999, pp. 2 and 3.

[xii]PAHO/WHO, p. 4.

[xiii]OPS/OMS, May 1996, p. 83.

[xiv]OPS/OMS, May 1996, pp.147-150.

[xv]OPS/OMS, May 1996, p. 147.

[xvi]Système de Suivi du Secteur Eau Potable et Assainissement, *Actualisation des Taux de Couverture des Besoins en AEPA au 31 Décembre 1996*, OPS/OMS-UNICEF, December 1997, p. 5.

[xvii]OPS/OMS, May 1996, p. 149.

[xviii]OPS/OMS, May 1996, p. 83.

[xix]M. Ehrlich, et al., *Haiti–Country Environmental Profile-A Field Study,* Contract No. 521-0122-C-00-4090-00, Washington, DC: U.S. Agency for International Development, June 1985, p. 3.

[xx]OPS/OMS, May 1996, pp. 83-85.

[xxi]Department of the Army. *Haiti–A Country Study.* DA PAM 550-164, Edition 5, Washington, DC: American University, Foreign Areas Studies, 1985, pp. 11 and 12.

[xxii]W. Back, *Hydrogeology–The Geology of North America*, "Region 26, West Indies." Vol. O-2*,* Boulder, Colorado: Geological Society of America, 1988, p. 245.

[xxiii]United Nations, Department of Economic and Social Affairs, *Ground Water in the Western Hemisphere*, "Haiti," Natural Resources/Water Series No. 4, New York, 1976, p. 148.

[xxiv]M. Ehrlich, et al., p. 1.

[xxv]M. Ehrlich, et al., p. 20.

[xxvi]M. Ehrlich, et al., pp. 20-24.

[xxvii]United Nations, p. 148.

[xxviii]OPS/OMS, May 1996, p. 68.

[xxix]United Nations, p. 148.

xxxR. Gonfiantini and M. Simonot. *Isotope Techniques in Water Resources Development,* "Isotopic Investigation of Groundwater in the Cul-de-Sac Plain, Haiti." Proceeding of a Symposium, International Atomic Energy Agency, Vienna, 1997, p. 494.

[xxxi]United Nations, p. 148.

[xxxii]Department of the Army, pp. 11 and 12.

[xxxiii]M. Ehrlich, et al., p. 60.

[xxxiv]M. Ehrlich, et al., p. 20.

[xxxv]PAHO/WHO, p. 5.

[xxxvi]M. Ehrlich, et al., p. 26.

[xxxvii]L.A. Lewis and W.J. Coiffey, *AMBIO*, "The Continuing Deforestation of Haiti." Vol. 14, No. 3, Stockholm: Royal Swedish Academy of Sciences, 1985, pp. 159 and 160.

xxxviiiOPS/OMS, May 1996, pp. 21 and 22.

xxxixUnited Nations, pp. 150 and 151.

xlUnited Nations, p. 151.

xliF.J. Maurrasse, *Survey of the Geology of Haiti*, "Guide to the Field Excursions in Haiti of the Miami Geological Society," Miami, Florida: Miami Geological Society, March 1982, pp. 20-55.

xliiUnited Nations, pp. 150 and 151.

xliiiF.J. Maurrasse, March 1982, pp. 20-55.

[xliv]PAHO/WHO, p. 5.

[xlv]PAHO/WHO, p. 6.

[xlvi]PAHO/WHO, p. 137.

Bibliography

Arbuthnot, J. *Review of AID Rural Potable Water Programs, Haiti*. Water and Sanitation for Health Project Field Report No. 2, Arlington, Virginia: U.S. Agency for International Development, 16-29 November 1980.

Back, W. *Hydrogeology–The Geology of North America*, "Region 26, West Indies." Vol. O-2, Boulder, Colorado: Geological Society of America, 1988.

Barthelemy, Y., et al. *Hydrogéologie*, "Étude des Ressources en Eau de la Région de Port-au-Prince-Haiti." No. 4, Orleans, France: Bureau des Recherches Géologiques et Minieres, 1991.

Beauboeuf, P.Y. *Presentations Transactions,* "Potentiels Géothermiques d'Haiti." Port-au-Prince: First Colloque sur la Géologie d'Haiti, 27-29 March 1980.

Boulègue, J., M. Beneddetti, and P. Bildgen. *Applied Geochemistry*, "Geochemistry of Waters, Associated with Current Karst Bauxite Formation, Southern Peninsula of Haiti." Vol. 4, Great Britain: Pergamon Press, 1989.

Bredy, Mary. Untitled document prepared from "Brève Présentation de la SNEP." 1995.

Butterlin, J. *Bulletin de la* Société *Géologique de France,* "Les Formations Eocene, Sedimentaires et Ignees, des Montagnes Noires (République d'Haiti) et leur Importance pour l'Histoire Géologique des Antilles." Series 6, Tome Septième, Paris: Au Seige de la Société, December 1957.

Butterlin, J. *Géologie Generale et Règionale de la République d'Haiti.* Paris: Institut des Hautes Études de l'Amerique Latine, Université de Paris, 1960.

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

Centrale Autonome Metropolitaine d'Eau Potable. Internal report, Port-au-Prince, 1995.

Centre d'Études de Géographique Tropicale et Université de Bordeaux 3. *Atlas d'Haiti.* Talence, France: Ouvrage Publie avec le Concours de Ministère des Relations Exterieures, 1984.

Defense Mapping Agency Hydrographic/Topographic Center. *Joint Operations Graphics*. Maps, Scale 1:250,000, Series 1501, NE 1804, NE 1807, NE 1808, NE 1901, and NE 1905, Washington, DC, 1968 to 1991.

Department of the Army. *Haiti–A Country Study.* DA PAM 550-164, Edition 5, Washington, DC: American University, Foreign Areas Studies, 1985.

Desreumaux, C. *Pangea,* "Haiti–Science de la Terre et Developpement, Mythes et Realités." No. 22, Paris: Centre International pour la Formation et les Échanges Géologiques, December 1994.

Development and Resources Corporation. Power Supply from Peligre Dam and Electric Service for the Port-au-Prince Area, Republic of Haiti. New York, November 1961.

Ehrlich, M., et al. *Haiti–Country Environmental Profile–A Field Study.* Contract No. 521-0122-C-00-4090-00, Washington, DC: U.S. Agency for International Development, June 1985.

Emmanuel, Evens. *Atelier sur la Gestion et la Legislation de l'Eau, Haiti, Rapport Pre-Atelier.* Cooperation technique BID No. ATN/SF-5485-HA, Port-au-Prince: Ministère de l'Environnement, Programme de Formulation de la Politique de l'Eau, March 1998.

Fass, S.M. *Development and Change,* "Water and Politics–the Process of Meeting a Basic Need in Haiti." Vol. 13, London: SAGE, 1982.

Fass, S.M. *Water Resources Research*, “Water and Poverty–Implications for Water Planning.” Vol. 29, No. 7, Washington, DC: American Geophysical Union, July 1993.

Frenette, M., and P.Y. Julien. *Third International Symposium on River Sedimentation*, “Advances in Predicting Reservoir Sedimentation.” The University of Mississippi, 31 March-4 April 1986.

Frenette, M., J.P. Tournier, and T.J. Nzakimuena. *Canada Journal Civil Engineering*, “Cas Historique de Sédimentation du Barrage Péligre, Haiti.” Vol. 9, No. 2, Quebec, Canada: National Research Council of Canada, 1982.

Gonfiantini, R., and M. Simonot. *Isotope Techniques in Water Resources Development,* “Isotopic Investigation of Groundwater in the Cul-de-Sac Plain, Haiti.” Proceeding of a Symposium, International Atomic Energy Agency, Vienna, 1997.

Hall, P. *International Association of Hydrogeologists Memoirs*, “Ground Water Exploration in the Cul-de-Sac Plain, Republic of Haiti.” Vol. 12, Paris: International Association of Hydrogeologists, 1975.

Kinely, D. *Waterlines,* “Haiti Adopts Low-Cost Solutions to Its Water Problems.” Vol. 4, No. 3, London: Intermediate Technology Publications, Ltd., January 1986.

Krason, Jan, Marek S. Ciesnik, and Antoni Wodzicki. *Renforcement du Bureau des Mines et de l’Énergie, République d’Haiti.* Denver, Colorado: Geoexplorers International, Inc., September 1998.

Lalonde, Girouard, Letendre, and Associes, Ltd. *Project d’Inventaires des Ressources Hydrauliques, Hydrogéologie Préliminaire de la Plaine de Cul-de-Sac.* Vol. 110, Contract 444/00407, Montreal, Canada: Agence Canadienne de Developpement International, June 1977.

Lemoine, R.C. *Ground Water Conditions in Gonave Island*. Port-au-Prince: United States Geological Survey, April 1949.

Lewis, J.F., et al. *The Geology of North America*, *the Caribbean Region,* “Hispaniola.” Vol. H, Boulder, Colorado: Geological Society of America, 1990.

Lewis, L.A., and W.J. Coiffey. *AMBIO*, “The Continuing Deforestation of Haiti.” Vol. 14, No. 3, Stockholm: Royal Swedish Academy of Sciences, 1985.

Library of Congress, Science and Technology Division. *Draft Environmental Report on Haiti*. Contract No. SA/TOA 1-77, Washington, DC: U.S. Agency for International Development, January 1979.

Maternowska, C. *People & the Planet,* “Real Lives–Haiti.” Vol. 3, No. 4, Planet 21, London, 1994.

Maurrasse, F.J., and C. Jean-Poix. *Transactions,* “Hydrologeology of the Water-Supply Springs of Metropolitan Port-au-Prince, Haiti.” American Geophysical Union Spring Meeting, Baltimore, Maryland, 27-30 May 1997.

Maurrasse, F.J., F. Pierre-Louis, and J.G. Rigaud. *Transactions,* “Cenozoic Facies Distribution in the Southern Peninsula of Haiti and the Barahona Peninsula, Dominican Republic.” Vol. 1, 9th Caribbean Geological Conference, Santo Domingo, Dominican Republic, 1980.

Maurrasse, F.J. *Survey of the Geology of Haiti*, "Guide to the Field Excursions in Haiti of the Miami Geological Society." Miami, Florida: Miami Geological Society, March 1982.

Mendez, M. *Planning for Water and Sanitation Programs in the Caribbean–1991 Update.* Water and Sanitation for Health Project Field Report No. 335, Environmental Health Project, Washington, DC: U.S. Agency for International Development, February 1992.

Murray, K. *Environmental Assessment of Solid Waste Emergency Program for Port-au-Prince, Haiti*. Water and Sanitation for Health Project Reprint, Field Report No. 423, Environmental Health Project, Washington, DC: U.S. Agency for International Development, August 1991.

Organisation Panaméricaine de la Santé/Organisation Mondiale de la Santé, Comité National Interministeriel. *Analyse du Secteur Eau Potable et Assainissement*. Agenda 21, May 1996.

Organization of American States (OAS). *Données Hydrologiques et Utilisation des Eaux, République d'Haiti.* Map, Scale 1:250,000. Washington, DC: Office of Regional Development, 1972.

OAS. *Géologie, République d'Haiti.* Maps, Scale 1:250,000, 1972.

OAS. Haiti, Mission d'Assistance Technique Intègrèe. 1972.

Pan American Health Organization/World Health Organization. *Health Situation Analysis–Haiti 1996*. PAHO/WHO/AM/HAI/HST/96.01, Port-au-Prince: Ministry of Public Health and Population, June 1996.

Paskett, C.J., and C.E. Philoctete. *Journal of Soil and Water Conservation,* "Soil Conservation in Haiti." Ankemy, Iowa: Soil Conservation Society of America, July-August 1990.

Radstake, F., and Y. Chery. *Journal des Sciences Hydrologiques*, "Prospection Géophysique pour la Recherche de l'Eau Souterraine en Haiti." Vol. 37, No 1, Port-au-Prince: United Nations Department of Technical Cooperation for Development, February 1992.

Radstake, F. *Applied Hydrogeology*, "Electromagnetic Resistivity Profiling for Locating Buried River Channels–A Case Study in Haiti." Vol. 1, No. 2, Hannover, Germany: Verlag Heinz Heise, 1992.

Regional Surveys of the World, "South America, Central America, and the Caribbean 1993." Edition 4, London: Europa Publications Limited, 1993.

Service National d'Eau Potable. *Brève Presentation de la Situation de SNEP.* Internal report, Port-au-Prince, 1995.

Système de Suivi du Secteur Eau Potable et Assainissement, *Actualisation des Taux de Couverture des Besoins en AEPA au 31 Décembre 1996*. OPS/OMS-UNICEF, December 1997.

Taylor, G.C. *A Ground Water Reconnaissance of the Jacmel-Meyer Bench, Haiti.* Port-au-Prince: United States Geological Survey, January 1949.

Taylor, G.C. A Summary of the Results Achieved on a Program of Ground Water Studies in Haiti, From September 1948 Through 1949. Washington, DC, 1949.

Taylor, G.C., and R.C. Lemoine. A *Ground Water Reconnaissance in the Pine Forest Region, Haiti*. Port-au-Prince: United States Geological Survey, 1949.

Taylor, G.C., and R.C. Lemoine. Ground Water Conditions in the Plaine des Moustiques, Haiti. 1949.

Taylor, G.C., and R.C. Lemoine. Ground Water in the Archaie Plain, Haiti. 1949.

Taylor, G.C., and R.C. Lemoine. Ground Water of the Gonaives Plain–Haiti. 1949.

Taylor, G.C., and R.C. Lemoine. *Les Rivières et les Sources de la Plaine du Cul-de-Sac & Les Eaux Souterraines dans la Plaine des Gonaïves, Haiti*. Vol. 20, No. 75, Extrait de la Revue de la

Société Haïtienne d'Histoire et de Géographie, Port-au-Prince: Imprimerie V. Valcin, October 1949.

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

Turk, Michele. DisasterRelief.org, "Immortal Hurricane Georges Lives On in the Agony of the Victims." 9 October 1998. Internet: http://162.6.3.135:1020/Disasters/981008georges23. Accessed January 1999.

United Nations, Department of Economic and Social Affairs. *Ground Water in the Western Hemisphere*, "Haiti." Natural Resources/Water Series No. 4, New York, 1976.

United Nations Development Program, Department of Technical Cooperation for Development. *Carte Hydrogéologique, République d'Haiti.* Maps, Scale 1:250,000, New York, December 1990.

United Nations Development Program, Department of Technical Cooperation for Development. *Developpement et Gestion des Ressources en Eau, Disponibilités en Eau et Adequation Aux Besoins. Projet*. Hai/86/003, Vols. I, II, III, IV, V, and VI, New York, 1991.

United Nations Development Program, Food and Agricultural Organization. *Enquêtes sur les Terres et les Eaux dans la Plaine des Gonaïves et le Département du Nord-Quest, Haiti, Final Report*. Vols. I, II, and III, 45/HAI 3, Général Carte, FAO/SF, Rome, 1969.

United Nations Development Program, Industrial Development Organization. *Stone in Haiti.* Vienna, Austria: United Nations, 1980.

United Nations Development Program, Organisation Météorologique Mondiale. *Information Météorologique et Hydrologique pour le Developpement Économique et Social.* HAI\97\006, Haiti: United Nations, June 1997.

United Nations Educational, Scientific, and Cultural Organization. *First Workshop on the Hydrogeologic Atlas of the Caribbean Islands*. Santo Domingo, Dominican Republic: United Nations, 1966.

United Nations Educational, Scientific, and Cultural Organization. *Second Workshop on the Hydrogeologic Atlas of the Caribbean Islands*. Caracas, Venezuela: United Nations, 6-9 September 1988.

United States Corps of Engineers Water Assessment Mission. *The Water Situation in Haiti, A Presentation on CAMEP and SNEP.* Port-au-Prince, April 1998.

Van Den Bold, W.A. *AAPG Bulletin,* "Neogene of Central Haiti." Vol. 58/3, Tulsa, Oklahoma: American Association of Petroleum Geologists, Inc., March 1974.

Waite, Herbert A. Reconnaissance Investigation of Public Water Supplies of Port-au-Prince and in 12 Villages in the Department du Nord, Haiti. Washington, DC: United States Geological Survey, 1960.

Weyl, R. Geologie der Antillen–Beitraege zur Regionalen Geologie der Erde. Band 4, Berlin, Germany: Gebrüder Borntraeger, 1966.

White, T.A., and C.F. Runge. *Unasylva,* "Cooperative Watershed Management in Haiti–Common Property and Collective Action." Vol. 46, No. 1, Washington, DC: United Nations Development Program, Food and Agricultural Organization, 1995.

White, T.A., and C.F. Runge. *World Development*, "The Emergence and Evolution of Collective Action–Lessons from Watershed Management in Haiti." Vol. 23, No. 10, Great Britain: Elsevier Science, Ltd., 1995.

Woodring, W.P., J.S. Brown, and W.S. Burbank. *Geology of the Republic of Haiti.* Department of Public Works, Baltimore, Maryland: Lord Baltimore Press, 1924.

APPENDIX A

List of Officials Consulted and List of Agencies Contacted

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

List of Officials Consulted

Name Title	Government Agency, Relief Organization, or Non-Government Organization (NGO)	Address	Telephone Fax Email
Mr. Hyppolite –	Service National d'Eau Potable (SNEP)	Delmas 45 No. 1 Port-au-Prince	46-2927
Mr. Exantus Executive Director	SNEP	Delmas 45 No. 1 Port-au-Prince	–
Mr. Ludovic Cevere Engineer	SNEP	Delmas 45 No. 1 Port-au-Prince	–
Mr. Tom Kuhns –	Blue Ridge Ministry	LIC 28 Port-au-Prince	46-3676 (from 0700 to 0730 only)
Mr. Yvelt Cheri Executive Director	Department of Natural Resources	Rte. Nat'l. No. 1 Port-au-Prince	–
Mr. Jean Baptiste –	Centrale Autonome Metropolitaine d'Eau Potable (CAMEP)	–	23-4662
Mr. Gerton Rene Engineer	CAMEP	–	–
Mr. Marc Yves Philador –	Southern Baptist Convention (SBC)	Cazeau	22-5289
Pastor Joseph I. Elyse Director of Annex	SBC	Cazeau	22-5289
Mr. Pierre Camille –	SBC	Cazeau	22-5289
Mr. Luc Pierre Jean Agronomist	Association Haitienne pour la maîtrise de l'eau en milieu rural	Avenue N, Impasse Soray No. 7 Port-au-Prince	44-1035
Mr. Frantz Metellus Engineer, National Consultant	Pan American Health Organization/World Health Organization	Thomassin 32, Impasse Laurent No. 5 Port-au-Prince	45-0764 49-3542
Ms. Yolande Paultre Sanitation Engineer	Unité de Réforme du Secteur de l'Eau Potable	Delmas 45 No. 1 Port-au-Prince	46-0830 46-4770
Mr. Drew Kutschenreuter Agronomist	U.S. Agency for International Development (USAID)	USAID Haiti	–
Mr. Martin, Marc Eddy Senior Agronomist	USAID	USAID Haiti	33-5500 22-3102 memartin.gov
Ms. Chantel Santeli General Director	United Nations Development Program	–	–
Mr. Battiste –	United Nations Children's Fund	–	–
Mr. Appollon Nervellus General Director, Engineer	Poste Communautaire d'Hygiene et d'Eau Potable (POCHEP)	–	–
Mr. Franz Belgrade Technical Director, Engineer	POCHEP	–	–

List of Agencies Contacted

Organization	Acronym	Translation	Area of Responsibility
Association Haitienne pour la maîtrise de l'eau en milieu rural	ASSODLO	Haitian Association for Water Control in Rural Areas	ASSODLO is a non-government organization (NGO) that supplies water to rural areas.
Centrale Autonome Metropolitaine d'Eau Potable	CAMEP	Independent Metropolitan Water Company	CAMEP is the public agency responsible for water supply to the city of Port-au-Prince and the surrounding areas of Pétion-Ville, Delmas, and Carrefour.
Electricité d'Haiti	ED'H	Haitian Electricity Company	ED'H is responsible for the development of electricity.
Ministère de l'Agriculture, des Ressources Naturelles et du Developpement Rural	MARNDR	Ministry of Agriculture, Natural Resources, and Rural Development	MARNDR is responsible for the development of agriculture, including irrigation systems.
Ministère de l'Environnement	MDE	Ministry of the Environment	MDE's primary mission is to protect the environment.
Ministère de la Santé Publique et de la Population	MSPP	Ministry of Public Health and Population	MSPP is responsible for administering the public health system.
Ministère des Travaux Publiques, Transports et Communications	MTPTC	Ministry of Public Works, Transportation and Communication	MTPTC is responsible for infrastructure improvements.
Programme des Nations Unies pour le Developpement	PNUD	United Nations Development Program	PNUD has a program to repair the stream-gaging network, but budget constraints have the program on hold.
Poste Communautaire d'Hygiene et d'Eau Potable	POCHEP	Community Water Supply and Sanitation Post	POCHEP is the agency within the MSPP responsible for development of rural water supply systems.
Service National d'Eau Potable	SNEP	National Water Supply Service	SNEP is the public agency responsible for water supply to rural areas.
Service National de Ressources en Eau	SNRE	National Service for Water Resources	SNRE is responsible for the management of water resources in Haiti.
Unité de Reformé du Secteur en Eau Potable	URSEP	Potable Water Sector Reform Unit	URSEP is responsible for development of a plan to reform the water sector.

APPENDIX B

Glossary

Glossary

agricultural runoff	That portion of precipitation that flows over the ground's surface draining farmlands and feedlots. Usually it is polluted by agricultural wastes. Wastes include pesticides and fertilizers, animal manure and carcasses, crop residues, sediment from erosion, and dust from plowing.
agrochemicals	Chemicals used in agricultural practices, i.e., pesticides, herbicides, and fertilizers.
alluvial	Pertaining to processes or materials associated with transportation or deposition by running water.
alluvium	Sediment deposited by flowing water, as in a riverbed, flood plain, or delta.
andesite	A dense, fine-grained, dark colored to black, hard, extrusive igneous rock intermediate in composition between acidic and basic rocks. Occurs principally as thick extensive lava flows.
aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
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.
batholith (batholite)	A great mass of coarse-grained igneous rock with an exposed surface of more than 100 square kilometers.
bicarbonate (HCO_3)	A negatively charged ion which is the dominant carbonate system species present in most waters having a pH value between 6.4 and 10.3. Excessive concentrations typically result in the formation of scale.
biological contamination	The presence in water of significant quantities of disease-producing organisms.
brackish water	Water that contains more than 1,000 milligrams per liter but not more than 15,000 milligrams per liter of total dissolved solids.
calcareous	Composed of or containing calcium carbonate, calcium, or lime.
calcium (Ca)	An abundant alkali metal found in natural waters.
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.
chalk	A soft, pure, earthy, fine-textured, usually white to light gray or buff limestone of marine origin, consisting almost wholly of calcite. Normally very porous but impermeable, and considered a confining bed.
chemical contamination	The presence in water of significant quantities of chemicals that may be a health risk.
chert	A compact, microcrystalline, glassy, hard, variously colored, siliceous sedimentary rock composed of chalcedonic silica. Chert occurs as lenses, nodules, or thin beds.
cherty limestone	Limestone containing chert, a fine-grained sedimentary rock of varying colors usually found as lenses interbedded in the limestone.
chloride (Cl or Cl_2)	Negatively charged ions 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.
clastic	Consisting of fragments of preexisting rocks.
clastic rock	A sedimentary rock that is made up of fragments of preexisting rocks transported mechanically into the place of deposition.
clay	As a soil separate, the individual particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that contains 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.
claystone	A rock composed of mud, similar to shale but without the fine layering.
coastal plain	Any plain that has its margin on the shore of a large body of water, particularly the sea, and generally represents a strip of recently submerged sea bottom.

conglomerate	Gravel-size or larger, consolidated, rounded to semirounded rock fragments in a finer grained material. Conglomerate is usually a highly unpredictable rock for construction purposes, and normally avoided by the military engineer. Depending upon the degree of cementation, the drillability and ground water potential can vary significantly.
consolidated	Where loosely aggregated, soft or liquid earth materials have become firm and coherent rock.
contaminant or pollutant	As applied to water, any dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological material, radioactive materials, heat, wrecked or discarded equipment, rock sand, dirt or industrial municipal, and agricultural wastes discharge into water.
coral	An organism that separates carbonate material from seawater to form their external skeleton of calcium carbonate (limestone). Usually grow in colonies.
Cretaceous	A division of geologic time from 66 to 138 million years ago, during which certain rocks were formed. Falls chronologically after the Jurassic and before the Tertiary. Is the youngest division of the Mesozoic.
dacite	An extrusive igneous rock, massively bedded, light to dark gray, medium to coarse grained, and often foliated. The extrusive equivalent of quartz diorite.
deforestation	The removal or clearing away of the trees or forest.
delta	An alluvial deposit, often in the shape of the Greek letter “delta” from which it derives its name, which is formed where a stream drops its debris on entering a body of quieter water. Also, the terminal deposit of a river.
depression	(1) Any relatively sunken part of the ground’s surface; (2) a low-lying area surrounded by higher ground, having no outlet for surface water drainage.
diabase	An intrusive rock consisting essentially of labradorite and pyroxene.
diorite	A medium-to-coarse-grained, dark-colored, hard, intrusive igneous rock.
discharge	Volume of water passing through a cross section of a stream per unit time, quantity of flow.
dissolved oxygen (DO)	The amount of oxygen, in parts per million by weight, dissolved in water, now generally expressed in mg/L. 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.
drainage basin	The land area from which water drains into a stream, lake, or other body of water.
dug well	Well excavated by means of picks, shovels, or other hand tools.
Eocene	Division of geologic time between 38 and 55 million years ago. Falls chronologically after the Paleocene and before the Oligocene. Eocene is included in the Tertiary.
extrusive rock	A large series of igneous rocks that are extruded or forced into overlying formations such as to reach the surface. Their rapid ejection results in formation of very fine-to fine-grained textures.
fault	A fracture or fracture zone of the Earth along which there has been displacement of one side with respect to the other.
fine-grained (rock)	A sedimentary rock or sediment and its texture, in which the individual particles have an average diameter less than 0.6 millimeter (silt size or smaller).
flash flood	Flood of short duration with a relatively high peak rate of flow, usually resulting form a high-intensity rainfall over a small area.
folding	A bending in strata. Usually associated with a group showing common characteristics and trends. In many areas, folding causes the formation of joints and fractures.
formation	Strata or series of strata of rock or sediment showing distinct and unifying lithologic properties or characteristics and large enough to be mappable. Usually tabular in shape.
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.
granodiorite	A hard, crystalline, igneous rock that is massively bedded, light to dark gray, medium to coarse grained, and often foliated.

gravel	Individual rock or mineral fragments with more than 4.76 to less than 76 millimeters in diameter.
ground water	Water beneath the Earth's surface, often between saturated soil and rock, that supplies wells and springs.
group	A series of formations.
hand pump	A hand-operated device to move water from a well to the surface. Can be used to a depth of 45 to 50 meters and produces a yield of only a few liters per minute.
hard water or hardness	A measurement of the amount of calcium carbonate ($CaCO_3$) in the water which can form an insoluble residue.
high water	The flow occurring in a stream during the wettest part of the year.
hydroelectric	A facility that produces electrical energy by means of a generator coupled to a turbine through which water passes.
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.
impermeable	A bed or stratum of material through which water will not move.
incised (valley)	A stream channel that has been downcut or entrenched deeply into the surface.
infiltration	The flow or movement of water into the soil.
interbedded	Occurring between or lying in with other sediments or rock units; interstratified.
intermittent (lake)	A lake or small water body that contains water only at certain times of the year, as when it receives water from streams, springs, or from some surface source, such as rain.
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.
intrusive rock (intrusives)	Rock consolidated from magma beneath the Earth's surface that is squeezed into cracks or crevices or between layers of older rocks.
iron (Fe)	A metal which when dissolved in water may give a bad taste to the water.
karst	An area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.
karstification	The formation of cavities within limestone and dolomite by solution of the material by water.
lagoon	A shallow body of water with a restricted inlet from the sea that contains both brackish and saline water.
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 constituents from soils, landfills, mine wastes, sludge deposits, or other material by percolating water.
lee or leeward	The part or side of a hill or prominent object that is sheltered or turned away from the wind or is down wind.
lignite	A brownish-black soft coal in which the alteration of vegetal material has proceeded further than peal but no as far as sub-bituminous coal.
limestone	Soft to moderately hard rock composed of calcium carbonate, mainly shells, crystals, grains, or cementing material. Colors range from white through shades of gray to black. Commonly thick bedded, jointed, and containing fossils. Limestone is often highly fractured and soluble, and it often yields significant volumes of ground water.
lowland	A general term for extensive plains that are not far above sea level.
low water	The flow occurring in a stream during the driest period of the year.
magma	Molten rock material that forms igneous rocks upon cooling.
magnesium (Mg)	An abundant alkali metal found in natural waters that is essential in plant and animal nutrition.
manganese (Mn)	A hard, brittle, grayish metallic element used as an alloying agent in steel to give it toughness.
mangrove	A group of plants that grows in a tropical or subtropical marine swamp. A marine swamp dominated by a community of these plants.

marl	A sedimentary rock composed primarily of clay and calcium carbonate. Marl is interbedded with shale and limestone and has few construction uses. It is not normally a good aquifer and often acts as a confining bed.
marsh	A shallow lake, usually stagnant, filled with rushes, reeds, sedges, and trees.
massive	Rocks of any origin that are more or less homogeneous in texture or fabric, displaying an absence of flow layering, foliation, cleavage, joints, fissility, or thin bedding.
meander	A tortuous or winding stream channel.
metamorphic	Rocks formed in the solid state from previously existing rocks in response to pronounced changes in temperature, pressure, and chemical environment.
mineralized (water)	Water that contains a large amount of salts.
Miocene	Division of geologic time between 5 and 24 million years ago. Falls chronologically after the Oligocene and before the Pliocene. Included in the Tertiary.
mudstone	Includes clay, silt, siltstone, claystone, and shale; usually used when the precise identification of a deposit is in doubt.
municipal well	A high-yield well used to supply water to an urban area.
nitrate (NO_3)	A mineral compound characterized by a fundamental anionic structure of NO_3. Nitrate may be an indicator of ground water pollution.
Oligocene	Division of geologic time between 24 and 38 million years ago. Falls chronologically after the Eocene and before the Miocene. Included in the Tertiary.
Paleocene	Division of geologic time between 55 and 66 million years ago. Falls chronologically after the Cretaceous and before the Eocene. Paleocene is included in the Tertiary.
perennial stream	A stream that flows year-round and has a minimum flow of 0.04 cubic meter per second. A perennial stream is usually fed by ground water, and its water surface generally starts at a lower level than that of the water table in the area.
permeability (rock)	The property or capacity of a porous rock for transmitting a fluid. Permeability is a measure of the relative ease of fluid flow under unequal pressure. The customary unit of measure is a millidarcy.
pH	Hydrogen-ion concentration: a measure of the acidity or basicity of a solution.
pillow lava	A general term for those lavas displaying pillow structure and considered to have formed under water; usually basaltic or andesitic.
plateau	A relatively elevated area of comparatively flat land.
Pleistocene	Division of geologic time between 10,000 and 1.6 million years ago. Falls chronologically after the Pliocene and before the Holocene. Pleistocene is included in the Tertiary.
Pliocene	Division of geologic time between 1.6 million and 5 million years ago. Falls chronologically after the Miocene and before the Pleistocene. Included in the Tertiary.
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. Primary/original porosity developed during the final stages of sedimentation or was present within the sedimentary particulars at the time of deposition. Secondary porosity formed after sedimentation.
potable water	Describes water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
potassium (K)	An important and abundant alkali metal found in water that is essential in plant and animal nutrition.
quartz diorite	A hard, crystalline, igneous rock, massively bedded, light to dark gray, medium to coarse grained, and often foliated. Quartz diorite is also known as tonalite.
quartzite	An extremely hard, fine to coarsely granular massive rock which forms from sandstone. Quartzite is one of the hardest, toughest, and most durable rocks. Quartzite is poor as an aquifer unless highly fractured.
Quaternary	A division of geologic time from the present to 1.6 million years ago, during which certain rocks were formed or sediments deposited. Falls chronologically after the Tertiary. Includes the Pleistocene and Holocene. Quaternary is the youngest division of the Cenozoic.

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.
recharge area	An area in which water is absorbed that eventually reaches the zone of saturation in one or more aquifers.
reef/coral reef	A ridge or mount of limestone. The upper surface lies near the level of the seas and is formed by the action of reef-building coral organism.
reservoir	A pond, lake, tank, basin, or other space that is used for storage, regulation, and control of water for recreation, power, flood control, or drinking. A reservoir can be either natural or manmade.
runoff	That portion of the precipitation in a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, and seepage.
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion/ saline-water intrusion	Displacement of fresh surface or ground water by the advance of salt water due to its greater density. Saltwater intrusion usually occurs in coastal and estuarine areas where it contaminates fresh water wells.
sandstone	A soft to moderately hard sedimentary rock composed primarily of cemented quartz grains. The harder, massive rock is generally good for most construction uses. Many aquifers and oil reservoirs are sandstone.
sandy limestone	Limestone interbedded with sand.
schist	A fine- to coarse- grained, foliated, metamorphic rock composed of discontinuous thin layers of parallel minerals.
sedimentary (rocks)	A class of rocks formed from the accumulation and solidification of a variety of sediments.
shale	A soft to moderately hard sedimentary rock composed of very fine-grained quartz particles. Shale often weathers or breaks into very thin platy pieces or flakes. In most places, it can be excavated without drilling and blasting. Due to weakness and lack of durability, it makes very poor construction material. Shale is a confining bed to many aquifers in sedimentary rock.
siltstone	A fine-grained, moderately hard, sedimentary rock that is thin bedded to massive. Siltstone is distinguished from shale because it has a slightly larger grain size.
sinkhole	A funnel-shaped depression in the Earth's surface formed in a soluble rock by water.
sluiceway	An artificial channel for conducting water with a valve or gate to regulate the flow.
sodium (Na)	Most important and abundant alkali metal found in natural waters. Sodium can be an indicator of sewage and industrial waste contamination.
solution cavities	Caves or channels in limestone formed by the effects of carbonic acid over a period of thousands or millions of years.
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.
storm surge	Wind-driven oceanic waves that flood low coasts not ordinarily subject to overflow.
sulfate (SO_4)	A salt of sulfuric acid containing the divalent negative radical SO_4.
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.
tactical well	Generally a well with an electrical pump capable of yielding greater than 3.35 liters per second. In military operations, a well capable of supplying the raw water needs of a 600-gallon per hour reverse osmosis water purification unit (ROWPU).
Tertiary	A division of geologic time from 1.6 to 66 million years ago, during which certain rocks were formed. Falls chronologically after the Cretaceous and before the Quaternary. Includes the Paleocene, Eocene, Miocene, and Pliocene. Is the oldest division of the Cenozoic. Outside the United States is sometimes divided into the Paleogene and Neogene.
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.
tropical maritime	A type of warm, wet air mass originating at low latitudes over ocean areas.
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 composed of small volcanic rock fragments and ash moderately compacted forming a texture more characteristic of sedimentary rocks.
turbidity	A measure of the reduction in water clarity. Unclear or muddy water is caused by suspended particles of sand, silt, clay, or organic matter. Excessive turbidity must be removed to make water potable.
unconsolidated	Loose, soft, or liquid earth materials that are not firm or compacted.
wastewater	The spent or used water from a community or industry, which contains dissolved and suspended matter.
water points	The location where equipment is set up to gather water for purification and distribution.
watershed	The area contained within a drainage divide above a specified point on a stream.
water table	The depth or level below which the ground is saturated with water.
weathering	Physical and chemical changes that atmospheric agents produce in rocks or other deposits at or near the Earth's surface. These changes result in disintegration or decomposition of material into soil.
well	Artificial excavation that derives water from the interstices of the rocks or soil which it penetrates.
wetlands	A lowland area, such as a marsh, swamp, or seasonally unedited area that is saturated with moisture.
windward	The side of an object or hill located toward the direction from which the wind is blowing.
yield or well yield	The volume of water produced from a well. Reported as liters per second (L/s) or gallons per minute (gal/min).

APPENDIX C

Surface Water and Groundwater Resources

Tables and Figures

Prepared by: U.S. Army Topographic Engineering Center Operations Division
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Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water perennially available	Major perennial streams, lakes, and lagoons.	Moderate to very large quantities are available year-round. High flow period generally occurs from May to October. Discharge for a selected stream gaging station is listed below under its drainage basin. Due to increased runoff caused by deforestation, average and peak discharge values can be assumed to be larger than reported historical values. Also listed is information on the major lake under its basin.	Water is fresh. Domestic wastewater and agricultural runoff cause biological contamination near and downriver from populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment carried by the streams. The very high level of total suspended solids (TSS) in streams can clog and damage water purification equipment.	Access to and development of water points are principally influenced by topography, ground cover, and the transportation network. Conditions hindering access include high steep banks, dense vegetation, and extensive wetlands. Rivière de l'Artibonite upstream from Lac de Péligre is deeply incised. Near the coast are large swampy areas. The shoreline of Lac de Péligre is rocky, steep, and irregular.	Rivière de l'Artibonite is the largest stream in Haiti. Lac de Péligre covers 30 km^2 and is used for flood control, irrigation, and hydroelectric power generation. After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal maintenance of intake equipment along channels carrying high sediment loads is advised to counter rapid silting.
2 Fresh water perennially available	Major perennial streams and lakes.	Small to very large quantities are available year-round. Very large quantities are available during the high flow period that generally occurs from May to October. Selected stream gaging stations are listed below under their respective drainage basins. Due to increased runoff caused by deforestation, average and peak discharge values can be assumed to be larger than reported historical values.	Water is fresh. Domestic wastewater and agricultural runoff cause biological contamination near and downriver from populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment	Access to and development of water points are principally influenced by topography, ground cover, and the transportation network. Conditions hindering access include high steep banks, dense vegetation, and extensive wetlands. For most areas, the stream valleys are narrow and incised.	In the **Estère Basin (X)**, the Rivière de l'Estère has been completely reworked for irrigation. After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water perennially available (continued)	Rivière Bouyaha (1910N07204W).	measured at Paulin Lacorne (1956N07256W) from 1965 to 1967, ranged from 2.65 to 527 m^3/s and averaged 13.13 m^3/s.	volume of sediment carried by the streams. The very high level of TSS in streams can clog and damage water purification equipment.		Seasonal maintenance of intake equipment along channels carrying high sediment loads is advised to counter rapid silting.
3 Fresh water perennially available	Perennial streams and lakes.	Very small to very large quantities are available year-round. Very large quantities are available during the high flow period, which generally occurs from June to October, except in southern Haiti where high flows generally occur from May to June and from October to November. Selected stream gaging stations are listed below under their respective drainage basins. Due to increased runoff caused by deforestation, average and peak discharge values can be assumed to be larger than reported historical values.	Water is fresh. Domestic wastewater and agricultural runoff cause biological contamination near and downriver from populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment carried by the streams. The very high level of TSS in streams can clog and damage water purification equipment	Access to and development of water points are principally influenced by topography, ground cover, and the transportation network. Conditions hindering access include high steep banks, dense vegetation, and extensive wetlands. In the Limbé Basin (VI), streams are well incised in deep narrow valleys separated by steep hills. The Rivière du Limbé changes course frequently and is obstructed by alluvium after large floods. The lower	In the Cayes Zone (XXIV), Rivière de l'Islet and Rivière de Torbeck may disappear and reappear again before reaching the coast. After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal maintenance of intake equipment along channels carrying high

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)	(1910N07204W), Rivière de Fer à Cheval (1850N07206W), Rivière Guayamouc (1859N07152W), and Rivière Lociane (1915N07250W).	measured at Pont Gros Morne (1939N07239W) from 1923 to 1940 and from 1962 to 1966, ranged from 0.3 to 1,500 m^3/s and averaged 6.95 m^3/s.	purification equipment.	floods. The lower part of this basin is poorly drained and swampy. In the Saint-Marc-Duvalierville Zone (XII) and Roseaux-Voldrogue Zone (XXV), access may be difficult because streams lie in deeply incised valleys. In the Cul-de-Sac Zone (XIII), streams may be narrow and deep.	carrying high sediment loads is advised to counter rapid silting.

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)	**Cayes Zone (XXIV)** (1818N07350W): Rivière de l'Acul (1807N07351W), Rivière de l'Islet (1811N07344W), Ravine du Sud (1811N07345W), and Rivière de Torbeck (1810N07349W).	ranged from 0.6 to 420 m^3/s and averaged 5.88 m^3/s.			

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water perennially available (continued)		measured at Passe Ranja (1836N07408W) from 1925 to 1931, ranged from 0.7 to 850 m^3/s and averaged 26.85 m^3/s.			
4 Fresh water seasonally available	Perennial streams and lakes.	Meager to large quantities available year-round. Large quantities available during the high flow period generally from May to October, except in southern Haiti where high flows generally occur from May to June and from October to November. Selected stream gaging stations are listed below under their respective drainage basins. Due to increased runoff caused by deforestation, average and peak discharge values can be assumed to be larger than reported historical values.	Water is fresh. Domestic wastewater and agricultural runoff cause biological contamination near and downriver from populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment carried by the streams. The very high level of TSS in streams can clog and damage water purification equipment.	Access to and development of water points are principally influenced by topography, ground cover, and the transportation network. Conditions hindering access include high steep banks, dense vegetation, and extensive wetlands. In the Trois Rivières Basin (III), access to Les Trois Rivières may be difficult due to very rugged terrain and deeply incised stream valleys separated by scarped hills. In the Port-de-Paix-Port Margot Zone (IV), streams are moderately to deeply incised except for Rivière de Port Margot, which lies in a large valley. In the Cap-Haïtien Zone (VII), access to the Rivière Galois (Haut de Cap) may be difficult due to swampy areas. In the Fond Verrettes Zone (XIV), access to Rivière Soliette may be difficult due to steep valley walls. Access is difficult	In the Fond Verrettes Zone (XIV), Rivière Soliette is fed by Source Miel (1820N07151W). In the Corail-Anse à Veau Zone (XXIII), the Rivière des Baradères disappears into a limestone depression. After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal maintenance of intake equipment along channels carrying high sediment loads is advised to counter rapid silting.

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water seasonally available (continued)	**Fond Verrettes Zone (XIV)** (1853N07153W): Rivière Soliette (1830N07151W).	from 0.05 to 450 m^3/s and averaged 5.34 m^3/s.		in the Cayes Jacmel-Anse à Pitres Zone (XV) due to narrow steep grades. Streams in the Saint Louis du Sud-Aquin Zone (XX) are deeply incised and have torrential flows. Access to streams in the Corail-Anse à Veau Zone (XXIII), the Jérémie-Les Irois Zone (XXVII), and the Tiburon-St. Jean Zone (XXVIII) may be difficult because streams are incised in deep narrow valleys.	

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water seasonally available (continued)	Rivière de Dame Marie (1834N07425W).				
5 Fresh water seasonally available	Intermittent streams and lakes.	Meager to very large quantities are available during the high flow period from May to October, except in southern Haiti where high flows generally occur from May to June and from October to November. Streams are usually dry during part of the year.	Water is generally fresh. Some intermittent streams and small ponds may temporarily become brackish during the low flow period. Streams may become turbid during and following heavy rainfall. Domestic wastewater and agricultural runoff cause biological contamination near and downriver from populated places. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment carried by the streams. The very high level of TSS in streams can clog and damage water purification equipment.	Access to and development of water points are influenced by topography, ground cover, and the amount of time non-oceanic surface water is available. Access to most intermittent streams may be difficult due to steep-sided valley walls.	After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal maintenance of intake equipment along channels carrying high sediment loads is advised to counter rapid silting.

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water seasonally available	(island) (1837N07345W).				
6 Fresh water scarce or lacking	Brackish and saltwater lakes:	Moderate to enormous quantities of brackish to saline water available year-round. Mangrove swamps and marshy areas occur sporadically along the coast.	Water is brackish to saline. TDS values for the Étang Saumâtre range from 7,500 to 10,650 mg/L; Cl values range from 3,400 to 6,100 mg/L, while SO_4 values vary between 450 and 525 mg/L. Trou Caïman has TDS of 4,757 mg/L, Cl of 1,770 mg/L, and SO_4 of 310 mg/L. Surface water is generally saline and can contain large amounts of biological wastes and oceanic minerals. Biological contamination from untreated domestic wastewater is a serious problem. Chemical contamination may be a problem near major cities and industrial sites. Accelerated soil erosion caused by deforestation has greatly increased the volume of sediment carried by the streams. The very high level of TSS in streams can clog and damage water purification equipment.	Access to and development of water points are influenced by topography, ground cover, and the amount of time non-oceanic surface water is available. Access to Étang Saumâtre may be difficult due to a marshy shoreline. Access to many other areas may be difficult due to marshy ground.	The surface area of Étang Saumâtre is about 181 km^2. After heavy rains, the rivers rise rapidly with swift currents and floating debris that can damage or destroy water points. Protection of equipment against flooding and debris from intense tropical storms is required. Seasonal maintenance of intake equipment along channels carrying high sediment loads is advised to counter rapid silting.

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
6 Fresh water scarce or lacking (continued)	**Limonade-Ouanaminthe Zone (IX):** Along the coast.				

[1] 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 = $\leq$0.1 m^3/s (3.5 ft^3/s)

[2] Qualitative Terms:

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

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

[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:

Rivière de l'Artibonite………………………..(1915N07247W)

Geographic coordinates for Rivière de l'Artibonite that are given as 1915N07247W equal 19°15' N, 72°47' W and can be written as a latitude of 19 degrees and 15 minutes north and a longitude of 72 degrees and 47 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:

Cl = chloride
ft^3/s = cubic feet per second
gal/min = gallons per minute
km^2 = square kilometers
L/s = liters per second
m^3/s = cubic meters per second
mg/L = milligrams per liter
Mm^3 = million cubic meters
SO_4 = sulfate
TDS = total dissolved solids
TSS = total suspended solids

Table C-2. Ground Water Resources

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 Quaternary alluvium found in the Plaine du Nord (1940N07210W)[3], the Rivière de l'Artibonite valley (1915N07247W), Plaine du Gonaïves (1930N07240W), Plaine du Cul-de-Sac (1836N07210W), Plaine des Cayes (1814N07346W), and in most other river valleys and coastal plains. In the Plaine du Nord, the Plaine du Cul-de-Sac, the Rivière de l'Artibonite valley, and in the Plaine des Cayes, the alluvium is generally >100 m thick and may be up to 300 m thick. In the smaller river valleys and coastal plains, the alluvium is generally <40 m thick, but can be locally much thicker. Ground water in the alluvial deposits is typically found in 1- to 8-m-thick layers of sand and gravel that are separated by layers of silt and clay. Near the city of Jacmel (1814N07232W), in parts of the Plaine du Cul-de-Sac and in other isolated areas, the aquifers include very porous and permeable Pleistocene reef and carbonate deposits. These deposits are generally between 25 and 50 m thick. The Plaine du Nord is in the Nord (1936N07218W) and Nord-Est (1932N07142W) departments. The Rivière de l'Artibonite valley is in the Artibonite	Small to enormous quantities are available. Well yields are generally between 4 and 100 L/s. Locally, wells may have yields >150 L/s. Yields from selected wells are listed below. **1** Well near Quartier Morin (1942N07209W): 15 L/s; **2** Well near La Rue (1943N07211W): 12 L/s; **3** Well near Aufilier (1928N07239W): 76 L/s; **4** Well near Haut Saut d'Eau (1849N07212W): 25 L/s; **5** Well near Port-au-Prince (1832N07220W): 96 L/s; **6** Well near Lamartinière (1836N07212W): 25.2 L/s; and **7** Well near Les Cayes (1812N07345W): 4 L/s.	Water is fresh with TDS values typically <800 mg/L. Away from the coast, TDS values generally range from 300 to 600 mg/L. Water quality data from selected wells are listed below. **1** Well near Quartier Morin: TDS 230 mg/L, pH 8.53, temperature 26 °C, Ca 2.85 mg/L, Mg 15.73 mg/L, Na 21.64 mg/L, K 1.05 mg/L, HCO_3 195.25 mg/L, Cl 13.4 mg/L, SO_4 15.88 mg/L, NO_3 3.4 mg/L. **3** Well near Aufilier: TDS 690 mg/L, pH 7.3, Ca-Mg 45 mg/L, Na 56 mg/L, HCO_3 380 mg/L, Cl 90 mg/L, SO_4 180 mg/L. **4** Well near Haut Saut d'Eau: TDS 186 mg/L, pH 7.86, temperature 22 °C, Ca 40 mg/L, Mg 9.42 mg/L, Na 1.49 mg/L, K 0.33 mg/L, HCO_3 163.23 mg/L, Cl 1.92 mg/L, SO_4 2.14 mg/L, NO_3 2.8 mg/L. **5** Well near Port-au-Prince: TDS 396 mg/L, Ca 33 mg/L, HCO_3 169 mg/L, Cl 20 mg/L, SO_4 trace, NO_3 1 mg/L. **6** Well near Lamartinière: TDS 348 mg/L, Ca 39 mg/L, Mg 9 mg/L, Cl 84 mg/L,	Most drilled wells are between 26 and 120 m deep. Wells can be >200 m deep. Hand-dug wells are generally <35 m deep. Depth to water is usually between 5 and 50 m but can be >150 m. In the Plaine du Nord, depth to water is usually between 5 and 25 m. In the Rivière de l'Artibonite valley, depth to water is usually between 20 and 40 m. In the Plaine du Cul-de-Sac, depth to water is usually between 30 and 50 m. In the Plaine des Cayes, depth to water can be as great as 150 m. In other alluvial deposits, depth to water is generally between 2 and 15 m. Seasonally, fluctuation of the water table can be >4 m. Access is generally feasible but is locally difficult to very difficult. Along the coast, swampy ground may hinder access. In urban areas, congestion may hinder access and limit the availability of well sites. The country's overall poor road network may also hinder access.	These alluvial deposits are widely tapped for domestic supply and locally by irrigation wells. Nearly all areas are suitable for hand pump or tactical wells. Many areas are suitable for high-yield municipal and irrigation wells. Aquifers are generally recharged by runoff from the mountains and locally by rainfall. Deforestation is increasing runoff and decreasing the amount of water available for recharge. Deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation.

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)	Artibonite (1920N07230W) and Centre (1900N07200W) departments. The Plaine du Gonaïves is in the Artibonite department. The Plaine du Cul-de-Sac is in the Ouest (1840N07220W) department. The city of Jacmel is in the Sud-Est (1818N07224W) department. The Plaine des Cayes is in the Sud (1815N07340W) department.		SO_4 36 mg/L, NO_3 1.5 mg/L, hardness 250 mg/L $CaCO_3$. **7** Well near Les Cayes: TDS 315 mg/L, Cl 15 mg/L, hardness 220 mg/L $CaCO_3$. Near the coast, overuse is causing an increase in saltwater intrusion. The main pollution problem is biological contamination from human and animal wastes. Chemical contamination is increasing, especially near the major towns. Shallow aquifers are generally contaminated.	Generally, soft rock drilling techniques can be used.	
2 Fresh water locally plentiful	The aquifers consist of Pleistocene reef deposits or karstic and highly fractured limestones. These deposits form the most extensive aquifer system in the country. This system stores and transmits water through systems of fractures and solution cavities. The Pleistocene reef deposits are up to 300 m thick and consist of weathered and fractured limestone. The reef deposits are mainly in the Plateau de Bombardopolis (1945N07320W) of the Nord-Ouest (1945N07305W) department; in the Île de la Tortue (2004N07249W); in the Île de la Gonâve (1851N07303W); and in parts of the coastal area of the Artibonite,	Unsuitable to enormous quantities are available. Yields range from <0.1 to 3,000 L/s. Average spring yields are between 20 and 50 L/s, but can be >100 L/s. Drilled wells average from 1 to 60 L/s. Locally, wells may have yields >100 L/s. Yields from selected springs and wells are listed below. **8** Spring near Fond Pomme (1947N07320W): 8 L/s; **9** Spring near Rouffer Quinte (1922N07231W): 60 L/s; **10** Spring near Coupe à l'Inde (1917N07231W):	Water is fresh with TDS ranging from 130 to 940 mg/L. Most wells have TDS values of <500 mg/L. The water is generally very hard and high in pH, bicarbonate, calcium, and magnesium. Water quality data from selected springs and wells are listed below. **8** Spring near Fond Pomme: TDS 360 mg/L, pH 7.52, temperature 27 °C, Ca 63.23 mg/L, Mg 10.27 mg/L, Na 33.98 mg/L, K 2.35 mg/L, HCO_3 189.16 mg/L, Cl 61 mg/L, SO_4 22 mg/L, NO_3 28.35 mg/L. **9** Spring near Rouffer Quinte: TDS 235 mg/L, temperature 25 ºC.	Most wells are between 15 and 200 m deep. Locally, especially in the mountains, wells may be >200 m. Average well depth is about 110 m. Depth to water is usually between 5 and 25 m, but locally may be much deeper. In the mountains, depth to water is usually between 100 and 200 m. Seasonally, fluctuation of the water table can be >15 m. Access is generally difficult to very difficult. The country's overall poor road network, steep slopes, and rugged terrain may hinder	Most areas may be suitable for hand pump wells. Well sites on large fractures or solution cavities may be suitable for tactical, high-yield municipal, and irrigation wells. In the mountains, few successful wells have been drilled due to the excessive depth to water. 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

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 locally plentiful (continued)	Grand' Anse (1830N07340W), Ouest, Sud, and Sud-Est departments. The karstic and highly fractured limestone aquifers are in units ranging in age from the Cretaceous to the Eocene. These formations generally have been strongly deformed by folding and faulting. These aquifers are in the Cretaceous Macaya Formation and in the upper parts of the Paleocene-early Eocene Marigot Formation, the Eocene Abuillot Formation, and the Middle Eocene Plaisance Formation. Aquifers of this type are also locally in several other formations. The Cretaceous Macaya Formation is estimated to be <1,000 m thick. It consists of massive limestone beds separated by clay and sandy limestone layers. The Macaya Formation is found in the Grand'Anse, Ouest, and Sud departments. The Paleocene-early Eocene Marigot Formation is between 900 and 1,000 m thick. The upper part of the formation consists of varying beds of limestone, chalky limestone, and clastic limestones. The Marigot Formation is found in the Grand'Anse,	15 L/s; **11** Well near Jeanton (1904N07243W): 100 L/s; and **12** Spring Jet d'Eau (1817N07224W): 300 to 400 L/s.	**10** Spring at Coupe à l'Inde: TDS 353 mg/L, pH 7.45, temperature 25 °C, Ca 71.54 mg/L, Mg 13.62 mg/L, Na 6.71 mg/L, K 0.9 mg/L, HCO_3 286.79 mg/L, Cl 50 mg/L, SO_4 7.18 mg/L, NO_3 22.57 mg/L. **11** Well near Jeanton: TDS 160 mg/L, pH 7.88, temperature 24 °C, Ca 8.9 mg/L, Mg 0.4 mg/L, Na 2.3 mg/L, K 4.4 mg/L, HCO_3 2.9 mg/L, Cl 6.5 mg/L, SO_4 140.3 mg/L, $CaCO_3$ 5.3 mg/L. The main pollution problem is biological contamination from human and animal wastes. Chemical contamination is limited due to the lack of industrial activity and limited use of agrochemicals. Most shallow aquifers are contaminated.	access and limit the availability of well sites. Generally, hard rock drilling techniques must be used. Drilling may be difficult because highly fractured zones may cause excessive loss of drilling fluids and may cause the hole to collapse.	should be sited on fracture intersections. Aquifers in the mountains are generally locally recharged by rainfall, while those in the lowlands are recharged by runoff from the mountains. Deforestation is increasing runoff and decreasing the amount of water available for recharge. Deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation.

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 locally plentiful (continued)	Ouest, Sud, and Sud-Est departments. The Eocene Abuillot Formation can be up to 1,000 m thick. It consists of limestones, sandy shales, sandstones, and shales. Only the limestone portion of the Abuillot Formation is karstic and highly fractured. The Abuillot Formation is found in the Artibonite, Centre (1900N07200W), Nord, and Nord-Est departments. The Middle Eocene Plaisance Formation is generally <500 m thick and consists primarily of thick-bedded limestone. The lower part consists of conglomerates, limestone, and shale. The Plaisance Formation is principally in the Artibonite and Nord-Ouest departments.				
3 Fresh water locally plentiful	Aquifers consist of fractured limestones, sandstones, conglomerates, and schists. These units are generally interbedded with shales, siltstones, marls, and chalks. Typically, these rocks are not very porous or permeable and have not been strongly deformed by folding and faulting. This lack of deformation results in only localized areas that contain fractures. Yields vary greatly within these units. The aquifers include parts of several	Unsuitable to moderate quantities are available. Yields range from <0.1 to 25 L/s. Average yields are between 0.1 and 25 L/s. Locally, wells may have yields >25 L/s. Yields from selected springs and wells are listed below. **13** Spring near Petit Bourg du Borgne (1949N07234W): 1.5 L/s; **14** Spring near	Water is fresh with TDS values ranging from 150 to 800 mg/L. Most springs and wells have TDS values between 150 and 500 mg/L. The water is generally very hard and high in pH, bicarbonate, calcium, and magnesium. Water quality data from selected springs and wells are listed below. **13** Spring near Petit Bourg du Borgne: TDS 207 mg/L, pH 8.16, temperature 26 °C,	Most wells are >200 m. Depth to water is usually between 5 and 50 m. In the mountains, depth to water is usually between 100 and 200 m. Seasonally, depth to water can fluctuate as much as 15 m. Fracture zones are generally more prevalent near the surface and less likely at depths >60 m. Access is generally difficult to very difficult.	Some areas may be suitable for hand pump wells. Well sites on fractures or solution cavities may be suitable for tactical wells. Most areas are not suitable for high-yield municipal and irrigation wells. In the mountains, few successful wells have been drilled due to excessive depth to water. Successful wells in these areas depend upon

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)	geologic formations ranging in age from the Cretaceous to the Miocene. The major rock units containing these aquifers include the Paleocene-early Eocene Marigot Formation, the Eocene Abuillot Formation, the Oligocene-Miocene Artibonite Group, and the Miocene La Crete Formation. Other formations containing these aquifers include the Cretaceous Beloc and Trois Rivières Formations, the Oligocene Jeremie Formation, the lower parts of the Middle Eocene Plaisance Formation, and locally other formations. The Paleocene-early Eocene Marigot Formation is between 900 and 1,000 m thick. The lower part of the formation consists of varying beds of conglomerates, sandy shales, calcareous sandstones, and clastic limestones. The Marigot Formation is found in the Grand'Anse, Ouest, Sud, and Sud-Est departments. The Eocene Abuillot Formation can be up to 1,000 m thick. It consists of limestones, sandy shales, sandstones, and shales. This type of aquifer is generally found in parts of the Abuillot Formation consisting of sandstones and	Nan Tinte (1950N07306W): 1 L/s; **15** Spring near Castel (1819N07235W): 10 L/s; **16** Spring near Pition Remard (1818N07255W): 1.75 L/s; and **17** Spring near Monnery (1830N07332W): 10 L/s.	Ca 2.7 mg/L, Mg 4.04 mg/L, Na 11.46 mg/L, K 0.86 mg/L, HCO_3 176.96 mg/L, Cl 13.5 mg/L, SO_4 9.55 mg/L, NO_3 4.9 mg/L. **14** Spring near Nan Tinte: TDS 469 mg/L, pH 7.66, temperature 30 °C, Ca 63.57 mg/L, Mg 14.32 mg/L, Na 51.76 mg/L, K 3.86 mg/L, HCO_3 292.90 mg/L, Cl 67.5 mg/L, SO_4 31 mg/L, NO_3 12.83 mg/L. **16** Spring near Pition Remard: TDS 235 mg/L, pH 7.4, temperature 24 °C. **17** Spring near Monnery has TDS 158 mg/L. **18** Well near Jeremie (1834N07410W): pH 7.4, temperature 30 °C, Ca 63.57 mg/L, Mg 0.03 mg/L, Na 64 mg/L, Fe 0.12 mg/L, Cl 250 mg/L, SO_4 20 mg/L, NO_3 5.6 mg/L, hardness 427 mg/L $CaCO_3$. The main pollution problem is biological contamination from human and animal wastes. Chemical	The country's overall poor road network, steep slopes, and rugged terrain may hinder access and limit the availability of well sites. Generally, hard rock drilling techniques must be used. Drilling may be difficult because highly fractured zones may cause excessive loss of drilling fluids and may cause the hole to collapse.	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. Aquifers are generally locally recharged by rainfall. Deforestation is increasing runoff and decreasing the amount of water available for recharge. Deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation.

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)	sandy shales. The Abuillot Formation is found in the Artibonite, Centre, Nord, and Nord-Est departments. The Oligocene-Miocene Artibonite Group consists of the Arc, Madame Joie, and Thomonde Formations. The Artibonite Group is >2,700 m thick. It consists of shale, siltstones, bedded limestones, conglomerates, sandstones, and marl. The Artibonite Group is principally found in the Artibonite, Centre, Nord, and Nord-Est departments. The Miocene La Crete Formation is about 500 m thick. It consists of hard limestones, shaley limestones, marls, and sandstones. The La Crete Formation is principally found in the Artibonite, Centre, Nord, and Nord-Est departments. The minor formations are generally <150 m thick and have limited areal extent. These formations consist of thin conglomerates, chalk, weathered igneous rocks, schist, limestones, shale, siltstones, and sandstones. The Cretaceous Beloc Formation is found in the Sud-Est department. The Cretaceous Trois Rivières Formation is found locally in the Artibonite, Centre,		contamination is limited due to lack of industrial activity and limited use of agrochemicals. Most shallow aquifers are contaminated.		

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)	Nord, and Nord-Ouest departments. The Middle Eocene Plaisance Formation is in the Artibonite and Nord-Ouest departments. The Oligocene Jeremie Formation is in isolated areas in the Grand'Anse, Ouest, Sud, and Sud-Est departments.				
4 Fresh water scarce or lacking	Aquifers consist of low-permeability shales, sandy shales, consolidated conglomerates, sandstones, marls, cherty limestones, claystones, and siltstones. Formations containing these aquifers include the Miocene Rivière Grise Formation, the Miocene-Pliocene Las Cashobas and Morne Delmas Formations, the Pliocene Hinche and Rivière Gauche Formations, and isolated zones in several other geologic formations. The Miocene Rivière Grise Formation consists of conglomerates, marls, and clays and is about 400 m thick. It is principally in the Ouest department. The Miocene-Pliocene Las Cashobas Formation also includes the Maissade Formation as a sub-unit or member. The Las Cashobas Formation consists of tight conglomerates, thin	Unsuitable to small quantities are available. Yields are typically <5 L/s, and most yields are between 0.1 and 2 L/s. Many springs yield <0.1 L/s. Locally, wells may have yields >10 L/s. Yields from selected springs are listed below. **19** Spring near Nan Ruche (1945N07301W): 0.1 L/s; **20** Spring near Wallondry (1925N07213W): 3 L/s; **21** Spring near Maissade (1910N07208W): 0.1 L/s; and **22** Spring near Bois Pin (1852N07153W): 0.8 L/s.	Water is fresh with TDS generally <900 mg/L. Locally, mineralization may make the water brackish with TDS as high as 1,200 mg/L. Water quality data from selected springs and wells are listed below. **19** Spring near Nan Ruche: TDS 784 mg/L, pH 8.19, temperature 30 °C, Ca 34.73 mg/L, Mg 22.7 mg/L, Na 170.9 mg/L, K 4.99 mg/L, HCO_3 274.59 mg/L, Cl 184 mg/L, SO_4 7.2 mg/L, NO_3 44.4 mg/L. **21** Spring near Maissade: TDS 615 mg/L, pH 7.23, temperature 26.2 °C, Ca 76.15 mg/L, Mg 41.34 mg/L, Na 35.51 mg/L, K 0.55 mg/L, HCO_3 506.47 mg/L,	Most wells are >150 m. Locally, wells may be >200 m. Depth to water is usually between 5 and 50 m. In the mountains, depth to water is usually >100 m. Seasonal fluctuation in the water levels can be great. Fracture zones are generally more prevalent near the surface and less likely at depths >60 m. Access is generally difficult to very difficult. The country's overall poor road network, steep slopes, and rugged terrain may hinder access and limit the availability of well sites. Generally, hard-rock drilling techniques are required.	Most areas may be unsuitable for hand pump wells, except where fractures or weathered zones can be intercepted during drilling. Successful wells in these areas depend upon encountering water-bearing fractures. The best zones for ground water exploration are generally in areas of intense fracturing. Using remote sensing techniques to identify potential fracture zones before drilling should improve the chances for successful wells. Aquifers are generally locally recharged by rainfall. Deforestation is increasing runoff and decreasing the amount of water available for recharge.

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
4 Fresh water scarce or lacking (continued)	sandstones, sandy shales, and shales, while the Maissade Formation consists of marls, sandstones, and lignite. The Las Cashobas Formation is between 1,400 and 1,850 m thick. It is principally found in the Artibonite, Centre, Nord, and Nord-Ouest departments. The Miocene-Pliocene Morne Delmas Formation and the Pliocene Hinche and Rivière Gauche Formations consist of conglomerates, clays, sandstones, and marls. The Morne Delmas Formation is between 300 and 400 m thick and is generally found in the Ouest department. The Hinche Formation is between 25 and 100 m thick. It is principally found in the Artibonite and Centre departments. The Rivière Gauche Formation is about 1,000 m thick and is principally found in the Grand'Anse, Ouest, Sud, and Sud-Est departments.		Cl 2.39 mg/L, SO_4 7.56 mg/L, NO_3 5.64 mg/L. **22** Spring near Bois Pin: TDS 275 mg/L, pH 7.62, Ca 64.13 mg/L, Mg 5.47 mg/L, Na 16.07 mg/L, K 0.59 mg/L, HCO_3 341.71 mg/L, Cl 12.85 mg/L, SO_4 23.66 mg/L, NO_3 20.26 mg/L. The main pollution problem is biological contamination from human and animal wastes. The shallower aquifers are typically contaminated near and downslope of populated areas.		Deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation.
5 Fresh water scarce or lacking	Aquifers consist mostly of Cretaceous to Quaternary igneous rocks and quartzite. The principal formations are the Cretaceous Dumisseau Formation; the Cretaceous Morne Cabrit, Terrier Rouge, La Mine, and Peraches series; the Eocene Perodin Formation; the	Unsuitable to small quantities are available. Springs typically yield between 0.05 and 1 L/s. Wells typically have yields of <5 L/s. Wells drilled into fracture zones may have greater yields. Yields from selected springs	Water is generally fresh with TDS typically between 200 and 600 mg/L. Water quality data from selected springs are listed below. **23** Spring Dieubonne: TDS 215 mg/L, pH 7.95, temperature 23 °C, Ca 12.02 mg/L, Mg 13.98 mg/L, Na 11.77 mg/L, HCO_3 122.14 mg/L	Most wells are between 20 and 80 m deep. Depth to water may be >100 m. Fracture zones are generally more prevalent near the surface and less likely at depths >60 m. Access is generally difficult to very difficult. The country's	Most areas are unsuitable for hand pump wells, except where fractures or weathered zones can be intercepted during drilling. Successful wells in these areas depend upon encountering water-bearing fractures. The

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 (continued)	Cretaceous to Miocene intrusives of the Batholite Loma de Cabrera (1930N07200W); and several undated formations. The igneous section ranges from a few meters to >1,500 m in thickness. The Dumisseau Formation consists of pillow lavas, basalt, diabase, and volcanic debris flows, interbedded with shales and limestones. It is found in the Grand' Anse, Ouest, Sud, and Sud-Est departments. The Cretaceous Morne Cabrit, Terrier Rouge, La Mine, and Peraches series consist of tuff, andesite, quartz diorite, dacite, and basalt, which locally can be slightly metamorphosed. These series are found in the Centre, Nord, and Nord-Est departments. The Perodin Formation consists of basalt, andesite, and tuff interbedded with marls and limestones. It is in the Artibonite and Centre departments. The Batholite Loma de Cabrera consists of quartz diorites and granodiorites and is in the Nord and Nord-Est departments. Scattered throughout are other undated and unnamed igneous formations that consist primarily of	are listed below. **23** Spring Source Dieubonne (1924N07205W): 0.1 L/s, and **24** Spring Source Mami (1823N07321W): 1 L/s.	HCO_3 122.14 mg/L, Cl 7.4 mg/L, SO_4 13.2 mg/L, NO_3 2.45 mg/L. **24** Spring Mami: TDS 552 mg/L, temperature 29.2 °C. Biological contamination may be a problem near and downslope of populated areas. Chemical contamination is limited due to lack of industrial activity and limited use of agrochemicals.	The country's overall poor road network, steep slopes, and rugged terrain may hinder access and limit the availability of well sites. Hard rock drilling techniques are required.	best zones for ground water exploration are generally in areas of intense fracturing. Using remote sensing techniques to identify potential fracture zones before drilling should improve the chances for successful wells. Aquifers are generally locally recharged by rainfall. Only a few wells have been drilled in these areas. Deforestation is increasing runoff and decreasing the amount of water available for recharge. Deforestation and overuse are lowering yields, dropping water levels, degrading water quality, and increasing the amount of seasonal fluctuation.

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
	basalt and are found within Cretaceous, Eocene, and Quaternary formations.				
6 Fresh water scarce or lacking	Aquifers consist mostly of Quaternary alluvium found in Plaine du Nord surrounding Fort Liberté, in the Rivière de l'Artibonite delta, in large parts of the Plaine du Cul-de-Sac, around Étang Saumâtre (1835N07200W), and in other alluvial deposits along the coast. In most coastal areas, the alluvium is generally <30 m thick, but in the Plaine du Cul-de-Sac and Rivière de l'Artibonite delta, the alluvium can be >100 m thick. Locally, aquifers exist of other types of deposits, especially permeable or fractured limestones. The Plaine du Nord is in the Nord and Nord-Est departments. The Rivière de l'Artibonite delta is in the Artibonite department. The Plaine du Cul-de-Sac and the Étang Saumâtre are in the Ouest department.	Very small to very large quantities are available. Typical well yields are from 1 to 100 L/s. Locally, wells may have yields >100 L/s. Yields from selected wells are listed below. **25** Well near Phaeton (1941N07154W): 4.5 L/s; **26** Well near Duclos (1917N07239W): 27 L/s; **27** Well with a hand pump near Port-au-Prince: about 1 L/s; and **28** Well near Source Sable (1836N07204W): 75.7 L/s.	Water is generally brackish but locally may be saline. TDS values are generally <7,000 mg/L. Along the coast, saltwater intrusion causes the water to be brackish to saline. In parts of the Plaine du Cul-de-Sac, especially near Étang Saumâtre, the mineralized soil causes the ground water to be brackish. TDS levels may increase during the dry seasons when recharge is minimal. Locally, other types of deposits may contain brackish to saline water due to saltwater intrusion. Water quality data from selected wells are listed below. **25** Phaeton: TDS 3,500 mg/L, pH 7.65, temperature 29.6 °C, Ca 62.12 mg/L, Mg 107.62 mg/L, Na 972.4 mg/L, K 1.91 mg/L, HCO_3 845.13 mg/L, Cl 630 mg/L, SO_4 11.9 mg/L. **26** Well near Duclos: TDS 3,220 mg/L, pH 7.57, Ca 70.14 mg/L, Mg 11.55 mg/L, Na 577 mg/L, K 3.13 mg/L, HCO_3 233.4 mg/L, Cl 875 mg/L, SO_4 15 mg/L, NO_3 2.73 mg/L. **27** Well near Port-au-	Most drilled wells are between 50 and 100 m deep. Hand-dug wells are generally <35 m deep. Depth to water is generally from 10 to 75 m. Access is generally feasible but may be locally difficult to very difficult. Along the coast, swampy ground may hinder access. In urban areas, congestion may hinder access and limit the availability of well sites. The country's overall poor road network may also hinder access. Generally, soft rock drilling techniques can be used.	Most areas are unsuitable for wells due to the brackish or saline water. Water should be treated to remove the dissolved solids before domestic use. Deforestation is decreasing the amount of water available for recharge. Deforestation and overuse are increasing the areas affected by saltwater intrusion. This is causing many wells that once produced fresh water to now produce brackish to saline water.

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
6 Fresh water scarce or lacking			Prince: TDS 1,280 mg/L, Ca 54 mg/L, Mg 13 mg/L, Na 11.77 mg/L, HCO_3 122.14 mg/L, Cl 850 mg/L, SO_4 116 mg/L, hardness 400 mg/L $CaCO_3$. **28** Well near Source Sable: TDS 5,528 mg/L. Biological contamination from human and animal wastes is widespread. Chemical contamination is increasing, especially near major towns. Shallow aquifers are generally contaminated.		

[1] Quantitative Terms:

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

[2] Qualitative Terms:

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

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:

Table C-2. Ground Water Resources (continued)

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	95.000	gallons per hour
gallons per minute	0.063	liters per second
gallons per minute	3.780	liters per minute

[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:

Plaine du Nord..(1940N07210W)

Geographic coordinates for Plaine du Nord that are given as 1940N07210W equal 19°40' N, 72°10' W and can be written as a latitude of 19 degrees and 40 minutes north and a longitude of 72 degrees and 10 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for location features on the country scale map. Geographic coordinates for rivers are generally at the river mouth.

Note:

ºC	= degrees Celsius	HCO_3	= bicarbonate	mg/L	= milligrams per liter
Ca	= calcium	K	= potassium	Na	= sodium
$CaCO_3$	= calcium carbonate	L/min	= liters per minute	NO_3	= nitrate
Cl	= chloride	L/s	= liters per second	pH	= hydrogen-ion concentration
Fe	= iron	m	= meters	SO_4	= sulfate
gal/min	= gallons per minute	Mg	= magnesium	TDS	= total dissolved solids