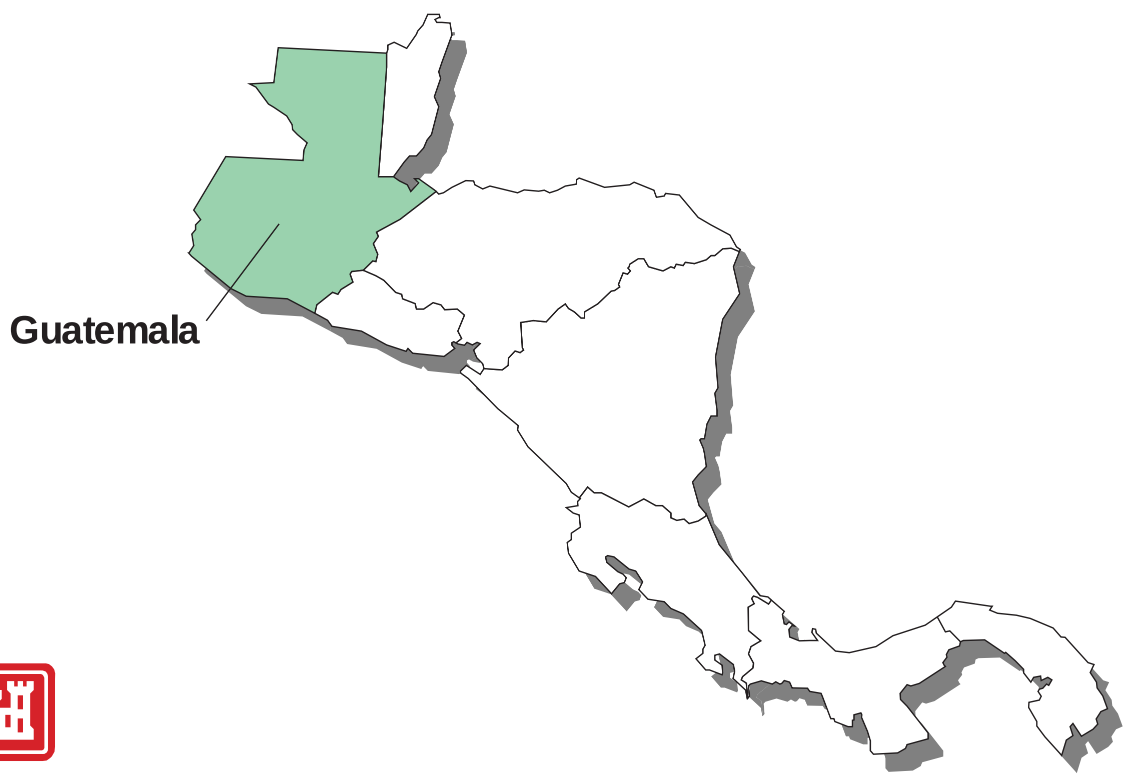
WATER RESOURCES ASSESSMENT OF GUATEMALA

UNITED STATES SOUTHERN COMMAND



US Army Corps of Engineers
Mobile District &
Topographic Engineering Center

JUNE 2000

Executive Summary

Guatemala has an abundance of water, with 18 major rivers originating in the volcanic highlands. 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. Water resources are stressed by an increasing demand, which has developed into a critical situation. The stress is partly due to the uneven distribution of the population; which is most densely populated in regions where water availability is low due to altitude or rainfall deficit. Guatemala City is a typical example. The opposite occurs in places where water resources are abundant.

Presently a comprehensive water law does not exist to control the use and abuse of the national waterways, and as a result, the rivers are used for sewage disposal. No authority controls the water resources, but a national commission for potable water and sanitation is being proposed this year. Commissions for other sectors, such as agriculture, electricity, environment, and health exist, but not for water supply. A national commission for potable water and a comprehensive, practical, and implementable national water law should be created to govern and protect the water resources of the nation.

The percentage of the population having access to potable water and sanitation services is extremely low. In 1994 it was estimated that 54 percent of the population had access to potable water services and 49 percent to sanitation services. Most rural areas have only latrines and no conventional sewerage systems. Diseases caused by water contamination are widespread. Guatemala has the highest child mortality rate of the Central American countries, owing in large part to water contamination.

Pollution of the water resources is a significant problem. Contamination of the surface water and shallow ground water are prevalent throughout the country. Domestic wastewater and agricultural runoff cause biological contamination of water near and downstream of populated places. Wastewater treatment is minimal nationwide. Numerous wastewater treatment plants exist, but few, if any, are functioning. As a result, surface water is laden with sewage, particularly in the heavily populated areas, and much of it is not usable for water supply. Many rivers are considered to be severely contaminated including the Rio Motagua, the Rio Villalobos, the Rio Michatoya, the Rio Las Vacas, and the Rio Samala. Lago de Amatitlan, south of Guatemala City, receives about 50 percent of the sewage of Guatemala City via Rio Villalobos and consequently is severely contaminated. Lago de Amatitlan is considered to be a ‘dead’ lake, but the first national watershed management agency, Autoridad para el Manejo Sustenable de la Cuenca y del Lago de Amatitlan, is working toward saving it.

Deforestation has altered the dynamics of the hydrologic cycle. It is a serious problem in Guatemala with devastating environmental consequences. Existing deforestation laws are difficult to enforce. The sedimentation caused by the deforestation carried in the national waterways reduces the amount of surface water available. Over the past 40 years, surface water availability has decreased 60 to 70 percent, primarily due to deforestation and increased population. Many rivers, including major ones, are dry in March and April.

As a result of surface water supply shortages and contamination, ground water is being relied upon to provide more water in the future. Many shallow aquifers are, however, becoming contaminated from surface pollution, causing dependency on deeper springs and wells to provide potable water.

Hydrologic data is lacking throughout the country, particularly since the mid-1980s when data collection decreased dramatically. Data is needed to solve water resources problems and to address critical need issues. Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia is making progress toward repairing the gaging network.

If the recommendations for watershed management are adopted, if progress is made toward reducing the untreated waste entering the waterways, and if a national water supply and sanitation commission is established, positive, immediate, and long-term benefits could be realized.

Preface

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

A team of water resources specialists from the U.S. Army Corps of Engineers Mobile District and the U.S. Army Topographic Engineering Center, listed below, conducted the water resources investigations in 1999 and subsequently prepared the report.

Thomas R. Spillman, Hydrologist
Topographic Engineering Center
Telephone: 703-428-7869
Facsimile: 703-428-6991
Internet:
thomas.r.spillman@tec02.usace.army.mil

Thomas C. Webster, Hydrologist
Topographic Engineering Center
Telephone: 703-428-6891
Facsimile: 703-428-6991
Internet:
thomas.c.webster@tec.02.usace.army.mil

Humberto Alas, Civil Engineer
Mobile District
Telephone: (503) 288-3329
Facsimile: (503) 288-3330
Internet:
ambrogic@embsansal.usinfo.org.sv

Laura Waite, Geologist and Report Manager
Mobile District
Telephone: 334-690-3480
Facsimile: 334-690-2674
Internet: laura.e.waite@sam.usace.army.mil

James Buckalew, Water Resources Engineer
Mobile District
Telephone: 334-694-3863
Facsimile: 334-690-2727
Internet: james.o.buckalew@sam.usace.army.mil

Water Resources Assessment of Guatemala

Contents

Contents (Continued)

Contents (Continued)

List of Acronyms and Abbreviations

Acronyms

AMSA	Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan (Authority for the Sustainable Development of the Amatitlan Lake and Watershed)
CARE	Cooperative for American Relief to Everywhere
CONAMA	Comision Nacional del Medio Ambiente (National Commission of the Environment)
DSM-MSPyAS	Division de Saneamiento del Medio del Ministerio de Salud Publica y Asistencia Social (The Environmental Sanitation Division of the Ministry of Public Health and Assistance)
EMPAGUA	Empresa Municipal de Agua (Municipal Management of Water)
ERIS	Escuela Regional de Ingenieria Sanitaria y Recursos Hidraulicos (The Regional School of Sanitary Engineering and Hydraulic Resources)
GDP	Gross domestic product
HCA	Humanitarian civic assistance
IGN	Instituto Geografico Nacional (National Institute of Geography)
INAB	Instituto Nacional de Bosques (National Institute of Forestry)
INDE	Instituto Nacional de Electrificacion (National Institute of Electricity)
INFOM	Instituto de Fomento Municipal (Institute of Municipal Development)
INSIVUMEH	Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia (National Institute of Seismology, Volcanology, Meteorology, and Hydrology)
INTA	Instituto Nacional de Transformacion Agraria (National Institute of Agrarian Transformation)
PAHO	Pan American Health Organization
PLAMAR	Plan de Accion para la Modernizacion y Fomento de la Agricultura Bajo Riego (Action Plan for the Modernization and Promotion of Agriculture under Irrigation; under Ministry of Agriculture)
UNICEF	United Nations Children’s Fund
USACE	U.S. Army Corps of Engineers (referred to in text as Corps)
USAID	U.S. Agency for International Development
USSOUTHCOM	U.S. Southern Command

Abbreviations

$CaCO_3$	calcium carbonate
Cl	chloride
cm/yr	centimeters per year
ft^3	cubic feet
gal/min	gallons per minute
km^2	square kilometers
L/min	liters per minute
L/s	liters per second
L/s/m	liters per second per meter
m^2/d	square meters per day
m^3/s	cubic meters per second
Mg	magnesium
mg/L	milligrams per liter
mL	milliliters
mm	millimeters
Mm^3	million cubic meters
MPN	most probable number
MW	megawatts
N	nitrogen
Na	sodium
NaCl	sodium-chloride
P	phosphorus
pH	hydrogen-ion concentration
SO_4	sulfate
TDS	total dissolved solids (the sum of all dissolved solids in water or waste water)

List of Place Names

Place Name	Geographic Coordinates
Alta Verapaz (department)	1540N09000W
Baja Verapaz (department)	1505N09020W
Belize	1715N08845W
Canal de Chiquimulilla	1355N09107W
Caribbean Sea	1630N08730W
Central Highlands (region)	1515N09030W
Chimaltenango (department)	1440N09049W
Chiquimula (department)	1440N08925W
Ciudad de Guatemala (also Guatemala City)	1438N09031W
El Golfete (lake)	1544N08853W
El Progreso (department)	1450N09000W
El Salvador	1400N08930W
Embalse Chixoy (reservoir)	1515N09030W
Escuintla	1418N09047W
Escuintla (department)	1410N09100W
Guatemala	1530N09015W
Guatemala City (also Ciudad de Guatemala)	1438N09031W
Guatemala (department)	1440N09030W
Gulf of Honduras	1610N08750W
Gulf of Mexico	2230N09000W
Honduras	1500N08830W
Huehuetenango (department)	1540N09135W
Izabal (department)	1530N08900W
Jalapa (department)	1435N08955W
Jutiapa (department)	1410N08950W
Lago de Amatitlan (lake)	1427N09034W
Lago de Atitlan (lake)	1442N09112W
Lago de Guija (lake)	1416N08931W
Lago de Izabal (lake)	1530N08910W
Lago Peten Itza (lake)	1659N08950W
Laguna de Ayarza (lake)	1425N09008W
Mayas Montanas (mountains)	1620N08918W
Mexico	1630N09200W
Mixco	1438N09036W
Montanas de Cuilco (mountains)	1530N09159W
Pacific Coastal Plain (region)	1410N09115W
Pacific Ocean	1400N09200W
Peten (department)	1650N09000W
Peten Highlands	1620N08925W
Peten Lowlands	1650N09000W
Quezaltenango	1450N09131W
Quezaltenango (department)	1445N09140W
Quiche (department)	1530N09055W
Retalhuleu (department)	1420N09150W
Rio Achiguate	1355N09055W

List of Place Names (Continued)

List of Place Names (Continued)

Place Name	Geographic Coordinates
Sacatepequez (department)	1435N09045W
San Marcos (department)	1500N09155W
Santa Rosa (department)	1410N09018W
Sierra de Chama (mountains)	1540N09030W
Sierra de Chuacus (mountains)	1505N09030W
Sierra de las Minas (mountains)	1510N08940W
Sierra de los Cuchumatanes (mountains)	1535N09125W
Sierra de Santa Cruz (mountains)	1540N08915W
Sierra Madre (mountains)	1435N09100W
Solola (department)	1440N09115W
Suchitepequez (department)	1425N09120W
Totonicapan (department)	1500N09120W
Zacapa (department)	1500N08930W

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:

Alta Verapaz (department).............1540N09000W

Geographic coordinates for Alta Verapaz (department) that are given as 1540N09000W equal 15°40' N 90°0' W and can be written as a latitude of 15 degrees and 40 minutes north and a longitude of 90 degrees and 0 minutes west. Geographic coordinates are approximate but are sufficiently accurate for locating features on the country-scale map. Geographic coordinates are generally at the mouth of rivers and at the center of mountain ranges.

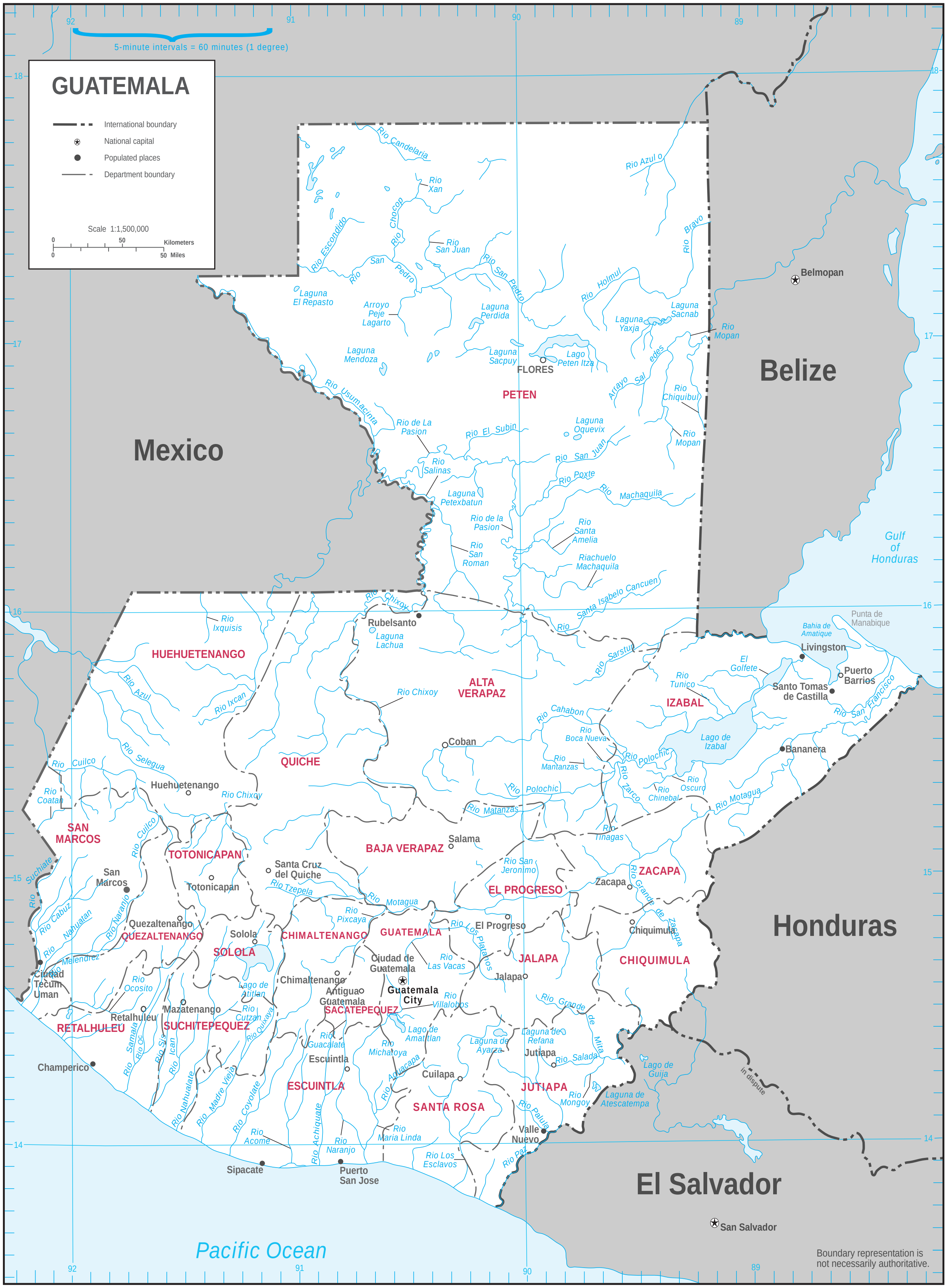


Figure 1. Country Map

Water Resources Assessment of Guatemala

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.[1]

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.[2] In developing countries, water use drops from 40 liters per day per person when water is supplied to the residence, to 15 liters per day per person if the source is 200 meters away. If the water source is more than 1,000 meters away, water use drops to less than 7 liters per day per person.[3] As well as being in abundant supply, the available water must have specific quality characteristics, such as the low concentration of total dissolved solids (TDS). The TDS concentration of water affects the domestic, industrial, commercial, and agricultural uses of water. The natural nontoxic constituents of water are not a major deterrent to domestic use until the TDS concentration exceeds 1,000 milligrams per liter. As TDS values increase over 1,000 milligrams per liter, the usefulness of water for commercial, industrial, and agricultural uses decreases. In addition to TDS concentrations, other quality factors affect water. These factors include the amount of disease-causing organisms, the presence of manufactured chemical compounds and trace metals, and certain types of natural ions that can be harmful at higher concentrations. Guatemala has no public wastewater treatment facilities, and most effluent is discharged untreated into the waterways.

The purpose of this assessment is to document the general overall water resources situation in Guatemala. 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. The scope was confined to a 'professional opinion', given the size of the country and the numerous technical reports available on the various aspects of the water resources of Guatemala.

This information can be used to support current and potential future investments in managing water resources and to assist military planners during troop engineering exercise and theater engagement planning. The surface water and ground water maps (figures C-1 and C-2), 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 map divides the country into surface water regions, based on water quantities available. The ground water map 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 devastating effects of deforestation on the water resources, the lack of wastewater treatment, water pollution, 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 Guatemala is shared by several government agencies and institutions. The U.S. Army Corps of Engineers assessment team met and consulted with the organizations most influential in deciding priorities and setting goals for managing water resources (see appendix A). Most of these agencies conduct their missions with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources.

II. Country Profile

A. Geography

Guatemala, with its 108,890 square kilometers of territory, is slightly smaller than the U.S. state of Tennessee. It lies southeast of Mexico and northwest and west of the other countries of Central America. Guatemala shares a 266-kilometer border with Belize to the northeast, a 203-kilometer border with El Salvador to the southeast, a 256-kilometer border with Honduras to the east, a 962-kilometer border with Mexico to the west and north, and has a 400-kilometer coastline, mainly on the North Pacific Ocean. Its location on the narrow strip, which joins the continental masses of the Americas, as well as its topographic relief, gives the country an enormous diversity of climatic regions.[4]

Figure 2. Vicinity Map

South to north, the topography transitions from a southern coastal plain to a large expanse of west-to-east-trending volcanic mountains which are dominant in the central part of the country. The terrain is mainly mountainous with narrow coastal plains and rolling limestone plateaus (Peten). The large Inter-American Andean Mountain range (Sierra Madre), which crosses the country in the northwest and southeast, is the main physiographical feature of the country. This range can be divided into four geographical areas of two lowland areas and two mountain systems. The lowland areas consist of: (1) the Peten and Belize lowlands, which have a typical karst topography in the north where altitude varies from a few to 600 meters; and (2) the Pacific coastal belt, from 25 to 50 kilometers wide in the south with altitudes reaching 500 meters above sea level. The two mountain systems consist of: (1) a ridge of volcanic mountains, including 33 volcanoes with maximum heights of 3,000 to 4,200 meters above sea level, parallel with the Pacific Coast; and (2) the Cuchumatanes, Chama, and Las Minas massifs, which include summits up to 3,800 meters, lying north of the volcanic mountains. In the northeast, the terrain is dominated by the flood plain of the Rio Motagua and the low-lying coastal plains of the Caribbean coast.

Guatemala is susceptible to volcanic eruptions and is subject to frequent violent earthquakes. At least 60 destructive earthquakes with intensities greater than six on the mercalli scale have occurred during the last 450 years. The last major earthquake struck on 3 February 1976 causing great destruction and 2,500 deaths. The Caribbean coast is subject to hurricanes and other tropical storms, such as Hurricane Mitch, which caused extensive damage in 1998. See figures 1 and 2 for general geographic information.

B. Population and Social Impacts

In 1994 the population was estimated to be 10,322,000. At a growth rate of 2.9 percent, the population is estimated to be 16 million by 2010. Most Guatemalans live in the valleys of the mountainous regions in the center of the country, characterized by numerous lakes and volcanoes and a temperate climate. (See Table 1. Population Distribution)

About 60 percent of the population live in rural areas, with 90 percent of this population living in communities of less than 500. About 2.1 million people live in the metropolitan area of Guatemala City. The most populous urban areas of the country are Guatemala City, Mixco, Quezaltenango, Escuintla, Mazatenango, Puerto Barrios, and Retalhuleu. The average population density of the country is 94.8 people per square kilometer.[5] About 55 percent of the total population live in extreme poverty. By the year 2000, it is estimated that 65 percent of the population will be under the age of 25.[6]

Table 1. Population Distribution

Department	Population	Capital	Approximate Area (km^2)
Alta Verapaz	650,126	Coban	8,726
Baja Verapaz	200,020	Salama	3,124
Chimaltenango	374,898	Chimaltenango	1,973
Chiquimula	268,379	Chiquimula	2,376
El Progreso	115,469	El Progreso	1,922
Escuintla	592,647	Escuintla	4,385
Guatemala	2,188,652	Guatemala City	2,025
Huehuetenango	790,183	Huehuetenango	7,880
Izabal	359,057	Puerto Barrios	9,038
Jalapa	206,355	Jalapa	2,063
Jutiapa	378,662	Jutiapa	3,219
Peten	295,130	Flores	35,270
Quezaltenango	606,556	Quezaltenango	2,164
Quiche	631,786	Santa Cruz del Quiche	8,559
Retalhuleu	261,136	Retalhuleu	1,856
Sacatepequez	196,536	Antigua Guatemala	493
San Marcos	766,950	San Marcos	3,596
Santa Rosa	285,456	Cuilapa	2,955
Solola	265,902	Solola	1,142
Suchitepequez	392,704	Mazatenango	2,392
Totonicapan	324,225	Totonicapan	1,050
Zacapa	171,146	Zacapa	2,692
Total	**10,321,975**		**108,900**

Source: Organizacion Panamericana de la Salud. *Plan Regional de Inversiones en Ambiente Salud*, "Analisis Sectorial de Agua Potable y Saneamiento en Guatemala." Serie Analisis Sectoriales, No. 4, Washington, DC, March 1995.

The water resources of the country are stressed in part because of the population distribution. The population is dense in regions where water availability is low due to altitude or rainfall deficit, and the opposite is true in regions where water resources are abundant. Guatemala City is a prime example. The city is home to more than 20 percent of the population. However, the valley in which Guatemala City is located crosses the Continental Divide where river discharge is minimal. The scarce surface water resources of Guatemala City cannot support the requirements of its population. Consequently, ground water resources are required to supplement the needs of the city.

C. Economy

With the approval of the North American Free Trade Agreement, Guatemala has become the immediate neighbor of the largest economic block in the world. The labor force of Guatemala is estimated to be 3.32 million, with unemployment estimated at 5.2 percent (1997).

Agriculture dominates the economy, employing about 50 to 60 percent of the labor force, accounting for 25 percent of gross domestic product (GDP), supplying two-thirds of exports. Coffee, sugar, and bananas are the main products, with coffee being the principal cash crop of the country. Present trends point to an accelerated increase in the production of new or nontraditional agricultural export products, such as tropical fruits and vegetables. Industry accounts for about 20 percent of GDP and 15 percent of the labor force.

The signing of the Peace Accords in December 1996, which ended 36 years of civil war, removed a major obstacle to foreign investment. In 1997 Guatemala met its economic target when GDP growth accelerated to 4.1 percent and inflation fell to about 9 percent after being as high as 37 percent in 1986.[7,8]

D. Flood Control

The government agency responsible for conducting research and development in flood control is the Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH).

The Motagua river valley, at the lower end of the Rio Motagua near the Atlantic coast, suffered severe flooding from Hurricane Mitch in October and November 1998, affecting 60,000 inhabitants and 24,170 acres of banana plantations. This acreage represents an estimated 83 percent of the crop, with an estimated rehabilitation cost of 80 million US dollars. The estimated losses of the banana companies, BANDEGUA, COBSA, and COBIGUA, of fruit lost during the storm and future harvests are 130 million US dollars. About 40 kilometers of existing dikes, 68 kilometers of roads, considerable lengths of railroad, and one bridge, the Conchas Bridge, were damaged. The riverbed itself was altered as a result of the extensive flooding. Also noted in the river was extensive erosion in some reaches, extensive sedimentation in others, and changes in channel form, alignment, and length.[9]

Mike 11, a mathematical model for flood prediction and control, was developed and published in 1998 by the Danish Hydraulic Institute. This model was created to study, investigate, and mitigate natural disasters caused by flooding in Central America. The institutions involved in this project were INSIVUMEH, Escuela Regional de Ingenieria Sanitaria y Recursos Hidraulicos (ERIS), San Carlos University of Guatemala, and Instituto Nacional de Electrificacion (INDE). The Cahabon Polochic river basin was the basin selected to be modeled. The purpose for developing this project was to minimize as much as possible the loss of human lives caused by the flooding in the low parts of the confluence of the Cahabon-Polochic rivers; to improve the management and operation of the reservoir and the Chixoy Hydroelectric Complex; and to improve the capacity of the country to mitigate material damages in villages and agriculture which are constantly threatened by this type of natural disaster. The initial objective was to train the members of these institutions on the management, utilization, and application of the model, with the purpose of using it in Central America.[10]

One of the last projects executed was the Map of Flood Threats (historic) on the national level. Recently, a reconnaissance of the river basins on the national level was made with the objective of establishing mitigation and monitoring controls. This work by INSIVUMEH is being coordinated with other public and private institutions with the purpose of reducing the effects of the predicted flooding in the winter of 1999. River basins such as the Rio Coyolate and Rio

Maria Linda would be monitored with basic alerts implemented. To be beneficial, the systems need to be automated with real time alerts, with a complete flood control program in the risk zone.

E. Legislative Framework

According to the constitution, the water of the country belongs to the people. However, no comprehensive water policy exists to properly manage and regulate the water resources and supply. Numerous agencies share responsibility for overseeing the water resources with little coordination; therefore, work efforts are duplicated and use of resources is inefficient. The fact that no wastewater effluent treatment laws exist has created uncontrolled abuse of the rivers, causing pervasive water contamination throughout the country. Deforestation laws exist, but enforcement is extremely difficult.

A national water law, negotiated for the past 10 years, has not yet passed, but is expected to pass in the new government in the year 2000. This law proposes the establishment of a water resources commission and policy to address the critical areas of deforestation and watershed management, effluent treatment, water supply, and sanitation.

The Secretaria de Recursos Hidraulicos de la Presidencia de la Republica was established in 1992 because of droughts resulting from El Nino. The aims of the agency were to establish a coherent policy for water resources, to formulate and develop the national hydraulic plan, to coordinate the planning and construction of hydraulic facilities for public use, and to evaluate and approve plans, programs, and projects relating to the use of national resources. The agency also represented the state for the international organizations specializing in national resources to coordinate studies, strategies, or projects of social benefits. This agency reported directly to the President but was abolished in 1998.[11,12,13]

III. Current Uses of Water Resources

A. Water Supply

Lack of water supply is a very serious problem, although the country has an average annual rainfall of 2,000 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.

No national water authority exists for water supply for the country. Each municipality is responsible for its own water supply and for maintaining the quality of the water. If the water fails the quality standards, the municipality is obligated to correct the problem. The Division de Saneamiento del Medio del Ministerio de Salud Publica y Asistencia Social (Environmental Sanitation Division of the Ministry of Public Health and Assistance) (DSM-MSPyAS) contacts the mayors of the municipalities directing them to solve the problem. The problem is often not addressed because of lack of enforcement. Only 10 percent of the municipalities use chlorine, but all are obligated to use it.[14] The lack of a national potable water supply and sanitation commission is the main reason for the absence of minimum health conditions in the country. There are no clear strategies, policies, or investment programs.[15]

Potable water supply and sanitation services are administered under many agencies and organizations including DSM-MSPyAS, Empresa Municipal de Agua (EMPAGUA), Instituto de Fomento Municipal (INFOM), the 329 municipalities, private corporations, nongovernment organizations, and international organizations and charities.

1. Domestic Uses and Needs

Much of the surface water is contaminated and is generally not usable for water supply. However, in the highlands, the streams originating in the volcanic mountains are not usually contaminated and are used for water supply with little or no treatment. In urban areas, ground water provides much of the domestic supply, and it will be heavily relied upon to provide for future needs. Ground water from deeper wells is considered fresh and potable. However, many shallow aquifers are contaminated.

With the exception of Guatemala City, municipal offices provide water services, but an accounting registry is practiced in only 12 of the 329 municipalities. Water losses are high (over 50 percent) and water quality is poor.[16]

Coverage of potable water and sanitation services is extremely low. It is estimated that potable water coverage is 55 percent in rural areas and 90 percent in metropolitan and urban areas. The demand for potable water in 1995 was estimated at 12.78 cubic meters per second. By 2010 it is expected to be greater than 26 cubic meters per second. In 1994 it was estimated that sanitation services coverage was 49 percent overall.[17,18,19]

Guatemala City. The water supply system for Guatemala City is operated and maintained by EMPAGUA, which was created in 1972. EMPAGUA supplies about 60 percent of the real water needs for the 2.5 million inhabitants of the city. The amount of water supplied to the system is 3.6 cubic meters per second from both surface and ground water sources. As of 1998, 86 water wells are supplying 1 cubic meter per second, with the rest coming from surface water sources. Two aquifers supply ground water for the city. The more productive one is in the southern part of the city, while the less productive one is in the northern part. EMPAGUA has its own water-testing laboratory at the University of San Carlos, which tests 60 samples per day.

A new project is underway to supply an additional 2.5 cubic meters per second from ground water and 4.7 cubic meters per second from surface water. The ground water will come from new wells north of the city, and the surface water will come from two rivers outside the city.

About 45 percent of the water produced is lost in the very old distribution system, including losses due to theft. The rationing of water has never occurred, but the system ‘pauses’ to allow the necessary quantities to recharge for proper distribution pressure, which usually occurs in March and April of the dry season.[20]

Urban Areas. The 329 municipalities of the country make up the urban areas, with each municipality having the responsibility for their own water supply and sanitation. The government agency INFOM supports the socioeconomic development of the 329 municipalities, including potable water and sanitation. INFOM provides financial and technical assistance. They aim to centralize all the aid and support from all the agencies and all activities for potable water and sanitation for the rural areas. Although all of the municipalities are obligated to chlorinate the water supply, few do. Coverage of potable water services is estimated to be 90 percent in the urban areas. Surface water sources supply about 70 percent of the water supply for urban areas. Ground water sources will be relied upon more in the future to supply more of the water. Coverage of sanitation services in 1994 in urban areas was estimated to be 70 percent.[21,22,23]

Rural Areas. Each community is responsible for their own water supply. Surface water sources supply 90 percent of the water supply for rural areas. Potable water services coverage is estimated to be about 55 percent in rural areas, which means at least 3 million people in the rural areas do not have access to potable water services. In 1994 coverage of sanitation services was estimated to be 35 percent. Most rural areas have only latrines and no conventional sewerage.[24,25,26]

Numerous relief agencies work to supply water for the rural areas. These organizations range from international donor agencies such as the Cooperative for American Relief Everywhere (CARE), the United Nations Development Program, and Catholic Relief Services to numerous smaller organizations such as Aqua del Pueblo.

The types of projects constructed by these organizations include the construction of small irrigation systems, the capture of water from streams in the volcanic highlands with direct distribution to the community, and, on a small scale, the drilling of wells and the capturing of springs in rural areas.

2. Industrial/Commercial Uses and Needs

Most industrial and commercial operations are located within the boundaries of major municipalities, particularly Guatemala City. These municipalities depend on their own water supply for their operations. The water supply comes from both surface and ground water. In the future, ground water will be relied upon more heavily to meet the industrial and commercial water needs due to the declining supply of surface water. Minimal data exists on industrial water use.

3. Agricultural Uses and Needs

Plan de Accion para la Modernizacion y Fomento de la Agricultura Bajo Riego (PLAMAR) is the responsible agency for irrigation. Presently, most (about 95 percent) of the water irrigation is from surface water sources, but since the quantity of surface water available for irrigation is decreasing due to deforestation, ground water is beginning to be used more.

Officials at PLAMAR estimate that 130,000 hectares (about 5 percent of potential) are currently irrigated, and about another 2 million hectares have the potential for irrigation. No measuring devices exist on the irrigation systems, but a new Japanese project to install water-measuring devices on the government-owned irrigation systems is underway. This project is not well received by the population because they do not want to pay more for their irrigation water. This same project is also trying to show the user that the funds paid are being returned to the system for maintenance and upgrading for better service.

Bananas, sugarcane, and coffee are the main irrigated crops of the country. The private sector irrigates 80,000 hectares for bananas, sugarcane, and hay, and the government irrigates 20,000 hectares for vegetables, berries, and watermelon. Numerous sugarcane plantations exist on the south coast. Many sugarcane plantation owners will divert rivers for their usage, leaving downstream users without sufficient water supply. Such situations are addressed in a proposed comprehensive water law. Another problem is that many secondary and major rivers are dry during March and April, which is the period of time when sugarcane needs the most irrigation. To meet the irrigation water demand during the dry season of November through April, storage dams or ground water resources must be used.

Drip irrigation is the type of irrigation system used in the country, as it uses the least amount of water, 0.5 liter per second per hectare, compared to 2 liters per second per hectare for gravity-fed systems, and 1 liter per second per hectare for spray irrigation.[27,28]

B. Hydropower and Geothermal Power

INDE is responsible for the electrical energy system. Five major hydropower plants and one geothermal plant operate in the country. In Guatemala, about half of the electricity is supplied by hydropower and the other half by thermal power (other than geothermal). More geothermal power is expected to be used in the future. Table 2 contains a listing of the INDE hydropower plants and their capacities.[29]

Table 2. Hydropower Plants, 1998	
Project	**Installed Capacity (MW)**
Chixoy	265
Aguacapa	75
Jurun Marinala	60
Esclavos	6.5
Santa Maria	5
Rio Hondo	2
El Porvenir	2
Michatoyas	1
Chichaic	0.5
Total	**417**

Sources: Instituto Nacional de Electrification de Guatemala (INDE), *El Sector Electrico de Guatemala*, "Gerencia de Planificacion," Guatemala City, 1997.

INDE, *Informe Estatistico 1997*, 1997.

Chixoy is by far the largest hydropower plant in the country. Plants of this size are no longer being planned. The country is planning smaller hydroelectric projects. Chixoy, located in karst terrain, operates at lower capacity during the dry season. Two potential sites upstream of Chixoy were studied as potential hydropower sites, but it was determined there is insufficient water to build a reservoir.

The two most serious problems facing the hydropower projects are water contamination and deforestation, which cause erosion and sedimentation that is rapidly filling the reservoirs. To reduce the detrimental impacts of sedimentation, reforestation of the watershed has been undertaken, and tunnels have been installed to capture and remove sediments in the reservoir, but these efforts are having minimal impact on the increasing sediment accumulation. Chemical and biological contamination of the water has increased operating costs and adversely affected the turbines and other equipment. The reservoirs are not used for recreation.

Near Amatitlan, a 5-megawatt geothermal plant has been operating since November 1998. It has a capacity of 12 megawatts. Of four wells (about 1,000 feet depth each), two are producing wells, and two are injection wells with one injection well in reserve. Five additional potential geothermal sites have been identified in the volcanic chain. Once the water is used, before it completely cools, it is reinjected into the earth through the injection wells. The water is highly mineralized, but because of the high temperature, the minerals stay in solution, and the water is reinjected before mineral deposition occurs. Zunil is a 24-megawatt-capacity geothermal plant under construction now, which is scheduled to be operating in the year 2000.[30,31]

C. Stream Gage Network

INSIVUMEH is the agency responsible for the collection of water data. However, budget and other problems have caused the deterioration of the data-gathering network. Most of the available water data is through the mid-1980s. Many hydrometric stations were lost in the war and INSIVUMEH is in the process of recovering them. Approximately 17 hydrometric stations were recovered in 1998 and 1999. Most of the hydrometric network is concentrated in the Pacific coastal area and in the agricultural areas, particularly along the Rio Motagua. The network is very limited in the Peten Lowlands. Deforestation is becoming critical in many of the mountainous areas, making the need for accurate climatological information even more important. Due to the 36-year-long civil war that recently ended, many of the gaging stations are in a state of disrepair. However, efforts are being made to rebuild and replace the equipment and continue gathering data. A great need exists to reestablish the national network of river and rain gages. The technical information obtained from such a network is essential for effective water resources management. Lack of hydrological data is a problem in planning and developing water projects in the country.[32,33]

D. Waterway Transportation

Of the rivers, the Rio Dulce, Rio Polochic, Rio Sarstun, Rio de la Pasion, Rio Salinas, and Rio Usumacinta have the largest quantities of water and are navigable in lower reaches. During high flow, they are navigable by small vessels. The major lakes, such as Lago de Atitlan, Lago Peten Itza, and Lago de Izabal, have lake navigation. On the Pacific Coast, navigation is possible via the 153-kilometer-long Chiquimulilla Canal which carries saline water. Guatemala has an estimated 1,035 kilometers of navigable channels and 950 square kilometers of navigable lakes.34

E. Recreation

Tourism is considered as the second source of income after coffee. Most tourism deals with history and archaeology, but adventure and ecological tourism are closely related to water resources. The country possesses much natural beauty, such as mountains, valleys, volcanoes, and tropical jungles with more than 30 ecological reserves rich in flora and fauna.[35]

Lakes and rivers are a vital part of the landscape. Lago de Atitlan, Lago Peten Itza, and Lago de Izabal are particularly important for recreation. Also important is the Rio Dulce with its connection to the Atlantic Ocean. Whitewater rafting is possible in many rivers in the country, such as in the Rio Cahabon in the Departamento de Alta Verapaz and in the Rio Naranjo and Rio Usumacinta. Travel through the Rio Dulce provides bird-watching opportunities and access to historical and archaeological sites, with a canyon leading to the mouth of the river in the Atlantic Ocean. Lago de Atitlan, in the highlands in the Departamento de Solola, is a very interesting geological site, with a surface area of 80 square kilometers and an altitude of 1,571 meters.

The total aquatic surface is estimated to be 1,093 square kilometers with a great potential for development, but utilization and conservation controls need to be considered in developing tourism.[36,37]

IV. Existing Water Resources

A. Surface Water Resources

Fresh water (<1,000 milligrams per liter TDS) is available throughout most of Guatemala from streams and lakes. Surface water covers about 1,000 square kilometers of the 108,900 square kilometers of land area in the country.[38] Surface water resources provide about 70 percent of the public water supply in urban areas and 90 percent of the water supply in the rural areas of the country.[39] Although surface water resources are abundant, they are unequally distributed, highly seasonal, and generally polluted. During the dry season, many streams cease to flow. Along divides, surface water resources are typically at their initial point and minimum flow.[40] Surface water resources downstream in the foothills or on the coastal plains have larger watersheds from which to supply a greater discharge that in turn can meet larger demands.

Deforestation and physiography also affect the quantity of surface water available in a given region. See table C-1 and figure C-1 for further details.

Water resources are becoming stressed by an increasing demand. Each year, the ability to supply water becomes more difficult due to the limited supply and the limited capacity of the delivery system. About 4 percent of the total water supply is in the highlands, which are the most populated areas in the country.

1. Precipitation and Climate

Weather is influenced by the predominantly mountainous terrain and varies accordingly. The climate is generally tropical with distinct wet and dry seasons. The wet season, known locally as *invierno*, extends from early May through October; the dry season, known locally as *verano*, extends through the rest of the year. In the lowland areas, the wet season usually begins slightly earlier during early-to-mid-April. During the dry season, stream flows decrease, and smaller streams dry up, particularly in the highlands. From late February until the start of *invierno* in May, drought conditions prevail throughout many of the highland and smaller stream basins in the country. Precipitation amounts vary with the terrain. Weather systems and prevailing winds generally travel from west to east in the country. Along the Pacific Coast, the average annual precipitation varies from 100 to 150 centimeters. Moving inland, rainfall generally increases from 150 centimeters to 350 centimeters per year in the foothills of the mountain range. Annual precipitation exceeds 400 centimeters in isolated pockets in the western foothills. Within the high plateau of the mountains, rainfall decreases to 100 to 200 centimeters per year. A rain shadow effect occurs to the north of the mountains with precipitation totals dropping to less than 100 centimeters per year. North of the Rio Motagua valley, annual precipitation begins to increase to the north averaging 250 centimeters. The greatest rainfall totals in the country occur in the Rio Ixcan basin with annual totals exceeding 600 centimeters. Rainfall totals decrease toward the northeast in the Peten and east along the Honduran border with annual totals averaging less than 200 centimeters. The precipitation totals combined with the growing amount of deforested land cause large amounts of surface runoff. Flood events are growing significantly during peak discharge but are of short duration.

Most of the population lives in the mountains due to the favorable climate. Average annual temperature in the mountains is 18.7 degrees Celsius (65.6 degrees Fahrenheit). Along the Pacific Coast, the average annual temperature is 26.7 degrees Celsius (80 degrees Fahrenheit) and along the Caribbean coast, the average annual temperature averages 25.5 degrees Celsius (78 degrees Fahrenheit).

Periods of drought also occur, primarily in March and April at the end of the dry season as streams go dry and ground water levels drop.

2. Drainage Basins

INSIVUMEH has divided the country into three drainage basins: the Pacific Ocean basin, the Caribbean Sea basin, and the Gulf of Mexico basin (see table 3 and figure C-1). These 3 principal basins can be further divided into 34 lesser basins that capture the significant streams of the country. There are 18 streams that discharge into the Pacific Ocean, 6 streams that drain into the Caribbean Sea, and 10 that empty into the Gulf of Mexico. About 55 percent of the watersheds in the country are shared with neighboring countries. Most of the monitored streams are in the Pacific Ocean basin.

The smallest basin, the Pacific Ocean basin, occupies 25 percent of the country. The basin has relatively straight streams with initially steep short courses, originating in the upper elevations of the Sierra Madre where they abruptly level off and flow south to the Pacific Ocean. The average length of the streams is 100 kilometers with the headwaters starting at elevations of 2,000 to

3,000 meters. The upper reaches of the basin have streams that provide meager to very small amounts of water only during the wet season, May through October. Downslope, the streams are able to provide small quantities of fresh water on a seasonal basis. Within the coastal plain, streams provide moderate amounts of fresh water on a seasonal basis. Many of the streams that provide large to enormous amounts of brackish to saline water year-round discharge into marshes or estuaries at the coastline. Surface water quantities are further depleted on the coastal plain by the current agricultural practices and the lack of regulations to enforce equitable use and treatment of the water resources. Plantations near the headwaters of the streams typically use as much of the stream water as they require, leaving the plantations closer to the coast with meager or no flow during the dry season. The principal streams in the basin include Achiguate, Acome, Coatan, Coyolate, Los Esclavos, Maria Linda, Madre Vieja, Nahualate, Naranjo, Ocosito, Olopa, Ostua-Guina, Paso Hondo, Paz, Pueblo Viejo, Samala, Sis, and Suchiate. The principal lakes include Lago de Amatitlan, Lago de Atitlan, Laguna de Ayarza, and Lago de Guija.

The Caribbean Sea basin, which occupies about 35 percent of the country, is located in the central and eastern parts of the country. Its streams also have initially steep short courses but long gradual descents. The streams of this drainage basin generally meander slightly to the northeast as they approach the Caribbean Sea. The longest stream in the country, the 486-kilometer-long Rio Motagua, drains this basin. Quantities initially begin as meager to very small on the north slope of the Sierra Madre. Quantities of fresh water increase in the Rio Motagua valley to seasonally moderate and eventually become large to enormous year-round in the lower reaches of the Rio Motagua, Lago de Izabal, and El Golfete basins. In the Sierra de las Minas and the Sierra de Santa Cruz, quantities of fresh water are expected to be small on a seasonal basis. In the eastern Peten centered around the Maya Mountains, only meager to very small quantities of fresh water are available on a seasonal basis. Along the Caribbean coast, expect large to enormous quantities of brackish to saline water year-round from marshes, lagoons, and estuaries. In the fall of 1998, Hurricane Mitch inflicted the most significant damages recorded in this basin. The lower reaches of the Rio Motagua basin were especially hard hit by flooding. The principal streams in the basin include the Cahabon, Dulce, Grande de Zacapa, Motagua, Polochic, and Sarstun. The principal lakes include El Golfete and Lago de Izabal.

The Gulf of Mexico basin drains the northwestern part of the country and the western part of the northern Peten Lowlands. Although streams in this basin display branching patterns, they are subject to some degree of structural control that results in near right-angle stream segments. The structural control is the result of four minor west-to-east-trending mountain ranges occurring in the southern part of the basin. This basin is the largest in Guatemala and occupies about 40 percent of the country. Meager to very small quantities of fresh water are available on a seasonal basis from the upper reaches of the streams originating in the Sierra Madre, Sierra de Chuacus, and the Montanas de Cuilco. Small quantities of fresh water are available on a seasonal basis from streams originating in the Sierra de los Cuchumatanes and in the Sierra de Chama. Moderate quantities of fresh water are available on a seasonal basis throughout most of the lower part of the basin. In the Peten Lowlands, meager to very small and small quantities of fresh water are seasonally available in the eastern and central parts of the basin. Large to very large quantities of fresh water are available year-round from the Rio Chixoy, Rio de La Pasion, Rio Salinas, and Rio Usumacinta. Enormous quantities of fresh water are perennially available from Lago Peten Itza in the central part of the Peten Lowlands. Streams may disappear in the northern lowlands due to internal drainage of the karstic limestone. The principal streams in the basin include Chixoy, Cuilco, Ixcan, La Pasion, Nenton, San Pedro, Selegua, Usumacinta, and Xaclbal. The principal lakes and reservoirs include Embalse Chixoy and Lago Peten Itza.

Table 3. Drainage Basins

Basin Number and Name (see Fig. C-1)	Selected Rivers	Drainage Area (km^2)	Length	Mean Discharge (m^3/s)
I Pacific Ocean	Rio Nahualate	2,005	130	61
	Rio Ocosito	3,158	107	30
	Rio Paz	1,733	134	23
II Caribbean Sea	Rio Motagua	12,716	487	209
	Rio Cahabon	2,446	196	164
	Rio Polochic	1,467	194	69
III Gulf of Mexico	Rio La Pasion	12,076	354	323
	Rio San Pedro	14,331	186	53
	Rio Selegua	1,123	102	38

Source: Instituto Nacional de Sismologia, Volcanologia, Meteorologia e Hidrologia, *Balance Hidrico Superficial de La Republica de Guatemala*, Guatemala City, June 1992.

3. Lakes and Swamps

Guatemala has about 20 lakes of varying sizes and environmental settings. The water in each lake is fresh but not potable. Of the 20 lakes, 5 are significant. The first lake, the largest natural lake in the country, is Lago de Izabal in the central part of the Departamento de Izabal near the Gulf of Honduras. This lake, which covers about 590 square kilometers, drains northeastward into El Golfete and ultimately into the Gulf of Honduras. The second lake, El Golfete, is the fourth largest lake covering an area of about 62 square kilometers. Both of these lakes have elevations of less than 1 meter above mean sea level and are subject to flooding during significant precipitation events. The third lake, Lago de Atitlan, is about 100 kilometers southwest of Guatemala City in the Departamento de Solola. It covers 130 square kilometers at an elevation of 1,562 meters above mean sea level, where volcanic peaks surround it. Lago Peten Itza, the fourth significant lake, is in the Departamento de Peten. It covers about 100 square kilometers at an elevation of 110 meters above mean sea level. Lago de Amatitlan, the fifth lake, is about 20 kilometers south of Guatemala City. It covers an area of 15 square kilometers at an elevation of 1,186 meters above mean sea level. This lake is the recipient of about half of the domestic and industrial effluents of Guatemala City, which are transported to the lake via the Rio Villalobos. Because of this pollution, Lago de Amatitlan is considered a dead lake.

The Embalse Chixoy, the largest reservoir in Guatemala, is capable of storing an estimated 460,000,000 cubic meters of water for use in the generation of hydroelectric energy. This reservoir is in the Departamento de Baja Verapaz and captures water from the Rio Chixoy. In addition to the Chixoy, Guatemala has four other large hydroelectric plants. Three of these, Aguacapa, Jurun Marinala, and Esclavos, have no information available concerning the existence or capacity of any associated reservoirs. The fourth, Santa Maria, stores 200,000 Mm3 of the Rio Samala and is also documented in Figure C-1 and Table C-1 with the Chixoy reservoir.

Mangrove and grass swamps exist along the Pacific and Caribbean coasts. Water in these swamps is brackish. The most extensive swamp area is along the Pacific Coast in the Escuintla and Santa Rosa departments. It flanks the port city of Puerto San Jose. Extending through this swamp area is an inland waterway called the Canal de Chiquimulilla. Another extensive wetland area along the Pacific Coast is near the border with Mexico in the Retalhuleu and San Marcos departments. This area is within the Reserva Natural El Manchon and is under environmental protection.

4. Deforestation

A major environmental problem that is adversely affecting the surface water resources is rapid deforestation. Both the commercial and private sectors contribute to deforestation. With 1.5 percent, Central America had the second highest deforestation rate in the world during the 1980s. According to *El Plan de Accion Forestal para Guatemala*, since 1992 deforestation is estimated to be 90,000 hectares per year. As of 1996, the Departamento de Peten had about 57 percent of the forests in the country, followed by Quiche with 9 percent and Izabal with 6 percent. In 1980 it was estimated that 51.2 percent of the country was covered in forests; in 1992, it was estimated to be 31 percent. A program is being implemented to determine deforestation rates more accurately using Landsat imagery. The Instituto Nacional de Bosques (INAB) has deforestation laws, but they are not enforced. INDE received 14 million US dollars for watershed management of the Lago Chixoy basin. However, due to environmental factors and the tremendous scale of the deforestation problem, the efforts of INDE are having minimal impact. Integral watershed management is needed to control deforestation and the resulting erosion and sedimentation.[41,42,43,44]

The removal of trees and vegetation allow for increased and faster runoff of rainfall. The faster runoff causes a rapid increase of the water entering the streams, 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. The lack of a sustainable water source causes the streams to go dry at the beginning of the dry season. 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. 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. Over the past 40 years, surface water availability has decreased 60 to 70 percent, primarily due to deforestation and increasing population. For all areas, current river discharge values are probably larger than historical data indicates, since evapotranspiration and infiltration losses are less with lower vegetation density, resulting in higher runoff.

Deforestation is also a social and economic problem. The population has had a ‘slash and burn’ mentality for generations. They were taught to use the trees and the water, and conservation is not in their culture. The rural areas do not have access to electricity for cooking or the means to pay for alternate sources of fuel. Therefore, trees are cut down to burn for domestic needs, which contributes to deforestation. It would cost an estimated 300 million US dollars annually to provide gas as a source of fuel to the rural areas to replace dependence upon wood.

5. Lago de Amatitlan Watershed Management

The Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan (AMSA) is a very well managed agency that has been in operation since 1996. AMSA is the watershed management agency of the Lago de Amatitlan basin, the first watershed in the country to be managed. About 50 percent of Guatemala City lies within this basin, which has an area of

381 square kilometers. Plans are to begin managing more basins, as funding becomes available, with the Izabal watershed being the next basin to be managed followed by Lago de Atitlan. The future watershed management programs will be modeled after the AMSA program. The main objective of AMSA is to control the quality of water in the rivers.

Lago de Amatitlan is considered a ‘dead’ lake. Swimming, fishing, or contact of any sort is not allowed. The lake receives about 50 percent of the domestic and industrial effluent of Guatemala City via Rio Villalobos. Lago de Amatitlan discharges into the Rio Michatoya and then into the Pacific Ocean. (Rio Villalobos, Lago de Amatitlan, and Rio Michatoya are considered to be severely contaminated.) In 1994, the Lago de Amatitlan basin had 1.1 million inhabitants. It is estimated that about 22,000,000 cubic meters per year of wastewater, 75,500 tons of solid waste, and 500,000 tons of sediment annually are discharged in the basin. With 800 industries here in 1998, the basin is also highly industrialized. In addition to the waste discharged due to the high population and the numerous industries, the extensive use of agrochemicals also contributes to eutrophication of the lake and to degradation of flora and fauna. Only 7 of 36 sewage treatment plants in the basin are working. Active restoration of the existing sewage treatment plants is ongoing. Soil and sand, predominantly of volcanic ash and rock, washing away from the land, have been gradually carried and deposited in the lake. Torrential storm-water flows in the tributary easily erode soils, and considerable amounts of surface soil in the rivers and other waterways eventually find their way into the lake.

If the current restoration efforts of Lago de Amatitlan fail, it is estimated that by the year 2020, the lake will be filled in.[45]

B. Ground Water Resources

Fresh ground water from wells and springs is an essential resource and a major source of consumable 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 involve the government of Guatemala and many international and private organizations.

Ground water is generally plentiful from sedimentary aquifers throughout the plains, valleys, and lowlands of the country. However, in the mountainous areas, the availability of fresh ground water varies considerably from locally plentiful to unsuitable. The two most productive aquifers are the Pacific Coastal Plain alluvium and the karstic and fractured limestone that extend beneath the Sierra de los Cuchumatanes, Sierra de Chama, and Peten Lowlands. Other more limited aquifers are important locally. The mountains and hills of Guatemala contain many types of aquifers, including karstic and fractured limestone, volcanic pyroclastic and lava deposits, low permeable sedimentary, igneous, and metamorphic aquifers. Alluvial plains, valleys and lowlands make up about 50 percent of the country but contain about 70 percent of the available ground water reserves (see appendix C, figure C-2, map units 1, 2, and 6).

The alluvial areas (map units 1 and 6) make up about 20 percent of the country and contain about 40 percent of the available ground water reserves. Areas containing karstic and fractured limestone aquifers (map unit 2) make up about 30 percent of the country and contain about 30 percent of the available ground water reserves. Areas containing aquifers consisting of volcanic pyroclastic deposits and lava flows (map unit 3) make up about 20 percent of the country and contain about 20 percent of the available ground water reserves. Aquifers with poor permeability (map units 4 and 5) make up about 30 percent of the country and about 10 percent of the available ground water reserves.

Deforestation has a negative impact on the ground water resources of the country by reducing the amount of water that recharges the aquifers, resulting in lower ground water levels. Most hand pumps cannot produce water from depths greater than 91 meters.

Although ground water is generally safer than untreated surface water supplies, many shallow aquifers are biologically contaminated near populated areas, primarily due to improper waste disposal. All wells in the Rio Motagua valley are considered to be biologically contaminated. This is the combined result from the flooding caused by Hurricane Mitch and preexisting conditions from agricultural chemicals and improper waste disposal. Most of the shallow wells on the Pacific Coastal Plain are also contaminated.

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. 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); karstic and highly fractured limestones (map unit 2); and aquifers consisting of volcanic ash, cinder, and lava flows (map unit 3). Other aquifers are and igneous and metamorphic deposits (map unit 4) and sedimentary deposits of interbedded sandstone, conglomerate, limestone, and shale with low permeability (map unit 5).

In the plains, lowlands, and valleys, depth to water is generally less than 50 meters. In the mountains, depth to water is generally less than 150 meters but locally may be as great as 300 meters. In many areas, the depth to water may be too deep for economical use. Seasonal fluctuation of the water table can be more than 5 meters. Aquifers in the mountains are generally recharged by rainfall, while those in the lowlands are primarily recharged by aquifers originating in the mountains and by rainfall.[46]

Access to well sites is generally difficult throughout the country. In the north, siting and drilling are made difficult by the underlying karst topography, dense vegetation, and lack of roads. Marshes and swamps are present along part of the Pacific Coastal Plain and Gulf of Honduras. In the southern part of the country, steep mountain slopes make ground water exploration difficult. The Pacific Coastal Plain and the Rio Motagua valley are easily accessible during the dry season of November through April.

Wells in all areas should be cased and screened especially where aquifers are composed of unconsolidated sediments or volcanic ash.

a. <u>Alluvial Aquifers (map units 1 and 6)</u>

Fresh water is generally plentiful from productive Quaternary-age aquifers in the Pacific Coastal Plain alluvium, northwestern Peten Lowlands, and large river valleys (map unit 1). The Pacific Coastal Plain is 20 to 60 kilometers wide. Ground water in the alluvial deposits is generally found in unconsolidated sand and gravel deposits interbedded with silt and clay at depths less than 10 meters.

Brackish to saline water is generally plentiful from alluvial aquifers near the coast (map unit 6). Thin fresh-water lenses may float on the saline water in many places. However, overpumping of these aquifers may lead to saltwater intrusion.

b. <u>Karstic Limestone Aquifers (map unit 2)</u>

Fresh water is locally plentiful from Cretaceous and Permian karstic and fractured limestone aquifers. The limestone aquifers are primarily found in the Peten Lowlands, Peten Highlands, Sierra de los Cuchumatanes, Sierra de Chama, and Sierra de Santa Cruz. Over extended periods, circulating ground water has caused dissolution of the limestone in this region. As a result, solution-enlarged openings in the form of caves, widened joints, and fractures have occurred in the subsurface. The rock overlying these underground openings sometimes collapses to form sinkholes at the surface. Locally, these are called cenotes. These solution features, which are fairly extensive in these areas, are good sites for potential ground water production. The aquifers beneath them can provide meager to very large quantities of fresh water, although brackish water occurs locally where gypsum is interbedded with the limestones.[47] Water levels are subject to significant variation from wet to dry seasons. Caution must be used in ground water exploration in karstic areas to either avoid underground chambers or anticipate and be prepared for their existence.

c. Volcanic Pyroclastic and Lava Aquifers (map unit 3)

Fresh water is locally plentiful from Quaternary- and Tertiary-age volcanic aquifers consisting of pyroclastics and lava. The ground water tends to be high in chlorides and sulfates because these aquifers consist mainly of volcanic lava and sediment such as ash, sand, and cinder, which are constituents of the volcanic deposits. The volcanic aquifers are found north of the coastal plains in the Pacific volcanic belt which extends through the Central Highlands. These aquifers are the most important aquifers in the Guatemala City metropolitan area. The Tertiary-age tuffs and lava deposits are the most productive aquifers of the volcanic deposits.[48] Very small to very large quantities of fresh water are available from these volcanic aquifers at depths of generally less than 150 meters.

d. Other Aquifers (map units 4 and 5)

Fresh water is locally plentiful from Tertiary- and Cretaceous-age interbedded sandstone, conglomerate, limestone, and shale. Ground water is primarily from solution fissures, bedding planes, joints, and pore spaces. Due to the low permeability of this aquifer, this unit is not considered a regional aquifer. Very small to large quantities of water are locally available from the sedimentary aquifers.

Fresh water is locally plentiful from Paleozoic age low-permeability igneous, metamorphic, and metasedimentary aquifers in the Central Highlands within a 20- to 60-kilometer-wide belt that extends across the country from east to west. These hard, dense rocks make poor aquifers. They are not favorable sites for ground water production except in places where they are highly fractured or weathered. However, meager to small amounts of fresh ground water are locally plentiful from these aquifers.[49]

C. Water Quality

The quality of surface water throughout Guatemala is a growing concern. Surface water is considered fresh except along the coastlines, where the quality gradually changes to brackish and finally to saline. Sedimentation problems resulting from deforestation occur throughout the country. Biological and chemical contamination occurs in varying intensities throughout the country. Sewage systems within the primary population centers are inadequate to nonexistent, and raw effluent is discharged directly into local streams. During the wet season, diseases such as cholera increase due to the spread of bacteria via these contaminated surface water sources.

Except for brackish or saline ground water near the Pacific and Caribbean coasts, ground water is suitable for most uses. Biological and chemical contamination occurs in unconfined shallow water table aquifers near population centers.

Chemical contamination from agricultural spraying is also a major source of surface and ground water contamination and degradation of rivers and streams. The Pacific Coastal Plain and the Rio Motagua valley are the agricultural areas that have the greatest concentrations of agricultural contamination. In these areas, both surface water resources and upper ground water aquifers are contaminated.

1. Surface Water

The quality of surface water resources is generally fresh except along the coastal areas of the country. However, based on established biological and chemical standards, every water body in the country should be considered contaminated. In agricultural areas, pesticides are a primary source of contamination. Sewage from Guatemala City has caused the Rio Villalobos, which receives 60 percent of the sewage, and the Rio Las Vacas, which receives the remaining 40 percent of the sewage, to be considered the most contaminated streams in the country. The Rio Las Vacas drains into the Rio Motagua and contaminates it and all points downstream. The Rio Motagua has contributed to the contamination of the upper aquifers in its lower floodplain during periods of flooding. Most shallow hand-dug wells in these areas are biologically and chemically contaminated. The Rio Villalobos eventually drains into and severely contaminates Lago de Amatitlan. The Rio Michatoya, which drains Lago de Amatitlan, is also severely contaminated throughout its entire length. The Rio Samala, which drains the city of Quezaltenango, is severely contaminated with biological and industrial pollution. The Rio Guacalate and the other minor streams, which drain the city of Escuintla, are severely contaminated by biological and industrial waste. A few streams originating near volcanoes contain large amounts of chlorides and sulfates. Throughout the country, but especially in the northwest, deforestation has resulted in increased sedimentation of streams and degradation of water quality. The streams of the Peten of northern Guatemala carry smaller amounts of suspended materials due primarily to the lack of human intervention. However, the water in these northern streams also tends to be moderately hard from the calcium carbonate of the host karstic environment, especially in the dry season when lower flows concentrate the elements. Some streams that flow through these areas underlain by gypsum carry large amounts of sulfates. Along both coasts are streams, marshes, and swamps that contain large quantities of brackish or saline water. Unless treated, these sources are unsuitable for most uses.

2. Ground Water

Biological contamination of shallow aquifers by pathogens due to the improper disposal of human or animal wastes is a problem in many populated and agricultural areas of the country. Chemical contamination is primarily related to the use of fertilizers and pesticides in the sugarcane and banana plantations of the Pacific and Caribbean coastal plains. Upper aquifers in major urban areas are contaminated from a variety of sources. In Guatemala City, untreated storm water is injected into the upper aquifer in an attempt to recharge the water supply of the city. Leaching from the landfill in Guatemala City has severely contaminated the local aquifers. Generally, only deep confined aquifers should be considered safe from biological and chemical contamination. All wells in the Rio Motagua valley are considered to be biologically contaminated.

During the dry season, shallow wells in the interior highlands may go dry until sufficient aquifer recharge occurs. Saltwater intrusion, while currently not a problem for the coastal areas, may occur in the future if coastal wells are overpumped. Water should be thoroughly tested from any well before consumption or use.

V. Water Resources Departmental Summary

A. Introduction

This chapter summarizes the water resources information of Guatemala, 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 5. 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 22 departments.

B. Water Conditions by Map Unit

Figure C-1 divides the country into five map unit categories based on water quantity, water quality, and seasonality. Map unit 1 depicts areas where fresh surface water is perennially plentiful in large to enormous quantities. Map units 2 and 3 depict areas where fresh surface water is seasonally plentiful in small to very large quantities during high flows. Map units 4 and 5 depict areas where fresh surface water is scarce or lacking, and meager to enormous quantities of brackish to saline water are perennially available. Figure C-1 also divides the country into three drainage basins. 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 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 very small to very large quantities. These areas appear, at a country scale, to be the most favorable areas for ground water exploration. Map units 2, 3, 4, and 5 depict areas where fresh ground water is locally plentiful, ranging from meager to very large quantities. At the local level, these areas might be suitable for ground water exploration but will require additional site-specific investigations. Map unit 6 depicts areas where fresh water is scarce or lacking and very small to very large quantities of brackish to saline water may be available. At the country scale, map unit 6 appears to be the least favorable area for ground water exploration.

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	= ≤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	= ≤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.

Departamento de Alta Verapaz

Area and relative size:	8,726 square kilometers (8 percent of the country)
Estimated Population (1994):	Urban: 97,572 Rural: 552,554 Total: 650,126 (6.5 percent of the population)
Population Density:	74.5 people per square kilometer
Department Capital:	Coban
Location:	In the central part of the country, surrounded by the departments of Peten to the north, Izabal to the east, Zacapa to the southeast, El Progreso to the south, Baja Verapaz to the southwest, and Quiche to the west.

Surface Water:

Large quantities of fresh water are available year-round from map unit 1 areas in the northwest corner along the Rio Chixoy and the east-central section along the Rio Polochic. Access to these areas is limited by lack of roads, especially in the northwestern section.

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Cahabon, Rio Polochic, Rio Sarstun, and Rio Chixoy in map unit 2. These quantities become small to meager during the dry season, November through April. Map unit 2 occupies the central, western, and northeastern sections of the department and includes the department capital of Coban. Map unit 3 provides small amounts of water from streams such as the upper reaches of Rio Polochic, Rio Sarstun, Rio Cahabon, and Rio Zarco during the wet season with quantities diminishing during the dry season. Map unit 3 is in the north-central and south-central sections of the department.

Ground Water:

The best areas for ground water exploration are the limestone aquifers in the Sierra de Chama, as depicted by map unit 2, and the alluvial aquifers along the Rio Polochic, as depicted by map unit 1. The department capital of Coban lies in map unit 2. Fresh ground water is locally available in meager to very large quantities in map unit 2, which covers about half of the department. Accessibility may be a problem due to steep slopes, dense vegetation, and karstic areas. About 10 percent of the department lies in map unit 1 where very small to very large quantities of ground water are generally plentiful from the alluvial aquifers. These aquifers located in the southeast along the Rio Polochic are suitable for hand-pump and tactical wells.

Map units 4 and 5 occupy about half of the department where map unit 5, present in scattered areas throughout the department, has sedimentary aquifers that locally yield very small to large quantities of fresh ground water. Map unit 4, in the southern and eastern parts of the department, consists of igneous and metamorphic aquifers. Due to the low permeability of these aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Baja Verapaz

Area and relative size:	3,124 square kilometers (3 percent of the country)
Estimated Population (1994):	Urban: 38,516 Rural: 161,504 Total: 200,020 (2 percent of the population)
Population Density:	64 people per square kilometer
Department Capital:	Salama
Location:	In the Central Highlands region of the country, surrounded by the departments of Alta Verapaz to the northeast, El Progreso to the southeast, Guatemala to the south, Chimaltenango to the southwest, and Quiche to the northwest.

Surface Water:

The Embalse Chixoy reservoir, located along the northern border of the department, is capable of providing enormous quantities of fresh water. Embalse Chixoy, the largest reservoir in the country, provides hydroelectric power for the country. The reservoir is considered contaminated and is rapidly filling with sediment from streams flowing through deforested areas. Access is limited due to lack of roads and steep terrain surrounding the reservoir.

The department is divided fairly evenly between map units 2 and 3. During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Motagua in map unit 2. These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the northwestern, southern, and extreme northeastern sections of the department. Map unit 3, which occupies the rest of the department, provides small amounts of water from streams such as the upper reaches of the Rio Matanzas during the wet season with quantities diminishing during the dry season. Map unit 3 is located in the north-central and central sections of the department. The department capital of Salama is in this unit.

Ground Water:

The best areas for ground water exploration are the karstic limestone aquifers in map unit 2 near Salama and the volcanic aquifers of the central highlands in map unit 3. Fresh ground water is locally available in meager to very large quantities in map unit 2, which covers about 10 percent of the department. Map unit 3 covers about 20 percent of the northern part of the department. Very small to very large quantities of fresh water are available locally from the volcanic aquifers. Accessibility may be a problem due to karst, steep slopes, dense vegetation, and unstable soil conditions. These aquifers are suitable for hand-pump and tactical wells. The department capital of Salama lies in map unit 3.

Map unit 4 occupies the rest of the department. Due to the low permeability of the igneous and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Chimaltenango

Area and relative size:	1,973 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 150,934
	Rural: 223,964
	Total: 374,898 (4 percent of the population)
Population Density:	190 people per square kilometer
Department Capital:	Chimaltenango
Location:	In the Sierra Madre, surrounded by the departments of Baja Verapaz to the northeast, Guatemala to the east, Sacatepequez to the east, Escuintla to the south, Solola to the west, and Quiche to the northwest.

Surface Water:

During the wet season, May through October, moderate to very large quantities of fresh water are available in map unit 2 areas in the northern part of the department from streams such as Rio Pixcaya. These quantities become small to moderate during the dry season, November to April. Access is difficult due to steep terrain and lack of passable roads.

Map unit 3 areas are located in the southern half of the department and provide small amounts of water during the wet season with quantities diminishing during the dry season. Map unit 4 occupies the central part of the department and includes the department capital of Chimaltenango. Meager to very small quantities of fresh water are available from streams generally from May through October. Quantities diminish during the rest of the year.

Ground Water:

Most of the department lies in map unit 3 in the Sierra Madre. Fresh water is locally available in very small to very large quantities from volcanic aquifers. The department capital of Chimaltenango lies in this map unit. Accessibility may be a problem due to steep slopes, dense vegetation, and unstable soil conditions. These aquifers are suitable for hand-pump and tactical wells.

The rest of the department lies in map unit 4. Due to the low permeability of the igneous and metamorphic aquifers in this map unit, ground water exploration is not recommended during military exercises without site-specific reconnaissance.

Departamento de Chiquimula

Area and relative size:	2,376 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 66,512 Rural: 201,867 Total: 268,379 (3 percent of the population)
Population Density:	113 people per square kilometer
Department Capital:	Chiquimula
Location:	In the eastern part of the country in the Sierra Madre, surrounded by the borders with Honduras to the east and El Salvador to the southeast and by the departments of Jutiapa to the south, Jalapa to the west, and Zacapa to the north.

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Grande de Zacapa in map unit 2. These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the northern part of the department and includes the department capital of Chiquimula. Access is difficult due to steep terrain and lack of passable roads.

Map unit 3, located in the southern half of the department, provides small amounts of water during the wet season, May through October, with quantities diminishing during the dry season. Map unit 4 occupies the remaining area, which is slightly more than one-third of the central part of the department. Meager to very small quantities of fresh water are available from streams generally from May through October. Quantities diminish during the rest of the year.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in map unit 1, which are in the northern part of the department. Fresh ground water is generally available in very small to very large quantities in this map unit, which covers about 10 percent of the department. Map unit 2 has karstic limestone aquifers that also cover about 10 percent of the department. These aquifers yield meager to very large quantities of fresh water locally. These areas are favorable for ground water exploration and are suitable for hand-pump and tactical wells. The department capital of Chiquimula lies in map unit 1.

Map unit 3 occupies about 40 percent of the department, where very small to very large quantities of fresh water are locally plentiful from the volcanic aquifers. Accessibility, however, may be a problem due to steep slopes, dense vegetation, and unstable soil conditions.

In the rest of the department, ground water exploration is not recommended during military exercises without site-specific reconnaissance.

Departamento de El Progreso

Area and relative size:	1,922 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 32,828 Rural: 82,641 Total: 115,469 (1 percent of the population)
Population Density:	60 people per square kilometer
Department Capital:	El Progreso
Location:	In the east-central part of the country in the Rio Motagua valley, surrounded by the departments of Alta Verapaz to the north, Zacapa to the east, Jalapa to the south, Guatemala to the southwest, and Baja Verapaz to the west.

Surface Water:

This department lies within map units 2 and 3. During the wet season, May through October, moderate quantities of fresh water are available in two-thirds of the department from streams such as Rio Motagua, Rio San Jeronimo, and Rio Los Platanos in map unit 2. These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the southern part of the department. Access is easy due to relatively gentle terrain and the number of passable roads. The department capital of El Progreso lies in this map unit. Map unit 3, in the northern section of the department, occupies the rest of the department. Map unit 3 provides small amounts of water from streams such as the upper reaches of the Rio San Jeronimo during the wet season. Quantities diminish during the dry season.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in map unit 1 along the Rio Motagua. Fresh ground water is generally available in very small to very large quantities in this map unit, which covers about 10 percent of the department. These alluvial aquifers are suitable for hand-pump and tactical wells.

Map units 2 and 3 occupy about 25 percent of the department. Karstic limestone aquifers in map unit 2 locally yield meager to very large quantities of fresh water. Very small to very large quantities of ground water are available from volcanic aquifers, but accessibility may be a problem due to steep slopes, dense vegetation, and unstable soil conditions. These aquifers are suitable for hand-pump and tactical wells.

Map units 4 and 5 occupy the rest of the department, where ground water exploration is not recommended during military exercises without site-specific reconnaissance. The department capital of El Progreso lies in map units 2 and 5.

Departamento de Escuintla

Area and relative size:	4,385 square kilometers (4 percent of the country)	
Estimated Population (1994):	Urban:	225,040
	Rural:	367,607
	Total:	592,647 (6 percent of the population)
Population Density:	135 people per square kilometer	
Department Capital:	Escuintla	
Location:	In the southern coastal plain bordering the Pacific Ocean, with the departments of Suchitepequez to the west, Chimaltenango to the northwest, Sacatepequez to the north, Guatemala to the northeast, and Santa Rosa to the east.	

Surface Water:

During the wet season, moderate quantities of fresh water are available from streams such as Rio Maria Linda, Rio Aguacapa, Rio Naranjo, Rio Achiguate, Rio Acome, Rio Coyolate, Rio Madre Vieja, Rio Nahualate, Rio Guacalate, and Rio Michatoya in map unit 2 (about two-thirds of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 is in the central and southern parts of the department on the coastal plain in the Pacific Ocean basin. Included in this unit is the department capital of Escuintla. The Rio Naranjo and other streams, which drain Escuintla, are heavily contaminated with biological and chemical wastes. The Rio Michatoya is heavily contaminated with organic and inorganic biological and chemical wastes from improper waste disposal from Guatemala City. Access is easy due to relatively gentle terrain and numerous passable roads.

Small amounts of water are available from streams such as the upper reaches of the Rio Michatoya, Rio Achiguate, Rio Acome, Rio Guacalate, and Rio Coyolate in map unit 3 (almost one-third of the department) from May through November. Quantities diminish during the dry season. Map unit 3 is in the northern section of the department in the foothills of the Sierra Madre. Brackish or saline water, limited to relatively small areas bordering the Pacific Ocean, is plentiful year-round from map unit 5 in low-lying coastal swamps, lagoons, and marshes.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers extending from northwest to southeast across the department. Alluvium thickness in the department ranges up to 200 meters (m). Fresh ground water is generally available in very small to very large quantities from map unit 1, which covers about 70 percent of the department. Yields from 18 drilled wells in the Pacific Coastal Plain alluvium range from 10 to 50 liters per second (L/s) with an average yield of 20 L/s. Specific capacities range from 1 to 5 L/s/m. Locally, yields range from 35 to 95 L/s with specific capacities of about 2 L/s/m. TDS for the Pacific Coastal Plain alluvium range from 150 to 250 milligrams per meter and pH ranges from 6 to 7. These alluvial aquifers are also suitable for hand-pump and tactical wells. The department capital of Escuintla is located in map unit 1.

Very small to very large quantities of fresh ground water are available locally from the volcanic aquifers in map unit 3 (about 20 percent of the department). However, steep slopes, dense vegetation, and unstable ground conditions hinder accessibility. These aquifers are also suitable for hand-pump and tactical wells.

Very small to very large quantities of brackish to saline water are available from alluvial aquifers in map unit 6 along the Pacific Coast. Ground water exploration during military exercises is not recommended without site-specific reconnaissance due to the potential for poor water quality.

Departamento de Guatemala

Area and relative size: 2,025 square kilometers (2 percent of the country)
Estimated Population (1994): Urban: 1,893,646
Rural: 295,006
Total: 2,188,652 (21 percent of the population)
The most populated department in Guatemala
Population Density: 1,081 people per square kilometer
The most densely populated department in Guatemala
Department Capital: Guatemala City (also Ciudad de Guatemala)
Location: In the Sierra Madre, surrounded by the departments of Baja Verapaz to the north, El Progreso to the northeast, Jalapa to the east, Santa Rosa to the southeast, Escuintla to the southwest, Sacatepequez to the west, and Chimaltenango to the northwest.

Surface Water:

Fresh water is perennially plentiful from Lago de Amatitlan in large to enormous quantities. However, this lake is severely contaminated from biological and industrial wastes from Guatemala City. During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Aguacapa in map unit 2 (almost one-third of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the northern part of the department. Access is easy due to dense road network. The streams draining Guatemala City are considered to be severely contaminated from improper disposal of sewage and industrial waste. These rivers include Rio Las Vacas and Rio Villalobos. Rio Villalobos flows south from the city discharging into Lago de Amatitlan causing extreme contamination in the lake. Rio Michatoya, which flows south from Lago de Amatitlan into the Departamento de Escuintla, is also severely contaminated.

During the wet season, small amounts of water are available from streams such as Rio Michatoya in map unit 3 (about one-third of the department in the south), but quantities diminish during the dry season. Generally from May through October, meager to very small quantities of fresh water are available from streams such as Rio Las Vacas and Rio Villalobos in map unit 4 (slightly more than one-third of the central part of the department). Quantities diminish during the dry season. Guatemala City, the departmental and national capital, is located in map unit 4.

Ground Water:

The best areas for ground water exploration are the volcanic aquifers in map unit 3, which cover about 75 percent of the department in the central and southern parts. Fresh ground water is generally available in very small to very large quantities, but steep slopes, dense vegetation, and unstable soil conditions hinder accessibility. These aquifers are tapped for domestic supply and irrigation; they are suitable for hand-pump and tactical wells. Much of the water supply (about 60 percent) for Guatemala City is from ground water resources from this map unit. As of 1998, a total of 86 wells supplied 1 cubic meter per second of water to the city. About 64 percent of the water supply for the Guatemala metropolitan area is from ground water. The quality of drinking water in the Guatemala City area for 1997 is given below for the following wells:

Well No. 1 Alameda Norte has Cl^- 2.47 mg/L, SO_4 113 mg/L, total P .282 mg/L, total Na 2.59 mg/L, turbidity 24 mg/L, biochemical oxygen demand after 5 days

0.4 mg/L, fecal coliform <3 MPN/100 mL;

Well No. 2 Jardines de Minerva has Cl- 24.7 mg/L, SO4 8.2 mg/L, total P .282 mg/L, total Na 5.93 mg/L, turbidity 8 mg/L, biochemical oxygen demand after 5 days 6.9 mg/L, chemical oxygen demand 21.5 mg/L, fecal coliform <3 MPN/100 mL.

Well No. 3 Roosevelt Hospital has Cl- 1.98 mg/L, SO4 256 mg/L, total P .636 mg/L, total Na 4.19 mg/L, turbidity 24 mg/L, biochemical oxygen demand after 5 days 1.3 mg/L, chemical oxygen demand 5.0 mg/L, fecal coliform <3 MPN/100 mL.

Well No. 4 Molino de la Flores has Cl- 5.4 mg/L, SO4 7.7 mg/L, total P .117 mg/L, total Na 1.24 mg/L, turbidity 4 mg/L, biochemical oxygen demand after 5 days 10.2 mg/L, chemical oxygen demand 15.3 mg/L, fecal coliform <3 MPN/100 mL.

Well No. 5 Ojo de Agua has Cl- 5.9 mg/L, SO4 4.3 mg/L, total P .133 mg/L, total Na 1.40 mg/L, turbidity 0 mg/L, biochemical oxygen demand after 5 days 7 mg/L, chemical oxygen demand 21.5 mg/L, fecal coliform <3 MPN/100 mL.

Guatemala City, the departmental and national capital, is in map unit 3.

Map units 4 and 5 occupy the northern part of the department. Due to the low permeability of the sedimentary, igneous, and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Huehuetenango

Area and relative size:	7,880 square kilometers (7 percent of the country)	
Estimated Population (1994):	Urban:	120,721
	Rural:	669,462
	Total:	790,183 (7 percent of the population)
Population Density:	100 people per square kilometer	
Department Capital:	Huehuetenango	
Location:	In the west-central part of the country, surrounded by the border with Mexico to the north and west and by the departments of San Marcos to the southwest, Totonicapan to the south, and Quiche to the east.	

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Selegua, Rio Ixquisis, Rio Ixcan, Rio Chixoy, and Rio Cuilco in map unit 2 (almost two-thirds of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 is in the western, northeastern, and southeastern parts of the department. Access is difficult due to a sparse road network and dissected terrain.

During the wet season, small amounts of water are available from streams such as the upper reaches of Rio Selegua, Rio Ixquisis, Rio Ixcan, and Rio Chixoy in map unit 3 (about one-third of the department). Quantities diminish during the dry season. Map unit 3 is in the central section of the department. The department capital of Huehuetenango is located in this unit. Generally from May through October, meager to very small quantities of fresh water are available from streams in map unit 4 (two small areas in the center of the department). Quantities diminish during the dry season.

Ground Water:

The best areas for ground water exploration are the limestone aquifers in scattered areas throughout the department. Fresh ground water is locally available in meager to very large quantities as depicted by map unit 2, which occupies about 40 percent of the department. Karstic areas may hinder accessibility. These limestone aquifers are suitable for hand-pump and tactical wells.

Very small to very large quantities of fresh ground water are available locally from volcanic aquifers in map unit 3 occupying less than 10 percent of the department in the west. The department capital of Huehuetenango lies in this map unit. Steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells.

The rest of the department lies in map units 4 and 5, where ground water exploration during military exercises is not recommended without site-specific reconnaissance due to the low permeability of the sedimentary, igneous, and metamorphic aquifers.

Departamento de Izabal

Area and relative size:	9,038 square kilometers (8 percent of the country)
Estimated Population (1994):	Urban: 78,848 Rural: 280,209 Total: 359,057 (3 percent of the population)
Population Density:	39.7 people per square kilometer
Department Capital:	Puerto Barrios
Location:	In the northeastern spur of the country bordering the Gulf of Honduras to the northeast, Belize to the north, and Honduras to the east, with the departments of Zacapa to the south, Alta Verapaz to the west, and Peten to the northwest.

Surface Water:

Map unit 1 occupies two locations in the department: (1) the lower Rio Motagua; and (2) the Rio Polochic, Lago de Izabal, and El Golfete in the central part of the department. Large quantities are available from streams, and enormous quantities are available from lakes year-round. Access is easy due to the relatively flat terrain and well developed road network. The Rio Motagua is considered to be severely contaminated from biological and chemical wastes.

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Sarstun, Rio Tunico, Rio San Francisco, Rio Motagua, Rio Oscuro, Rio Chinebal, Rio Zarco, Rio Tinajas, Rio Polochic, Rio Matanzas, Rio Boca Nueva, and Rio Cahabon in map unit 2 (almost one-third of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the northern and central parts of the department and includes the department capital of Puerto Barrios. During the wet season, small amounts of water are available from streams such as the upper reaches of Rio Oscuro, Rio Chinebal, Rio Zarco, and Rio Tinajas in map unit 3 (about one-third of the department), with quantities diminishing during the dry season. Map unit 3 is in the southwestern and northwestern sections of the department. Large to enormous quantities of brackish or saline water are available year-round from low-lying coastal swamps, lagoons, and marshes in map unit 5 that occupy small areas bordering the Gulf of Honduras.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers of map unit 1 and the limestone aquifers of map unit 2. Very small to very large quantities of ground water are available from the alluvial aquifers of map unit 1 occupying about 25 percent of the department along Lago de Izabal and Rio Polochic. Meager to very large quantities of fresh water are available from the limestone aquifers of map unit 2 occupying about 25 percent of the department in the north and northwest. These alluvial and limestone aquifers are suitable for hand-pump and tactical wells.

Meager to small quantities of fresh ground water are available from igneous and metamorphic aquifers in map unit 4 in less than one fourth of the department. This map unit is present in the northern, southwestern, and eastern parts of the department.

The rest of the department lies in map units 5 and 6, where ground water exploration is not recommended during military exercises without site-specific reconnaissance. The department capital, Puerto Barrios, lies in map unit 6 on the coast of the Gulf of Honduras.

Departamento de Jalapa

Area and relative size:	2,063 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 60,524 Rural: 145,831 Total: 206,355 (2 percent of the population)
Population Density:	100 people per square kilometer
Department Capital:	Jalapa
Location:	In the eastern Sierra Madre region of the country, surrounded by the departments of El Progreso to the north, Zacapa to the northeast, Chiquimula to the east, Jutiapa to the southeast, Santa Rosa to the southwest, and Guatemala to the west.

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Los Platanos in map unit 2 (almost one-third of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the northern part of the department. Access is difficult due to a lack of road network and steep terrain.

During the wet season, small amounts of water are available from streams such as the Rio Grande de Mita in map unit 3 (less than one-third of the department), but quantities diminish during the dry season. Map unit 3 is in the southern section of the department. Generally from May through October, meager to very small quantities of fresh water are available from streams such as the upper reaches of Rio Los Platanos and Rio Grande de Mita in map unit 4 (slightly more than one-third of the department). Quantities diminish during November through April. The department capital of Jalapa is located in this map unit.

Ground Water:

The best areas for ground water exploration are in the alluvial aquifers of two small areas in the south of the department in map unit 1 (about 10 percent of the department). Very small to very large quantities of fresh ground water are generally available in this map unit. These alluvial aquifers are suitable for hand-pump and tactical wells.

Very small to very large quantities of fresh ground water are available from the volcanic aquifers in map unit 3 (about 60 percent of the department). Steep slopes, dense vegetation, and unstable soil conditions hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of Jalapa lies in this map unit.

The rest of the department in the north lies in map unit 4 where igneous and metamorphic aquifers are found (about 30 percent of the department). Due to the low permeability of these aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Jutiapa

Area and relative size:	3,219 square kilometers (3 percent of the country)
Estimated Population (1994):	Urban: 79,132 Rural: 299,530 Total: 378,662 (4 percent of the population)
Population Density:	117.6 people per square kilometer
Department Capital:	Jutiapa
Location:	In the southeastern coastal plain along the Pacific Ocean, with El Salvador to the east and the departments of Santa Rosa to the west, Jalapa to the northwest, and Chiquimula to the northeast.

Surface Water:

Large to enormous quantities of fresh water are perennially available from Lago de Guija along the border with El Salvador. During the wet season, May through October, moderate to large quantities of fresh water are available from streams such as the Rio Paz in map unit 2 (less than one-third of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the eastern and southern parts of the department. Access is easy due to a dense road network in the southern half of the department, becoming progressively more difficult as the terrain rises into the Sierra Madre.

During the wet season, small amounts of water are available from streams such as Rio Grande de Mita, Rio Salado, Rio Mongoy, and Rio Pulula in map unit 3 (over two-thirds of the department), but quantities diminish during the dry season. Map unit 3 is in the central section of the department. The department capital of Jutiapa is located in this map unit. Generally from May through October, meager to very small quantities of fresh water are available from streams such as the lower reaches of Rio Grande de Mita and Rio Salado in map unit 4 (relatively small areas along the border with El Salvador). Quantities diminish during November through April. Throughout the year, large to enormous quantities of brackish or saline water are available from low-lying coastal swamps, lagoons, and marshes in map unit 5, a relatively small area bordering the Pacific Ocean.

Ground Water:

The best areas for ground water exploration are in the alluvial aquifers of map unit 1, which occupies a band trending parallel to the coast in the southern part of the department, and in three small areas in the central part. Very small to very large quantities of fresh ground water are available in this map unit (about 25 percent of the department). These alluvial aquifers are suitable for hand-pump and tactical wells.

Very small to very large quantities of fresh ground water are locally available from volcanic aquifers in map unit 3 (about 70 percent of the department). Steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of Jutiapa lies in this map unit.

The rest of the department is located in map unit 6, where ground water exploration is not recommended without site-specific reconnaissance due to poor water quality.

Departamento de Peten

Area and relative size:	35,270 square kilometers (32 percent of the country) (largest department in Guatemala)
Estimated Population (1994):	Urban: 101,908 Rural: 193,222 Total: 295,130 (3 percent of the population)
Population Density:	8.4 people per square kilometer
Department Capital:	Flores
Location:	In the northernmost part of the country, with Mexico to the west and north, Belize to the east, and the departments of Izabal to the southeast and Alta Verapaz to the south.

Surface Water:

Large to very large quantities of fresh water are perennially available from streams such as Rio Salinas, Rio Mopan, Rio de la Pasion, and Rio Usumacinta and from lakes including Lago Peten Itza and Laguna Sacnab in map unit 1 (one fifth of the department). Rio Usumacinta along the western border of the department has the highest sustained discharge of any stream in Guatemala. Steep incised banks, lack of roads, and thick vegetation make access difficult to water points along the streams. Access to Lago Peten Itza is less difficult, hindered only by thick vegetation. Map unit 1 is also the site of the department capital of Flores.

Fresh water is seasonally available in most of the department. During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Santa Isabelo Cancuen, Rio Azul Santa Maria, Rio San Roman, Rio de la Pasion, Rio Poxte, Rio San Juan, Rio El Subin, Rio San Pedro, Rio Escondido, Rio Chocop, Rio Xan, and Rio Candelaria in map unit 2 (almost half of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 is primarily in the western and southern parts of the department.

During the wet season, small amounts of water are available from streams such as Rio Machaquila in map unit 3. These quantities diminish during the dry season. Map unit 3 is in the central section of the department. Generally from May through October, meager to very small quantities of fresh water are available from streams such as Rio Bravo, Arroyo Sal Puedes, Rio Chiquibul, and Riachuelo Machaquila in map unit 4, which occupies the east-central part of the department. These sources diminish from November through April during the dry season.

Ground Water:

The best areas for ground water exploration are in the alluvial aquifers of map unit 1 (about one-fifth of the department). This unit occupies areas in the northwest along the western and northern border with Mexico and areas scattered in the northeastern parts of the department. Very small to very large quantities of fresh ground water are available in this map unit. These aquifers are suitable for hand-pump and tactical wells.

Meager to very large quantities of fresh water are locally available from limestone aquifers in the Peten Lowlands and Peten Highlands of map unit 2 (about one third of the department). Karstic areas can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The rest of the department lies in map unit 5 (about one-half of the department), where ground water exploration is not recommended during military exercises without site-specific reconnaissance.

Departamento de Quezaltenango

Area and relative size:	2,164 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 240,449 Rural: 366,107 Total: 606,556 (6 percent of the population)
Population Density:	280.3 people per square kilometer
Department Capital:	Quezaltenango
Location:	In the southwestern part of the country, surrounded by the departments of Huehuetenango to the north, Totonicapan to the northeast, Solola to the east, Suchitepequez to the southeast, Retalhuleu to the south, and San Marcos to the west.

Surface Water:

Fresh water is seasonally available in this department. During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Naranjo, Rio Samala, and Rio Ocosito in map unit 2 (almost one-half of the department). These quantities become small to moderate during the dry season, November through April. Map unit 2 occupies the southern and extreme northwestern parts of the department. Access is easy in the southern coastal plains due to relatively gentle terrain and the number of passable roads. Rio Samala, which drains the city of Quezaltenango, is severely contaminated with biological and industrial pollution.

During the wet season, small amounts of water are available from streams such as the upper reaches of the Rio Samala and Rio Naranjo in map unit 3 (one-third of the department). These quantities diminish during the dry season. Map unit 3 is in the south-central and north-central sections of the department in the foothills of the Sierra Madre. The department capital of Quezaltenango lies in this map unit. Generally from May through October, meager to very small quantities of fresh water are available from streams such as the extreme upper reach of the Rio Naranjo in map unit 4, which occupies the remaining central part of the department. From May through October, these quantities diminish.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in map unit 1 (10 percent of the department) which occupies the southwestern part of the department. Fresh ground water is generally available in very small to very large quantities. These alluvial aquifers are suitable for hand-pump and tactical wells.

Very small to very large quantities of fresh ground water are locally available from volcanic aquifers in map unit 3 (about 80 percent of the department). Steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of Quezaltenango lies in this map unit. Shallow aquifers downstream of Quezaltenango are probably very contaminated.

The rest of the department lies in map unit 4. Due to the low permeability of the igneous and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Quiche

Area and relative size:	8,559 square kilometers (8 percent of the country)
Estimated Population (1994):	Urban: 74,169 Rural: 557,617 Total: 631,786 (6 percent of the population)
Population Density:	73.8 people per square kilometer
Department Capital:	Santa Cruz del Quiche
Location:	In the west-central part of the country, with Mexico to the north and the departments of Alta Verapaz to the east, Baja Verapaz to the southeast, Chimaltenango to the south, Solola to the southwest, Totonicapan to the west, and Huehuetenango to the west.

Surface Water:

Large quantities of fresh water are available year-round from map unit 1 areas in the northeast corner along the Rio Chixoy and the southeast section along the Embalse Chixoy which is capable of providing enormous quantities of fresh water. Embalse Chixoy is the largest reservoir in Guatemala and provides hydroelectric power for the country. The reservoir is considered contaminated and is rapidly filling with sediment deposited into the reservoir by streams flowing through deforested areas. Access to these areas is limited by lack of roads, especially in the northeastern section.

During the wet season, May through October, moderate quantities of fresh water are available from streams such as Rio Chixoy and Rio Tzepela in map unit 2 (almost two-thirds of the department). These quantities become small to moderate during the end of the dry season of March and April. Map unit 2 occupies the northern and extreme southeastern parts of the department. Access is difficult due to mountainous to hilly terrain, thick vegetation, and lack of roads.

During the wet season, map unit 3 (almost one-third of the department) provides small amounts of water from the upper reaches of streams such as Rio Tzepela, but quantities diminish during the dry season. This map unit is in the southern section of the department in the foothills of the Sierra Madre and contains the department capital of Santa Cruz del Quiche. Map unit 4, located in the south, occupies the rest of the department. Generally from May through October, meager to very small quantities of fresh water are available from streams. Quantities diminish during November through April.

Ground Water:

The best areas for ground water exploration are in map unit 2 in the central part of the department. The limestone aquifers of this map unit comprise about 20 percent of the department. These aquifers yield meager to very large quantities of fresh water. Accessibility may be a problem in the karstic areas. These aquifers are suitable for hand-pump and tactical wells.

The department capital of Santa Cruz del Quiche is in map unit 3 (about 20 percent of the department). Very small to very large quantities of ground water are locally available from the volcanic aquifers. However, steep slopes, dense vegetation, and unstable soil conditions may hinder accessibility. These aquifers are suitable for hand-pump and tactical wells.

Map unit 4 (about 20 percent of the department) consists of igneous and metamorphic aquifers and is in the southern part of the department. Map unit 5 areas lie along the border with Mexico and in the Sierra de los Cuchumatanes (40 percent of the department), which consist of sedimentary aquifers that locally yield very small to large quantities of fresh ground water. Due to the low permeability of the sedimentary, igneous, and metamorphic aquifers, ground water exploration is not recommended during military exercises in map units 4 and 5 without site-specific reconnaissance.

Departamento de Retalhuleu

Area and relative size:	1,856 square kilometers (2 percent of the country)
Estimated Population (1994):	Urban: 76,913 Rural: 184,223 Total: 261,136 (2.5 percent of the population)
Population Density:	140.7 people per square kilometer
Department Capital:	Retalhuleu
Location:	In the southwestern coastal plain bordering the Pacific Ocean to the south, with the departments of San Marcos to the southwest, Quezaltenango to the north, and Suchitepequez to the east.

Surface Water:

Moderate to large quantities of fresh water are available from map unit 2 (more than two-thirds of the department) from streams such as Rio Samala, Rio Oc, and Rio Sis during the wet season, May through October. These quantities become small to moderate during the dry season, November through April. The relatively gentle terrain and the number of passable roads provide easy access. The department capital of Retalhuleu lies within this map unit. Rio Samala is considered to be heavily contaminated with biological and industrial pollution from the city of Quezaltenango.

Map unit 3 provides small amounts of water from streams such as upper reaches of the Rio Sis, Rio Oc and Rio Samala during the wet season with quantities diminishing during the dry season. The map unit is along the eastern border of the department.

Small areas on the coast lie in map unit 5 where brackish or saline water is perennially available from swamps, lagoons, and marshes.

Ground Water:

Most of the department lies in map unit 1 in the Pacific Coastal Plain consisting of alluvial aquifers where ground water is available in very small to very large quantities. These are the best areas for ground water exploration. These aquifers are suitable for hand-pump and tactical wells. The department capital of Retalhuleu lies within this map unit.

Map unit 3 (about 20 percent of the department) lies in the northern part of the department and provides very small to very large quantities of fresh ground water locally from volcanic aquifers. However, steep slopes, dense vegetation, and unstable ground conditions may hinder accessibility. These aquifers are suitable for hand-pump and tactical wells.

The rest of the department along the Pacific Coast lies within map unit 6. Ground water exploration during military exercises is not recommended without site-specific reconnaissance due to the potential for poor water quality.

Departamento de Sacatepequez

Area and relative size:	493 square kilometers (0.5 percent of the country) (Smallest in Guatemala)
Estimated Population (1994):	Urban: 146,265 Rural: 50,271 Total: 196,536 (2 percent of the population)
Population Density:	398.6 people per square kilometer
Department Capital:	Antigua Guatemala
Location:	In the central Sierra Madre region of south-central Guatemala, surrounded by the departments of Escuintla to the south, Chimaltenango to the west, and Guatemala to the north and east.

Surface Water:

In the northernmost part of the department, moderate quantities of fresh water are available from streams during the wet season, May through October from map unit 2 (almost one-fifth of the department). These quantities become small to moderate during the dry season, November through April. Access is difficult due to steep terrain and thick vegetation.

During the wet season, map unit 3 (about one-third of the department) in the southern part of the department provides small amounts of water from streams such as Rio Guacalate, but quantities diminish during the dry season. Map unit 4 occupies the remaining area, about one-half of the central part of the department. Generally from May through October, meager to very small quantities of fresh water are available from streams with quantities diminishing during the dry season. The department capital of Antigua Guatemala is located in this unit.

Ground Water:

The entire department lies in map unit 3 where very small to very large quantities of fresh water are available from volcanic aquifers. Steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. The department capital is Antigua Guatemala.

Departamento de San Marcos

Area and relative size: 3,596 square kilometers (3.5 percent of the country)
Estimated Population (1994): Urban: 98,985
Rural: 667,965
Total: 766,950 (7 percent of the population)
Population Density: 213.3 people per square kilometer
Department Capital: San Marcos
Location: In the southwest bordering the Pacific Ocean to the south and Mexico to the west, with the departments of Huehuetenango to the north, Quezaltenango to the east, and Retalhuleu to the southeast.

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from map unit 2 (almost one-fifth of the department) from streams such as Rio Suchiate, Rio Cabuz, Rio Nahuatan, Rio Melendrez, and Rio Naranjo. These quantities become small to moderate during the dry season, November through April. The map unit is located in the northern and southern parts of the department. Access is considered difficult in the north due to steep terrain and thick vegetation. In the south, access is considered easy.

Map unit 3 (about one-third of the department) provides small amounts of water from streams such as the upper reaches of Rio Suchiate, Rio Cabuz, Rio Nahuatan, Rio Melendrez, and Rio Naranjo during the wet season, with quantities diminishing during the dry season. This map unit is in the northeastern and south-central sections of the department. Map unit 4 (about one-third of the department) occupies the central region. Generally from May through October, meager to very small quantities of fresh water are available from streams, with quantities diminishing during November through April. The department capital of San Marcos lies within this unit. Large to enormous quantities of brackish or saline water are plentiful from low-lying coastal swamps, lagoons, and marshes year-round from map unit 5 in two areas along the Pacific Ocean.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Pacific Coastal Plain. These areas where fresh ground water is generally plentiful in very small to very large quantities are depicted by map unit 1, which occupies less than one-fourth of the department. The alluvial aquifers are suitable for hand-pump and tactical wells.

About half of the department lies in map unit 3, where very small to very large quantities of fresh ground water are available locally from volcanic aquifers. Steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of San Marcos lies within this unit.

Less than one-fourth of the department is in map unit 4. Due to the low permeability of the igneous and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance. The rest of the department along the Pacific Coast lies in map unit 6. Ground water exploration during military exercises is not recommended without site-specific reconnaissance due to the potential for poor water quality.

Departamento de Santa Rosa

Area and relative size:	2,955 square kilometers (3 percent of the country)
Estimated Population (1994):	Urban: 68,219 Rural: 217,237 Total: 285,456 (3 percent of the population)
Population Density:	96.6 people per square kilometer
Department Capital:	Cuilapa
Location:	In the southeast bordering the Pacific Ocean to the south, with the departments of Escuintla to the west, Guatemala to the northwest, Jalapa to the north, and Jutiapa to the east.

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from map unit 2 (over one-third of the department) from streams and lakes such as Rio Los Esclavos, Rio Aguacapa, and Laguna de Ayarza. However, these quantities become small to moderate during the dry season, November through April. The map unit is located in the northern and southern parts of the department. Access is difficult in the north due to steep terrain. In the south, flat terrain and a well-developed road network provide easy access. The department capital of Cuilapa lies within this unit.

During the wet season, map unit 3 (about one-third of the department) provides small amounts of water from streams. However, quantities diminish during the dry season. The map unit is located in the northwestern and east-central sections of the department. Map unit 4 occupies the extreme northern region. Generally from May through October, very small to meager quantities of fresh water are available from streams with quantities diminishing during November through April. The rest of the department lies in map unit 5 along the Pacific Ocean coast, where brackish to saline water is perennially available from swamps, lagoons, and marshes.

Ground Water:

The best areas for ground water exploration extend from northwest to southeast across the department in the Pacific Coastal Plain and lie in map unit 1 (about 40 percent of the department). Very small to very large quantities of fresh water are generally available from the alluvial aquifers in this map unit. These aquifers are suitable for hand-pump and tactical wells.

Very small to very large quantities of fresh ground water are available locally from the volcanic aquifers in map unit 3 (about half of the department). Steep slopes, dense vegetation, and unstable ground conditions may hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of Cuilapa lies within this map unit.

The rest of the department along the Pacific Coast lies in map unit 6. Ground water exploration during military exercises is not recommended without site-specific reconnaissance due to the potential for poor water quality.

Departamento de Solola

Area and relative size: 1,142 square kilometers (1 percent of the country)
Estimated Population (1994): Urban: 97,967
Rural: 167,935
Total: 265,902 (3 percent of the population)
Population Density: 232.8 people per square kilometer
Department Capital: Solola
Location: In the central Sierra Madre region of the country, surrounded by the departments of Quiche to the north, Chimaltenango to the east, Suchitepequez to the south, Quezaltenango to the west, and Totonicapan to the northwest.

Surface Water:

Fresh water is perennially plentiful from Lago de Atitlan in large to enormous quantities from map unit 1. During the wet season, May through October, moderate quantities of fresh water are available from map unit 2 from streams such as Rio Nahualate. These quantities become small to moderate during the dry season, November through April. This map unit is located in the extreme southwestern part of the department. Steep terrain and dense vegetation hinder access.

Map unit 3 (two-thirds of the department) provides small amounts of water during the wet season from streams such as the upper reaches of Rio Quixaya and Rio Nahualate with quantities diminishing during the dry season. The department capital of Solola lies within this unit. The rest of the department lies in map unit 4 in the north. Generally from May through October, meager to very small quantities of fresh water are available from streams, with quantities diminishing during the dry season.

Ground Water:

Most of the department lies in map unit 3 where very small to very large quantities of fresh water are available locally from volcanic aquifers. However, steep slopes, dense vegetation, and unstable soil conditions can hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. Depth to suitable quantities of ground water locally may be greater than 300 meters. The department capital of Solola lies within this unit.

The rest of the department lies in map unit 4. Due to the low permeability of the igneous and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Suchitepequez

Area and relative size:	2,392 square kilometers (2.5 percent of the country)
Estimated Population (1994):	Urban: 129,896 Rural: 262,808 Total: 392,704 (4 percent of the population)
Population Density:	164.2 people per square kilometer
Department Capital:	Mazatenango
Location:	In the south-central coastal plain bordering the Pacific Ocean to the south, with the departments of Retalhuleu to the west, Quezaltenango to the northwest, Solola to the north, and Escuintla to the east.

Surface Water:

During the wet season, May through October, moderate quantities of fresh water are available from map unit 2 (over one-half of the department) from streams such as Rio Sis, Rio Ican, Rio Nahualate, and Rio Cutzan. These quantities become small to moderate during the dry season, November through April. The map unit is located throughout the department on the coastal plain. A relatively gentle terrain and numerous passable roads provide easy access. The department capital of Mazatenango lies within this map unit.

During the wet season, map unit 3 (one-third of the department) provides small amounts of water from streams such as the upper reaches of Rio Sis, Rio Ican, Rio Nahualate, and Rio Cutzan with quantities diminishing during the dry season. The map unit is along the western and northern borders of the department. In map unit 5, large to enormous quantities of brackish or saline water are plentiful from low-lying coastal swamps, lagoons, and marshes year-round. This unit is located along most of the Pacific coastline.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers in the Pacific Coastal Plain depicted by map unit 1. Map unit 1 occupies about three-fourth of the department, where fresh ground water is generally plentiful in very small to very large quantities. The alluvial aquifers are suitable for hand-pump and tactical wells. The department capital of Mazatenango lies within this map unit.

In map unit 3 (one-fifth of the department), very small to very large quantities of fresh ground water are available locally from the volcanic aquifers in the northern part of the department. However, steep slopes, dense vegetation, and unstable ground conditions may hinder accessibility. These aquifers are suitable for hand-pump and tactical wells.

The rest of the department lies in map units 4 and 6 where ground water exploration is not recommended during military exercises.

Departamento de Totonicapan

Area and relative size:	1,050 square kilometers (1 percent of the country)
Estimated Population (1994):	Urban: 49,041 Rural: 275,184 Total: 324,225 (3 percent of the population)
Population Density:	3.2 people per square kilometer
Department Capital:	Totonicapan
Location:	In the central Sierra Madre region of the country, surrounded by the departments of Quiche to the east, Solola to the south, Quezaltenango to the west, and Huehuetenango to the north.

Surface Water:

During the wet season of May through October, moderate quantities of fresh water are available from map unit 2 (over one-third of the department) from streams. These quantities become small to moderate during the dry season of November through April. The map unit is located in the northern part of the department. Access is considered difficult in the north due to steep terrain and thick vegetation. In the south, access is considered easy.

Map unit 3 (almost one-third of the department) provides small amounts of water from streams such as the upper reaches of Rio Samala during the wet season, with quantities diminishing during the dry season. This map unit is in the north-central and southern sections of the department. Map unit 4 (almost one-third of the department) occupies the central region. Generally from May through October, meager to very small quantities of fresh water are available from streams, with quantities diminishing from November through April. The department capital of Totonicapan lies within this unit

Ground Water:

Most of the department lies in map unit 3 where very small to very large quantities of fresh water are available from volcanic aquifers. Steep slopes, dense vegetation, and unstable soil conditions may hinder accessibility. These aquifers are suitable for hand-pump and tactical wells. The department capital of Totonicapan lies in map unit 3.

The rest of the department lies in map unit 4, consisting of two very small areas in the north. Due to the low permeability of the igneous and metamorphic aquifers, ground water exploration is not recommended during military exercises in these areas without site-specific reconnaissance.

Departamento de Zacapa

Area and relative size:	2,692 square kilometers (2.5 percent of the country)
Estimated Population (1994):	Urban: 50,339 Rural: 120,807 Total: 171,146 (1 percent of the population)
Population Density:	63.6 people per square kilometer
Department Capital:	Zacapa
Location:	In the east in the Rio Motagua valley bordering Honduras to the east, with the departments of Chiquimula to the south, Jalapa to the southwest, El Progreso to the west, Alta Verapaz to the northwest, and Izabal to the north.

Surface Water:

During the wet season of May through October, moderate quantities of fresh water are available from map unit 2 (two-thirds of the department) from streams such as Rio Motagua and Rio Grande de Zacapa. These quantities become small to moderate during the dry season of November through April. The Rio Motagua is considered heavily contaminated with biological and industrial pollution that originates in Guatemala City. This map unit is located in the central and southern parts of the department. A relatively gentle terrain and numerous passable roads provide easy access. The department capital of Zacapa lies within this map unit.

Map unit 3 (one-third of the department) provides small amounts of water from streams during the wet season with quantities diminishing during the dry season. Map unit 3 is located in the northern and eastern sections of the department.

Ground Water:

The best areas for ground water exploration are the alluvial aquifers of map unit 1 (about one-fourth of the department) along the Rio Motagua. In this map unit, fresh ground water is generally available in very small to very large quantities. These aquifers are suitable for hand-pump and tactical wells. Expect shallow wells to be contaminated. The department capital of Zacapa lies within this map unit.

Along the border with Honduras lies map unit 2. The limestone aquifers of this unit locally yield meager to very large quantities of fresh water. Accessibility may be a problem if the area is karstic. These aquifers are suitable for hand-pump and tactical wells.

Most of the department lies in map units 4 and 5, where ground water exploration is not recommended during military exercises without site-specific reconnaissance.

VI. Recommendations

A. General

Many government agencies are attempting to solve the water resources problems of the country. These agencies provided many comprehensive documents, which included excellent recommendations for improving the water resources situation, to the Corps assessment team. The following needs were identified by the Corps assessment team and by government officials.

B. National Water Resources Management and Policy

Water resources development and management programs are decentralized. The primary problem is the lack of a national commission for potable water supply and sanitation. Data related to wells and surface water systems is maintained separately by the various agencies and users responsible for water resources. As a result, lack of coordination exists between agencies and users, and also within the different sectors. This creates duplication of effort and a lack of exchange of technical knowledge and data.

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

Water resources management and policy are the core of efficient and equitable development. Recommended approaches for gradual improvement of the current management system are as follows: (1) form a national commission for potable water and sanitation; (2) establish a national water law; (3) form a water resources council; (4) conduct a comprehensive water resources evaluation; (5) establish a national clearinghouse; (6) sponsor national and international meetings; and (7) form task forces to address water resources issues. These approaches are explained in the following paragraphs.

1. National Water Commission

The other sectors of the country, such as agriculture, environment, health, and electricity have a national commission, but none exists for potable water and sanitation. Due to the lack of a national commission, the water users of the country act and use the water resources independently. Ideally, the different users should be unified under one commission. The users would include hydropower, domestic water supply, irrigation, industry, and tourism.

2. National Water Law

For the past 10 years, a water law has been proposed but failed to pass. It is believed that it will pass in the new government in the year 2000. In meetings and discussions with managers, it appears a good, practical, implementable water law is needed, but it also must be uncomplicated and enforceable.

3. Water Resources Council

Formation of a water resources council at the national or international level would encourage information exchange and possibly shared organizational funding for common needs. The council should be made up of high-level executives from member entities. At the national level, candidate members would be heads of national offices and development corporation presidents. At the international level, candidate members would include the heads of the U.S. Agency for International Development (USAID), CARE, and the European Economic Community. Each of the members could assign staff to help with special studies and evaluations. The focus of any such council would be to discuss water resources activities in Guatemala and act as a policy advisor to the Guatemalan President. It is conceivable that member nations or other entities could contribute to a fund that would finance common water resources development or interrelated needs. Examples of common needs are (1) development of a national database for hydrology and hydraulics information, (2) conservation of soil and water resources, and (3) environmental enhancement. The permanent establishment of a 'Water Resources Council' to oversee the water resources policy is encouraged.

4. Comprehensive Water Resources Evaluations

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

5. National Clearinghouse

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

6. National and International Meetings

National and international symposia or meetings are a common means of encouraging the exchange of information. These can be an excellent forum for scientists, engineers, and water managers to exchange ideas, concepts, and proven water resources management experiences. One word of caution–the meetings should not be too theoretical. There must be immediately implementable suggestions, as well as long-range proposals. A national gathering, with selected international participation, would be a good initial meeting. This meeting would also be a good forum to discuss other national water policy alternatives, i.e., water resources council, comprehensive water resources evaluations, and national clearinghouses. The meeting with a suggested duration of 3 to 7 days should be held in an easily accessible place such as Guatemala City. Suggested topics and workshops to be covered include: national water policy issues, water conservation, drought management, major water resources projects either planned or under construction, experiments in changing crops, reforestation, soil erosion, irrigation techniques, well drilling, water quality, water treatment, and hydropower.

7. Formulation of Task Forces

This idea is somewhat similar to others previously discussed. The difference is that one major national agency would have to take the initiative to lead the program. The first step would be to identify a national need that would be of widespread interest to entities operating in Guatemala. Such needs might include a national water law, a national education program, a national database for technical data, national surveys and mapping, and a national program for soil and water conservation.

The lead agency would then need to correspond with the various national and international entities to co-sponsor the project by assigning members of their organization to the task force.

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

8. Suggested Strategy

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

C. Watershed Protection and Management

A common concern of most government officials and technical experts is the impact of deforestation on the environment and on water resources. Integral watershed management is needed to control deforestation and the resulting erosion and sedimentation. Development of comprehensive watershed and basin management plans is needed to curb these impacts. 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).

The premiere watershed management program is being implemented in the Lago de Amatitlan basin by AMSA. Plans are to begin management of more basins as funding becomes available, starting next with Lago de Izabal and then continuing with the Lago de Atitlan basin, to be modeled after the AMSA program for Lago de Amatitlan.

D. Troop Exercise Opportunities

1. Well Exercises

More of the water supply needs of the country will be dependent upon ground water resources. Particularly, because many of the rivers are contaminated, and surface water availability is declining. 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. New wells installed should be designed to protect against surface water contamination. The wells should have a minimum 100-foot-thick grout seal to protect the aquifer from becoming contaminated from surface water runoff or from the shallow aquifer. These wells could be a source of safe potable water replacing contaminated surface water supplies in certain areas of the country.

2. Small Surface Impoundments

In certain areas of the country, the construction of small impoundments for capturing water for water supply may be considered. Mountain ranges cover much of the land surface. In these mountainous areas, depth to aquifers may be too great for troop exercises, and accessibility may be difficult. Other places, where small impoundments may 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 in the volcanic highlands, upstream from populated places, away from untreated domestic wastewater discharge, and away from industrial sites and major cities. The impoundments should be sited where water contamination would not be a problem. Design of these impoundments 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.

E. Water Quality and Supply Improvement

Much of the population lacks access to water supply and sanitation services, which directly affects the quality of life. Wastewater treatment is also lacking throughout the country, with much effluent discharged into the 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. As the quantity of available surface water decreases and the population continues to grow, the need for groundwater resources increases.

VII. Summary

Water resources of Guatemala are a major concern. Reasons for the increased competition for limited water resources are:

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

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

The lack of a national water and sanitation commission is the main reason for the absence of minimum health conditions in the country. There are no clear strategies, policies, or investment programs. Data is dispersed and unreliable. Coverage of potable water and sanitation services is extremely low.

The recommendations offered in this report present the 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 abundant water resources of Guatemala can provide adequately for the needs of the country.

Endnotes

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

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

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

[4]Guatemala On-line, <http//www.quetzalnet.com>, revised 15 December 1998, accessed February 1999.

[5]Organizacion Panamericana de la Salud, Plan Regional de Inversiones en Ambiente Salud, "Analisis Sectorial de Agua Potable y Saneamiento en Guatemala," Serie Analisis Sectoriales, No. 4, Washington, DC, March 1995, p. 5.

[6]Orlandino T. Artega, El Sector Recursos Hidricos y su Infraestructura Institucional–Republic de Guatemala, Draft, Guatemala, April 1998, p. i.

[7]Guatemala On-line, <http//www.quetzalnet.com>, revised 15 December 1998, accessed February 1999.

[8]General Information, <http//www.editie.nl/wj95/factsh/guatemal.htm>, accessed February 1999.

[9]United States Army Corps of Engineers Mobile District. Memorandum for Record: Hurricane Mitch Recovery, Motagua River, Mobile, Alabama, 10 December 1998.

[10]Chavarria, Federico, and Juan Jose Sandoval, Proyecto Modelaje Matematico para el Pronostico de Crecidas en Tiempo Real y Control de Inundaciones en America Central–Aplicacion del Modelo Matematico de Simulacion Hidrondinamica Danes, Mike-11, a las Cuencas de los Rios Cahabon, Polochic y Chixoy, en Guatemala, Guatemala City: Instituto Nacional de Sismologia, Volcanologia, Meteorologia e Hidrologia, July 1998.

[11]Empresa Municipal de Agua (EMPAGUA) officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[12]Escuela Regional de Ingenieria Sanitaria y Recursos (ERIS) officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[13]Instituto de Fomento Municipal (INFOM) officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[14]Division de Saneamiento del Medio del Ministerio de Salud Publica y Asistencia (DSM-MSPyAS) officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[15]Comision Nacional del Medio Ambiente (CONAMA), Sector Report on Guatemala's Infrastructure, Guatemala, 1998, Excerpts of Technical Report Obtained during In-Country Visit–Guatemala, February 1999, p. 30.

[16]CONAMA, February 1999, p. 30.

[17]Orlandino T. Artega, April 1998, p. i.

[18]Plan de Accion Para la Gestion Integrada de Los Recursos Hidricos del Istmo Centroamericano–Situacion Actual de Los Recursos Hidricos en Guatemala, Guatemala, August 1998.

[19]Plan Regional de Inversiones en Ambiente Salud, Analisis Sectorial de Agua Potable y Saneamiento en Guatemala, Serie Analisis Sectoriales, No. 4, March 1995.

[20]EMPAGUA officials, personal communication with water resources specialists team, February 1999.

[21]INFOM officials, personal communication with water resources specialists team, February 1999.

[22]DSM-MSPyAS officials, personal communication with water resources specialists team, February 1999.

[23]Agencia de Cooperacion Internacional del Japon, Estudio Sobre el Desarrollo de las Aguas Subterraneas en el Altiplano Central de la Republic de Guatemala, Tokyo: Kokusai Kogyo Co., Ltd., July 1995, pp. 5-1 and 6-1.

[24]DSM-MSPyAS officials, personal communication with water resources specialists team, February 1999.

[25]CONAMA, February 1999, p. 30.

[26]Plan de Accion Para la Gestion Integrada de Los Recursos Hidricos del Istmo Centroamericano–Situacion Actual de Los Recursos Hidricos en Guatemala, August 1998.

[27]Plan de Accion para la Modernizacion y Fomento de la Agricultura Bajo officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[28]ERIS officials, personal communication with water resources specialists team, February 1999.

[29]Instituto Nacional de Electrificacion (INDE) officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[30]INDE officials, personal communication with water resources specialists team, February 1999.

[31]Instituto Nacional de Electrificacion de Guatemala, Breve Historia de la Geotermia en Guatemala, Guatemala City, June 1998.

[32]Instituto Nacional de Sismologia, Vulcanologia, Meteorologia officials, personal communication with water resources specialists team, Guatemala City, February 1999.

[33]Plan de Accion Para la Gestion Integrada de Los Recursos Hidricos del Istmo Centroamericano–Situacion Actual de Los Recursos Hidricos en Guatemala, August 1998.

[34]Orlandino T. Artega, April 1998, pp. i-l.

[35]Orlandino T. Artega, April 1998, pp. i-l.

[36]Orlandino T. Artega, April 1998, p. i-l.

[37]Welcome To Guatemala, <http//www.guatemala.travel.com.gt>, accessed February 1999.

[38]Ministeria de Agricultura, Ganaderia y Alimentacion, Plan Maestrode de Riego y Drenaje. Etapa I, Guatemala City, February 1991, p. 34.

[39]Library of Congress, Science and Technology Division, Draft Environmental Report on Guatemala, Department of State Contract No. SA/TOA/1-77, Washington, DC, May 1979, p. ii.

[40]Orlandino T. Artega, April 1998, p. i.

[41]ERIS officials, personal communication with water resources specialists team, February 1999.

[42]INDE officials, personal communication with water resources specialists team, February 1999.

[43]Steven A. Sader, Forest Monitoring and Satellite Change, "Detection Analysis of the Mayo Biosphere Reserve," Peten District, Guatemala City: Propeten Conservation International, 1 October 1996.

[44]Facultad de Agronomia, Universidad de San Carlos de Guatemala, La Deforestacion en Guatemala, 1996.

[45]Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan, Boletin Informativo, "Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan," No. 2, Edition 3, Guatemala City, 1998.

[46]Ministerio de Agricultura, Ganaderia y Alimentacion, Direccion Tecnica de Avenamiento, Division de Estudios. Plan Maestro de Riego y Drenaje Documento–Hidrogeologia. No. 2, Guatemala City, February 1991, pp. 3-72.

[47]United Nations, Ground Water in the Western Hemisphere–Guatemala, Natural Resources Water Series No. 4, New York, 1976, pp. 103-106.

[48]Estuardo Velasquez, Ground Water in Water Resources Planning, "Underground Water in Volcanic Rocks," Vol. 1, Koblenz, Germany, 1983, pp. 201-207.

[49]Ministerio de Agricultura, 1991, pp.3-72.

Bibliography

Agencia de Cooperacion Internacional del Japon. *Estudio Sobre el Desarrollo de las Aguas Subterraneas en el Altiplano Central de la Republic de Guatemala*. Tokyo: Kokusai Kogyo Co., Ltd., July 1995.

Agency for International Development, Bureau of Science and Technology, Office of Forestry, Environment, and Natural Resources. *Draft Environmental Report on Guatemala*. Washington, DC, May 1979.

Artega, Orlandino T. *El Sector Recursos Hidricos y su Intraestructura Institucional-Republic de Guatemala*. Guatemala, April 1998.

Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan. *Boletin Informativo*, "Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan." No. 2, Edition 3, Guatemala City, 1998.

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

Chavarria, Federico, and Juan Jose Sandoval. *Proyecto Modelaje Matematico para el Pronostico de Crecidas en Tiempo Real y Control de Inundaciones en America Central–Aplicacion del Modelo Matematico de Simulacion Hidrondinamica Danes, Mike-11, a las Cuencas de los Rios Cahabon, Polochic y Chixoy, en Guatemala*. Guatemala City: Instituto Nacional de Sismologia, Volcanologia, Meteorologia e Hidrologia, July 1998.

Choc, Fernando Lopez. *Instalacion de Limnigrafos en Estaciones de la Red Hidrologica Nacional y Aforado de Corrientes Superficiales de Guatemala*. Guatemala City: Instituto Nacional de Sismologia, Volcanologia, Meteorologia e Hidrologia, 1999.

Comision Nacional del Medio Ambiente. *Sector Report on Guatemala's Infrastructure, Guatemala, 1998*. Excerpts of Technical Report Obtained during In-Country Visit-Guatemala. February 1999.

Cooperative for American Relief to Everywhere. *Proyecto Agua y Salud Rural PN-50*. Guatemala City, 1998.

Empresa Municipal de Agua de la Ciudad de Guatemala. *Municipalidad de Guatemala Crease la Empresa Municipal de Agua de la Ciudad de Guatemala-la Cual Puede Abreviarse*. Guatemala City, 1998.

Facultad de Agronomia, Universidad de San Carlos de Guatemala. *La Deforestacion en Guatemala*. 1996.

Gaillard, Claudio Cabrera. *Sintesis Historica de la Deforestacion en Guatemala*. Guatemala, 1996.

General Information. <http//www.editie.nl/wj95/factsh/guatemal.htm>. Accessed February 1999.

Guatemala Infoguat. <http//www.infoguat.guatemala.org>. Accessed February 1999.

Guatemala On-line. <http//www.quetzalnet.com>. Accessed February 1999.

Gysel, M. *International Power and Dam Construction*, "The Headrace Tunnel for the Chixoy Scheme-Guatemala." Vol. 39, No. 2, February 1987.

Instituto Geografico Nacional (IGN). *Atlas Hidrologico-Inventario del Recurso Agua en Guatemala*. Map, Scale 1:1,000,000, Edition 1, Guatemala City, March 1976.

IGN. *Calidad del Agua*. Boletin No. 1, 1972.

IGN. *Guatemala*. Map, Scale 1:500,000, 1973.

IGN. *Mapa Geologico de La Republica de Guatemala*. Map, Scale 1:500,000, 1970.

Instituto Nacional de Electrificacion de Guatemala (INDE). *Breve Historia de la Geotermia en Guatemala*. Guatemala City, June 1998.

INDE. *El Sector Electrico de Guatemala-INDE: Gerencia de Planificacion*. 1998.

INDE. *Informe Estadistico 1997*. 1998.

INDE. *Memoria de Labores 97*. 1998.

Instituto Nacional de Sismologia, Volcanologia, Meteorologia e Hidrologia (INSIVUMEH). *Balance Hidrico Superficial de La Republic de Guatemala*. Guatemala City, June 1992.

INSIVUMEH. *Boletin Hidrologico No. 15-Ano Hidrologico 1983-1984*. 1985.

INSIVUMEH. *Boletin Hidrologico No. 16-Informacion Hidrologica,* "Curvas de Caudal 1986-1988, Estado de la Informacion de Campo 1990-1996, Programa de Rehabilitacion de Estaciones 1997." March 1998.

INSIVUMEH. *Diseno de Drenajes y Recarga de Acuiferos en el Valle de la Ciudad de Guatemala*. November 1998.

International Travel Maps. *Guatemala*. Map, Scale 1:500,000, Edition 3, Vancouver, Canada, 1998.

Library of Congress, Science and Technology Division. *Draft Environmental Report on Guatemala*. Department of State Contract No. SA/TOA/1-77, Washington, DC, May 1979.

Martin, David. *Hochtief Nachrichten-Tunnels & Tunnelling, "*Guatemalan Gremlins Wreak Havoc Underground." Vol. 17, No. 1, London: Morgan-Grampian, Ltd., January 1985.

Ministerio de Agricultura, Ganaderia y Alimentacion, Direccion Tecnica de Avenamiento, Division de Estudios*. Plan Maestro de Riego y Drenaje Documento-Hidrogeologia.* No. 2, Guatemala City, February 1991.

Ministerio de Agricultura, Ganaderia y Alimentacion. *Plan Maestro de Riego y Drenaje*, "El Papel de los Sectores Publico y Privado en el Desarrollo del Riego y Drenaje Agricola en Guatemala." No. 1, 1992.

Organization of American States. *Inter-American Dialogue on Water Management, Directory of Water Resources Organization in the Americas*. Vol. 11, Central America, <http//iwrn.ces.fau.edu/centreng.htm>. Accessed February 1999.

Organizacion Panamericana de la Salud. *Analisis Sectorial de Agua Potable y Saneamiento en Guatemala.* Washington, DC, March 1995.

Plan de Accion Para la Gestion Integrada de Los Recursos Hidricos del Istmo Centroamericano-Situacion Actual de Los Recursos Hidricos en Guatemala. Guatemala, August 1998.

Sader, Steven A. *Forest Monitoring and Satellite Change,* "Detection Analysis of the Mayo Biosphere Reserve." Peten District, Guatemala City: Propeten Conservation International, 1 October 1996.

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

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

United Nations. *Estudio de Aguas Subterraneas Guatemala, Conclusiones y Recomendaciones del Proyecto.* DP-UN-GUA-72-011-1, New York, 1978.

United Nations. *Ground Water in the Western Hemisphere–Guatemala.* Natural Resources Water Series No. 4, New York, 1976.

United States Army Corps of Engineers, Mobile District. *Memorandum for Record: Hurricane Mitch Recovery, Motagua River.* Mobile, Alabama, 10 December 1998.

Universidad Rafael Landivar Instituto de Ciencias Ambientales y Tecnologia Agricola. *Perfil Ambiental de la Republica de Guatemala.* Vista Hermosa, Guatemala, November 1984.

University of Georgia, Institute of Ecology. *Draft Environmental Profile on Guatemala Phase 1.* National Park Service Contract No. CX 0001-0-0004, Athens, Georgia, May 1981.

University of Maine, Maine Image Analysis Laboratory. Time-Series Tropical Forest Change Detection for the Maya Biosphere Reserve: Updated Estimates for 1995 to 1997. Maine, 1998.

Velasquez, Estuardo. Ground Water in Water Resources Planning, "Underground Water in Volcanic Rocks." Vol. 1, Koblenz, Germany, 1983.

Welcome To Guatemala. < http//www.guatemala.travel.com.gt>. Accessed February 1999.

Weyl, Richard. Geology of Central America. Edition 2, Berlin: Gebrüder Borntraeger, 1980.

World Conservation Monitoring Centre. The Latin American Alliance-Forests and Forest Protected Areas. <http//www.latinsynergy.org/gua_map.htm>. Accessed February 1999.

APPENDIX A

Lists of Officials Consulted and 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	Agency/Firm	Address	Tel/Fax/Email
Lt. Col. Grady Reese	U.S. Military Group	Avenida La Reforma 7-45 Zona 10 Guatemala City	Tel: (502) 332-3254 Fax: (502) 332-2844 Email: usmilgp@guate.net
Alberto Fernandez, Acting Deputy Chief of Missions	U.S. Embassy	Avenida La Reforma 7-01 Zona 10 Guatemala City	
Chris Becker Environmental Officer, Economics Section	U.S. Embassy	Avenida La Reforma 7-01 Zona 10 Guatemala City	Tel: (502) 331-1541 Ext. 4633 Fax: (502) 334-8474
Carlos Chacon Environmental Officer	U.S. Agency for International Development (USAID)	1a Calle 7-66 Zona 9 Guatemala City 40907	Tel: (502) 332-0202 Fax: (502) 332-0532
Erwin Estrada Environmental Officer	USAID	1a Calle 7-66 Zona 9 Guatemala City 40907	Tel: (502) 332-0202 Fax: (502) 332-053 Email: egarzona@usaid.gov
Ing. Eddy Sanchez Benett Director General	Instituto Nacional de Sismologia Vulcanologia Meteorologia e Hidrologia (INSIVUMEH)	7a Avenida 14-57 Zona 13 Guatemala City	Tel: (502) 331-5944 Fax: (502) 331-5005 Email: insivume@ops.org.gt
Ing. Sector Hernandez Hydrogeologist	INSIVUMEH	7a Avenida 14-57 Zona 13 Guatemala City	Tel: (502) 331-5944 Fax: (502) 331-5005 Email: insivume@ops.org.gt
Juan Carlos Chevez Manager	DAHO POZOS	17 Avenida 26-02 Zona 11 Guatemala City	Tel: (502) 442-1844 (502) 476-1593 Fax: (502) 476-1597 Email: jccheves@infovia.com.gt
Barbara Gay Coordinator for Emergency Relief	Catholic Relief Services	1a Avenida 10-57 Zona 10 Guatemala City 01010	Tel: (502) 331-0285 (502) 331-0603 (502) 331-0682 Fax: (502) 332-0107 Email: crsgua@guate.net
Todd Holmes Project Assistant	Catholic Relief Services	1a Avenida 10-57 Zona 10 Guatemala City 01010	Tel: (502) 331-0285 (502) 331-0603 (502) 331-0682 Fax: (502) 332-0107 Email: crsgua@guate.net
Dr. Sergio Hurtarte B. Manager, Health Projects	Catholic Relief Services	1a Avenida 10-57 Zona 10 Guatemala City 01010	Tel: (502) 331-0285 (502) 331-0603 (502) 331-0682 Fax: (502) 332-0107 Email: crssalud@emailgua.com
Ing. Alfredo Ortiz	PLAMAR, Ministry of Agriculture	7a Avenida 12-90 Zona 13 Guatemala City	Tel: (502) 332-4120 Fax: (502) 332-4082 Email: plamar@starnet.net.gt
Ing. Carlos Quezada Vega Manager	Empresa Municipal de Agua (EMPAGUA)	Municipalidad de Guatemala, 3er Nivel Guatemala City	Tel: (502) 232-9720 (502) 253-1711 Fax: (502) 232-0601

List of Officials Consulted, continued

Name, Title	Agency/Firm	Address	Tel/Fax/Email
Adolfo Gonzalez	EMPAGUA	Municipalidad de Guatemala, 3er Nivel Guatemala City	Tel: (502) 232-9720 (502) 253-1711 Fax: (502) 232-0601
Ing. Alvaro Solana Chemical and Sanitary Engineer	DSM-MSP y AS, Division de Saneamiento del Medio del Ministerio de Salud Publica y Asistencia Social	2a Avenida 0-61 Zona 10 Guatemala City	Tel: (502) 332-1279 Email: divsan@ops.org.gt
Ing. Jose Efrain Aguilera Advisor	Direccion de Limites y Aguas Internacionales, Ministerio de Relaciones Exteriores	14 Calle ‘A’ 9-49 Zona 1 Guatemala City	Tel: (502) 253-4944 Email: aguilera@micro.com.gt
Ing. Jose Luis Ordonez Director	Direccion de Limites y Aguas Internacionales, Ministerio de Relaciones Exteriores	14 Calle ‘A’ 9-49 Zona 1 Guatemala City	Tel: (502) 253-4944
Dr. Steve Ault	Pan American Health Organization ((PAHO)	7a Avenida 12-23 Edificio Etisa, 3er Nivel Apartado Postal 383 Zona 9 Guatemala City	Tel: (502) 332-2032 (502) 339-4358 Fax: (502) 334-3804 Email: sault@ops.org.gt
Ing. Fernando Boiton Director General	Instituto Geografico Nacional (IGN)	Avenida Las Americas 5-76, 1er Nivel Zona 13 Guatemala City	Tel: (502) 332-2611 (502) 332-0982 (502) 332-3983 Fax: (502) 331-3548 Email: ign@ign.gob.gt
Ing. Efrain Lopez	IGN	Avenida Las Americas 5-76, 1er Nivel Zona 13 Guatemala City	Tel: (502) 332-2611 (502) 332-092 (502) 332-3983 Fax: (502) 331-3548 Email: ign@ign.gob.gt
Ing. Carolina Grajeda Manager, Modernization Program	Instituto Nacional de Electrificacion, Programa de Modernizacion (INDE)	Edif. La Torre, 7a Avenida 2-29 Zona 9, 01009 Guatemala City	Tel: (502) 334-5711/19 Ext. 2201 Fax: (502) 334-5785 Email: gpinde@guate.net
Ing. Victor Manual Ortiz Geologist	INDE, Geothermal Studies and Development	Edif. La Torre, 7a Avenida 2-29 Zona 9, 01009 Guatemala City	Tel: (502) 334-5711/19 Ext 2273 Fax: (502) 334-5036 Email: geotinde@guate.net
Ing. Julio Cesar Palma Chief	INDE, Geothermal Studies and Development	Edif. La Torre, 7a Avenida 2-29 Zona 9, 01009 Guatemala City	Tel: (502) 334-5711/19 Ext 2216 Fax: (502) 334-5036 Email: geotinde@guate.net
Ing. Marco Antonio Bocaletti M. Chief of Civil Works	INDE	Edif. La Torre, 7a Avenida 2-29 Zona 9, 01009 Guatemala City	Tel: (502) 334-5711/19 Ext 2237 Fax: (502) 334-5036 Email: geotinde@guate.net
Ing. Rene Rolando Mena Klee First Vice President	Instituto Nacional de Transformacion Agraria (INTA)	13 Calle 5-16 Edificio Torre San Francisco, 5 Nivel Zona 1 Guatemala City	Tel: (502) 253-4137 Fax: (502) 253-4197
Ing. Teofilo Alvarez	Escuela Regional de Ingenieria Sanitaria y Recursos Hidraulicos (ERIS), University of San Carlos	Universidad San Carlos Ciudad Universitaria Edificio T-1, 3er Nivel Guatemala City	Tel: (502) 476-0424 Fax: (502) 476-9567

List of Officials Consulted, continued

Name, Title	Agency/Firm	Address	Tel/Fax/Email
Ing. Elfego Orozco	ERIS	Universidad San Carlos Ciudad Universitaria Edificio T-1, 3er Nivel Guatemala City	Tel: (502) 334-0205/0206 (502) 331-5958 Fax: (502) 476-9567
Contact through PLAMAR	Instituto Nacional de Bosques (INAB)	7a Avenida 6-80 Zona 13 Guatemala City	Tel: (502) 472-0736
Ing. Joram Gil	Cooperative for American Relief to Everywhere (CARE)	Avenida Reforma 664 Edificio de Banora Torre 1, 8 Nivel Apartado Postal 1211 Zona 9 Guatemala City	Tel: (502) 339-1139 Ext. 253 Fax: (502) 339-1166 Email: jgil@care.org.gt
Ing. Guillermina Cortez	Comision Nacional del Medio Ambiente (CONAMA)	5 Av. 8-07 Zona 10 Guatemala City	Tel: (502) 334-1708 2723 7174
Ing. Juantin	CONAMA	5 Av. 8-07 Zona 10 Guatemala City	Tel: (502) 334-1708 2723 7174
Ing. Estuardo Velasquez, Executive Director and Hydrogeologist	Instituto de Fomento Municipal (INFOM)	11 Avenida 'A' 11-67 La Verbena Zona 7 Guatemala City	Tel: (502) 440-2315 Fax: (502) 472-0970
Ing. Fernando Valladares, Chemical Engineer	Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan (AMSA)	10a Avenida 18-02 Comercial Prisa Los Proceres, 3er Nivel Zona 10 Guatemala City	Tel/ Fax: (502) 367-5184 5187 5188 5189 Email: arrla@guate.net

List of Agencies Contacted

Organization	Acronym	Translation	Area of Responsibility
Autoridad para el Manejo Sustentable de la Cuenca y del Lago de Amatitlan	AMSA	Authority for the Sustainable Development of the Amatitlan Lake and Watershed	To rescue and protect the Amatitlan Lake and watershed.
Comision Nacional del Medio Ambiente	CONAMA	National Commission of the Environment	Coordination of all environmental work in the country.
Division de Saneamiento del Medio del Ministerio de Salud Publica y Asistencia Social	DSM-MSP y AS	The Environmental Sanitation Division, of the Ministry of Public Health and Assistance	The technical division is in charge of preparing and executing programs which improve and maintain sanitary environmental conditions; establishing rules and procedures to avoid environmental deterioration and supervising and evaluating special activities carried out at the working level.
Empresa Municipal de Agua	EMPAGUA	Municipal Management of Water	Guatemala City's water and sewer authority, responsible for water administration for the growing metropolitan population, and for rain and sanitary sewerage, and sanitation.
Escuela Regional de Ingenieria Sanitaria y Recursos Hidraulicos	ERIS	The Regional School of Sanitary Engineering and Hydraulic Resources	An engineering school offering master's degrees in sanitary engineering and water resources, with a strong continuing education program in technology.
Instituto Geografico Nacional	IGN	Institute of National Geography	Generation of basic information of the state of natural resources of river basins, geographic data collection, and river basin maps. Oversees all cartographic projects in the country.
Instituto Nacional de Bosques	INAB	National Institute of Forestry	Protecting and preserving the country's forests.
Instituto Nacional de Electrificacion	INDE	Institute of National Electricity	The primary provider of electricity for the country.
Instituto de Fomento Municipal	INFOM	Institute of Municipal Development	Supports the socio-economic development of the 329 municipalities in the country.
Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia	INSIVUMEH	National Institute of Seismology, Volcanology, Meteorology and Hydrology	Develops technical and scientific activities related to the hydraulic resources of the country since it is responsible for the basic information used in planning the use of water resources. Manages the country's rivers flow, processes hydrologic data and publishes hydrologic annual reports, hydrologic applications and research on water resources.
Instituto Nacional de Transformacion Agraria	INTA	National Institute of Agrarian Transformation	Legalization of tenancy throughout the country; aiding the government in reincorporating repatriated population.
Ministerio de Relaciones Exteriores, Direccion de Limites y Aguas Internacionales		Ministry of Foreign Affairs, Water Boundaries and International Waters	In charge of all territorial and international boundary matters pertaining to the Republic and everything related to water boundaries and international waters.
Pan American Health Organization	PAHO	Pan American Health Organization	Collaborates with government and non-government agencies to strengthen national and local health systems and to improve the health of the peoples of the country.
Plan de Accion para la Modernizacion y Fomento de la Agricultura Bajo Riego	PLAMAR	Action Plan for the Modernization and Promotion of Agriculture under Irrigation	Falls under the Ministry of Agriculture; promotes, coordinates irrigation projects.

APPENDIX B

Glossary

Glossary

alluvial	Pertaining to processes or materials associated with transportation or deposition by running water.
alluvial fan	A cone-shaped deposit of sediment that has been transported by water typically from mountains to the lowlands.
alluvium	Unconsolidated material deposited by the action of water, usually rivers. Alluvium can have very good hydrogeological properties.
aquifer	A zone below the surface of the Earth capable of producing water as from a well.
basalt	A very fine-grained, hard, dense, dark-colored, extrusive igneous rock which occurs widely in lava flows. Usually has poor hydrogeological properties.
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.
chloride	A compound of chlorine and a positive radical of one of more elements.
clastic	Consisting of rock fragments that may have been transported from their places of origin.
confined aquifer	An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the aquifer itself.
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. Cretaceous is the youngest division of the Mesozoic.
deforestation	The process by which large tracts of land are cleared of vegetation for agricultural or economic reasons.
dolomite	A soft to moderately hard sedimentary rock composed of magnesium carbonate. Compact crystalline varieties are generally good construction materials. If highly fractured or chemically weathered, dolomite may yield significant volumes of ground water.
estuary	A drowned river mouth typically subject to both tidal fluctuations and variations is stream discharge. Water quality is usually brackish.
evaporite	A sedimentary rock formed by the evaporation of a solution, usually sea water. Evaporite commonly forms either gypsum or anhydrite.
fault	A fracture or fracture zone of the Earth with displacement of one side from the other.
flood plain	Nearly level land on either side of a channel which is subject to overflow flooding.
fracture	Break in a rock.
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.
gneiss	A medium- to coarse-grained, hard, metamorphic rock consisting of alternating bands of light- to dark-colored minerals.
granite	A coarsely crystalline, hard, massive, light-colored, intrusive igneous rock. If not fractured or weathered, granite will normally yield only small amounts of ground water.
gypsum	An evaporitic sedimentary rock, light colored, soft, and massively bedded.
hydrologic cycle	The movement of water and water vapor from the sea to the atmosphere, to the land, and back to the sea and the atmosphere again.

igneous	A class of rocks formed by the solidification of molten material. If the material is erupted onto the Earth's surface, the rock is called extrusive or volcanic; if the material solidifies within the Earth, the rock is called an intrusive or plutonic rock. If not fractured or weathered, it will normally yield only small amounts of ground water.
interbedded	Occurring between or lying in with other sediments or rock units; interstratified.
intermittent	Describes a stream or reach of a stream that flows only at certain times of the year, as when it receives water from springs or from some surface source.
intrusive	A rock that crystallized from magma within the Earth's surface.
karst	A topography formed over soluble rock (limestone, dolomite) characterized by sinkholes, caves, and underground drainage.
lahar	Landslide or mudflow of pyroclastic deposits on the flank of a volcano.
lava	Fluid rock such as that which issues from a volcano or a fissure in the Earth's surface. Lava is also the same material solidified by cooling.
limestone	Soft to moderately hard sedimentary rock primarily composed of calcium carbonate.
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	An area of saturated ground dominated by grasslike aquatic plants.
metamorphic	A class of rocks formed from the compression, chemical alteration, or heating of igneous or sedimentary rock.
Miocene	A geologic system that represents an epoch of time approximately 5 to 25 million years before present. Falls chronologically after the Oligocene and before the Pliocene. This division is in the Tertiary Period and the Cenozoic Era.
Paleozoic	A division of geologic time from 240 to 560 million years ago during which certain rocks were formed. Falls chronologically after the Proterozoic and before the Mesozoic. Includes the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian.
perennial	Pertaining to water that is available throughout the year.
permeability	The capability of a rock to transmit fluids.
Permian	A division of geologic time from 240 to 290 million years ago, during which certain rocks were formed. Falls chronologically after the Pennsylvanian and before the Triassic. Permian is the youngest division of the Paleozoic Era.
pH (potential of hydrogen)	A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.
Pliocene	A geologic system that represents an epoch of time from about 2 to 5 million years before present. This epoch is in the Tertiary Period and the Cenozoic Era.
porosity	The ratio of the volume of the openings (voids, pores) in a rock to its total volume; usually stated as a percentage.
potable water	Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
pyroclastic	A type of rock formed by the accumulation of fragments of volcanic rock scattered by volcanic explosions.
Quaternary	A geologic system that represents a period of time from Recent to 1.6 million years before present. This period is in the Cenozoic Era.

saline water (saltwater)	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion	Displacement of fresh surface or ground water by the advance of saltwater due to its greater density. Saltwater intrusion usually occurs in coastal and estuarine areas where it contaminates fresh water wells.
sandstone	A soft to moderately hard sedimentary rock composed primarily of cemented quartz grains. This rock has good hydrogeological properties.
schist	A medium- to course-grained metamorphic rock that is moderately hard, gray to black in color, platy, and often folded.
sedimentary	A class of rocks formed from the accumulation and solidification of a variety of sediments.
sedimentation	The process of deposition of sedimentary material, especially by mechanical means from a state of air or water over time.
shale	A soft to moderately hard, platy, sedimentary rock composed of very fine-grained particles. Shale often weathers into thin platy pieces. It generally has high porosity and low permeability, thus is a very poor aquifer.
sinkhole	A funnel-shaped depression in the Earth's surface formed in a soluble rock by water.
spring	A place where ground water flows from a rock or the soil onto the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, especially permeable and impermeable strata; on the position of the water table; and on the topography.
sulfate	A salt of sulfuric acid containing the divalent, negative radical SO_4.
swamp	An area of saturated ground dominated by trees and shrubs.
tectonic	Pertaining to or designating a rock structure as being the result of the deformation of the Earth's crust.
Tertiary	A period of geologic time from 1.6 to 66 million years ago, during which certain rocks were formed. Tertiary falls chronologically after the Cretaceous and before the Quaternary. It includes the Paleocene, Eocene, Miocene, and Pliocene. Tertiary is the oldest division of the Cenozoic. Outside the United States is sometimes divided into the Paleogene and Neogene.
tuff	A soft, light-colored, extrusive igneous rock formed from the compaction of pyroclastic (ash and dust) material.
unconfined aquifer	An aquifer having a water table.
water table	The upper surface of a zone of saturation. No water table exists where that upper surface is formed by an impermeable body.

APPENDIX C

Surface Water and Ground Water Resources

Tables and Figures

Prepared by: U.S. Army Topographic Engineering Center Operations Division
Hydrologic Analysis Branch
7701 Telegraph Road
Alexandria, VA 22315-3864

Table C-1. Surface Water Resources

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water perennially plentiful	Perennial streams and lakes throughout the country. Major streams are listed below. **Caribbean Sea Basin (II)**: Rio Cahabon (1525N08936W)[3], Rio Motagua (1544N08814W), and Rio Polochic (1528N08922W). **Gulf of Mexico Basin (III)**: Rio Chixoy (1604N09027W), Rio Salinas (1628N09033W), Rio de la Pasion (1628N09033W), and Rio Usumacinta (1714N09124W). Major lakes are listed below. **Pacific Ocean Basin (I)**: Lago de Atitlan (1442N09112W), Lago de Amatitlan (1427N09034W), Laguna de Ayarza (1425N09008W), Laguna de Refana (1425N08956W), Laguna de Atescatempa (1412N08942W), and Laguna de Guija (1416N08931W). **Caribbean Sea Basin (II)**: Lago de Izabal (1530N08910W), Laguna Yaxja (1704N08924W), and El Golfete (1544N08853W). **Gulf of Mexico Basin (III)**: Lago Peten Itza (1659N08950W) and Laguna Perdida (1704N09013W). Major reservoirs are listed below. **Pacific Ocean Basin (I)**: Santa Maria (1444N09132W). **Gulf of Mexico Basin (III)**: Embalse Chixoy (1517N09030W).	Large to very large quantities are available year-round from streams. Enormous quantities are available year-round from lakes and reservoirs. Slight seasonal fluctuations in stream and lake levels occur. Selected station numbers, rivers, and their average annual discharges from 1983-96 are listed below. **Caribbean Sea Basin (II)**: **34**, Rio Motagua at Morales (1528N08852W), 208.7 m^3/s; and **38**, Rio Cahabon at Panzos (1524N08935W), 164.20 m^3/s. **Gulf of Mexico Basin (III)**: **47**, Rio Salinas at San Augustin Chixoy (1605N09028W), 544.2 m^3/s, **73**, Embalse Chixoy reservoir (1517N09030W) stores about 460,000,000 Mm^3 of the Rio Chixoy, 320,000,000 Mm^3, **76**, Rio de la Pasion at El Porvenir (1631N09029W), 322.8 m^3/s, and **77**, Rio Usumacinta (1714N09124W) has a reported discharge of 1,559 m^3/s, the largest in Central America. **Pacific Ocean Basin (I)**: **74**, Santa Maria reservoir (1444N09132W) which stores 200,000 Mm^3 of the Rio Samala.	Water is generally fresh. TDS concentrations range from 192 to 389 mg/L, with varying amounts of suspended materials, depending on rainfall. Streams are biologically contaminated near many populated areas. The Rio Motagua is biologically and chemically contaminated. Water hardness ranges from moderate to hard in the limestone areas of the Peten. Lower reaches of coastal streams become brackish.	Development and access to water points are dependent upon topography, ground cover, and climate. Adverse topographic conditions that hinder access include high steep banks of streams and lakes. After heavy rains, roads may become impassable for equipment. Rapidly rising streams may also contain debris that may destroy water points. Access and development of water points are generally feasible in populated areas and broad flood plains.	Expect high sediment loads in the streams within this category during the wet season, May through November. Protection of equipment against flooding and debris is required. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting.
2 Fresh water locally plentiful	Perennial and intermittent streams throughout the country. Major streams are listed below. **Pacific Ocean Basin (I)**: Rio Aguacapa (1406N09039W), Rio Coyalate (1357N09119W), Rio Ican (1408N09140W), Rio Los Esclavos (1350N09020W), Rio Maria Linda (1356N09042W), Rio Nahualate (1403N09132W), Rio Ocosito (1430N09211W), Rio Paz (1345N09008W), Rio Samala (1411N09147W), and Rio Selegua (1542N09155W).	Moderate to very large quantities are available seasonally. Quantities may be small to moderate toward the end of the dry season, March to April. Selected station numbers, rivers, and their average annual discharges are listed below. **Pacific Ocean Basin (I)**: **2**, Rio Cabuz at Malacatan (1454N09202W), 21.30 m^3/s; **4**, Rio Naranjo at Coatepeque (1446N09152W), 20.70 m^3/s; **5**, Rio Melendrez at Melendrez II (1443N09153W), 10.26 m^3/s; **6**, Rio Nahuatan at Pajapita (1444N09203W), 10.80 m^3/s; **7**, Rio Ocosito at Caballo Blanco (1430N09151W), 31.10 m^3/s; **8**, Rio Ocosito at Retalhuleu (1432N09141W), 26.20 m^3/s; **9**, Rio Samala at El Palmar (1439N09135W), 10.36 m^3/s; **13,** Rio Ican at Mazatenango (1432N09131W), 35.60 m^3/s; **14**, Rio Nahualate at San Miguel Moca (1427N09127W), 33.52 m^3/s;	Water is generally fresh with TDS ranging from 89 to 299 mg/L. Some streams may contain high levels of chlorides and sulfates. Biological contamination occurs near many settlements. The Rio Guacalate (1411N09053 W), which drains the city of Escuintla (1418N09047 W), is heavily contaminated with organic (70 to 80 percent) and biological wastes.	Development of and access to water points depend on topography, ground cover, and climate. In the coastal plains of the north and south coasts, access is generally easy due to gentle terrain and well developed road network. Lack of a fully developed road network in the northwest and Peten region severely limits access. Adverse topographic conditions that hinder access include high steep banks of	Protection of equipment against flooding and debris is required. Contamination of streams is to be expected on the coastal plains. Agricultural, organic, and biological wastes exist in all water bodies and lesser industrial wastes are to be expected in streams which drain major population centers.

Table C-1. Surface Water Resources (continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water locally plentiful (continued)		**18**, Rio Coyolate at Puente Coyolate (1422N09108W), 14.40 m^3/s; **19**, Rio Acome at La Gomera (1405N09103W), 27.00 m^3/s; **22**, Rio Maria Linda at Guanagazapa (1414N09039W), 16.30 m^3/s; **23**, Rio Nahualate at Santo Domingo (1418N09027W), 71.20 m^3/s; **24,** Rio Los Esclavos at Cuilapa (1417N09018W), 15.80 m^3/s; **25**, Rio Paz at Jalpatagua (1408N08957W), 23.20 m^3/s; and **50**, Rio Aguacapa at Pueblo Nuevo Vinas (1414N09032W), 11.00 m^3/s. **Caribbean Sea Basin (II)**: **29**, Rio Motagua at Granados (1454N09033W), 52.70 m^3/s; **30**, Rio Los Platanos at Panajax (1453N09027W), 25.03 m^3/s; **31**, Rio Motagua at Puente Orellana (1455N08948W), 20.54 m^3/s; **33**, Rio Grande de Zacapa at Camotan (1449N08922W), 27.00 m^3/s; **36**, Rio Matanzas at Matucy (1521N08941W), 52.93 m^3/s; **37**, Rio Boca Nueva at Boca Nueva II (1523N08938W), 12.48 m^3/s; **39,** Rio Polochic at Panzos (1522N08934W), 78.30 m^3/s; and **40**, Rio Gracias a Dios at Modesto Mendez (1556N08913W), 28.16 m^3/s. **Gulf of Mexico Basin (III)**: **41**, Rio Selegua at Chojil (1542N09155W), 38.00 m^3/s; **42**, Rio Cuilco at Cuilco (1526N09157W), 16.96 m^3/s; **43**, Rio Selegua at Colotenango (1527N09143W), 10.70 m^3/s; **44**, Rio Chixoy at Uspantan (1523N09050W), 56.30 m^3/s; **49**, Rio San Pedro at San Pedro Mactun (1715N09045W), 49.10 m^3/s; and **75**, Rio Azul at La Laguna (1546N09151W), 31.47 m^3/s.	Selected station numbers, rivers, and water quality characteristics are listed below. **Pacific Ocean Basin (I)**: **7**, Rio Ocosito at Caballo Blanco (1430N09151W), pH 7.9, TDS 192 mg/L, and hardness 58 mg/L; **24**, Rio Los Esclavos Cuilapa (1417N09018W), pH 7.8, TDS 262 mg/L, and hardness 63 mg/L; **60**, Rio Aguacapa at Agua Caliente (1420N09028W), pH 8.2, TDS 299, and hardness 99 mg/L; **61**, Rio Tapalapa at Pozo Escondida (1429N09006W), pH 7.9, TDS 340, and hardness 34 mg/L, and **64**, Rio Paz at El Jobo (1355N09006W), pH 8.4, TDS 389 mg/L, and hardness 105 mg/L. **Caribbean Sea Basin (II)**: **71**, Rio Motagua at Concua (1452N09032W), pH 8.2, TDS 219 mg/L, and hardness 71 mg/L; **72**, Rio Motagua at El Rancho (1457N09000W), pH 8.1, TDS 216 mg/L, and hardness 95 mg/L. **Gulf of Mexico Basin (III)**: **65**, Rio Selegua at Xemal (1527N09142W), pH 8.3, TDS 224 mg/L, and hardness 149 mg/L; **68**, Rio Chixoy at Chixoy (1523N09039W), pH 8.3, TDS 192 mg/L, and hardness 136 mg/L; **69**, Rio Cahabon at Chajcar (1529N09010W), pH 8.4, TDS 134 mg/L, and hardness 144 mg/L; and **70**, Rio Pixcaya at El Tesoro (1439N09054W), pH 8.1, TDS 186 mg/L, and hardness 58 mg/L.	streams and lakes and sinkholes in the Peten. After heavy rainfalls, roads may become impassable for equipment. Rapidly rising streams may also contain debris, which may destroy water points. Access and development of water points are generally feasible in populated areas, because of developed infrastructures and are feasible in the flood plains.	
3 Fresh water locally plentiful	Numerous small perennial and intermittent streams throughout the country. Sources are primarily in the headwaters of drainage basins that feed streams on the mountains flanks. Major sources are listed below.	Small quantities of fresh water are available during the wet season of May through January and following heavy rainfall. Quantities may significantly diminish or even become dry from February to April. Selected station numbers, rivers, and their average annual discharges are listed below. **Pacific Ocean Basin (I):** **1**, Rio Coatan at Cunlaj (1513N09210W), 1.29 m^3/s; **3**, Rio Naranjo at Corral Grande (1456N09145W), 1.74 m^3/s;	Water is fresh. TDS range from 89 to 283 mg/L with varying amounts of suspended materials, depending on rainfall, especially in the south. Streams are biologically contaminated near many populated areas. The upper reaches of highland streams probably have minimal biological contamination. Water hardness ranges from moderate to hard in limestone areas. Many streams on volcanic slopes in the southern part of the central highlands are high in sulfates.	Development and access to water points are dependent upon topography, ground cover, and climate. In the mountains and Peten the lack of fully developed road network will restrict access. Steep banks restrict access in the mountains.	Expect high sediment loads within this category during the wet season, May through November. Protection of equipment against

Table C-1. Surface Water Resources (continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 Fresh water locally plentiful (continued)	**Pacific Ocean Basin (I)**: Rio Coatan (1510N09214W), Rio Guacalate (1411N09053W), Rio Michatoya (1406N09039W), Rio Naranjo (1430N09211W), Rio Quixaya (1431N09107W), Rio Sis (1419N09132W), and Rio Xaya (1427N09106W). **Caribbean Sea Basin (II):** Rio Sunzapote (1441N09156W), Rio Tzepela (1458N09104W), and Rio Chilasco (1507N09006W). **Gulf of Mexico Basin (III)**: Rio Salama (1518N09027W) and Rio Las Flautas (1506N09011W).	**10**, Rio Samala at Cantel (1434N09139W), 3.92 m^3/s; **11**, Rio Sis at La Maquina (1418N09138W), 4.06 m^3/s; **12**, Rio Samala at Candelaria (1439N09130W), 8.73 m^3/s; **15**, Rio Cutzan at Montecristo (1431N09122W), 6.08 m^3/s; **17**, Rio Quixaya at Puente Quixaya (1435N09108W), 1.88 m^3/s; **20**, Rio Guacalate at Alotenango (1429N09053W), 1.16 m^3/s; **21**, Rio Michatoya at Palin (1424N09042W), 4.80 m^3/s; **27**, Rio Mongoy at El Jicaral (1417N08940W), 1.04 m^3/s; and **48**, Rio Machaquila at Machaquila (1623N08931W), 8.64 m^3/s. **Caribbean Sea Basin (II):** **28**, Rio Tzepela at Chiche (1459N09104W), 2.07 m^3/s; **32**, Rio Sunzapote at Pasabien (1502N08941W), 2.07 m^3/s; and **35**, Rio Chilasco at Chilasco (1507N09006W), 1.18 m^3/s. **Gulf of Mexico Basin (III)**: **45**, Rio Salama at San Jeronimo (1504N09014W), 2.98 m^3/s; **46**, Rio Las Flautas at Matanzas (1506N09011W), 1.57 m^3/s; and **48**, Rio Machaquila at Machaquila (1623N08931W), 8.64 m^3/s.	Selected station numbers, rivers, and water quality characteristics are listed below. **Pacific Ocean Basin (I):** **10**, Rio Samala (1434N09139W), pH 7.7, TDS 218 mg/L, and hardness 55 mg/L; **16**, Rio Panajachel (1448N09109W), pH 8.1, TDS 166 mg/L, and hardness 60 mg/L; **51**, Rio Samala at San Cristobal (1455N09126W), pH 7.8, TDS 163 mg/L, and hardness 45 mg/L; **52**, Rio Nahualate at Santo Catarina Ixtahuacan (1448N09122W), pH 8.0, TDS 142 mg/L, and hardness 53 mg/L; **53**, Rio Yatza at Yatza (1438N09124W), pH 8.1, TDS 143 mg/L, and hardness 60 mg/L; **54**, Rio Quiscab at Jaibal (1445N09111W), pH 8.1, TDS 205 mg/L, and hardness 61 mg/L; **55**, Rio Madre Vieja at Panibaj (1440N09106W), pH 8.1, TDS 168 mg/L, and hardness 64 mg/L; **56**, Rio Santo Tomas at Santo Tomas Perdido (1435N09107W), pH 8.0, TDS 260 mg/L, and hardness 144 mg/L; **57**, Rio Xaya at La Sierra (1438N09058W), pH 8.0, TDS 166 mg/L, and hardness 68 mg/L; and **58**, Rio Guacalate at Monte Maria (1425N09044W), pH 8.0, TDS 283 mg/L, and hardness 130 mg/L. **Caribbean Sea Basin (II)**: **66**, Rio San Jeronimo at Las Astras (1506N09009W), pH 7.7, TDS 89 mg/L, and hardness 45 mg/L. **Gulf of Mexico Basin (III)**: **67**, Rio San Jeronimo at San Jeronimo (1503N09013W), pH 8.1, TDS 92 mg/L, and hardness 46 mg/L.	After heavy rains, roads may become impassable for equipment. Rapidly rising streams may also contain debris that may destroy water points. Access and development to water points is considered difficult throughout this map unit.	flooding and debris is required. Frequent maintenance of equipment along channels carrying high sediment loads is recommended to counter rapid silting. In the karst environment of the Peten rapid variations of water levels may occur. Expect biological, agricultural, and organic wastes in all water bodies near population centers.
4 Fresh water locally plentiful	Numerous small intermittent streams in the highlands; shallow sinkholes, depressions, and seasonally inundated areas in the north. Much of the drainage in the north is underground due to dissolution of the underlying limestone. **Pacific Ocean Basin (I)**: Rio Las Vacas (1452N09024W), Rio Mongoy (1415N08942W), Rio Panajachel (1444N09109W), and Rio Villalobos (1429N09034W).	Meager to very small quantities of fresh water are available from streams during the wet season of May through October and following heavy rainfall. Quantities may significantly diminish or become dry during the dry season. Selected station numbers, rivers, and their average annual discharges are listed below. **Pacific Ocean Basin (I)**: **16**, Rio Panajachel at Concepcion Potrero (1448N09109W), 0.35 m^3/s; **26**, Rio Mongoy at La Montanita (1415N08943W), 0.59 m^3/s; and **59**, Rio Villalobos at Villalobos (1430N09033W), 0.778 m^3/s.	Water is fresh. TDS range from 220 to 817 mg/L with varying amounts of suspended materials, depending on rainfall, especially in the south. Streams are biologically contaminated near many populated areas. The Rio Villalobos and the Rio Las Vacas, which drain Guatemala City, have concentrations of phosphorous, nitrate, potassium, and sodium that exceed the maximum limits established by the World Health Organization. The high amounts of nitrogen and phosphorus induced the microcystis aeroginosa algae to reproduce in large quantities. This algae causes skin and digestive tract problems in people. These streams also carry high total coliform counts indicative of fecal contamination from untreated sewage. Dangerous constituents from industrial wastes in Guatemala City include chromium VI, arsenic, lead, cyanide, aluminum, and others. The upper parts of the highland streams outside of urban areas probably have minimal biological contamination. Water hardness ranges from moderate to hard in limestone areas. Many streams on volcanic slopes in the southern part of the central highlands are high in sulfates.	Access and development of water points are difficult. Adverse topographic conditions that impede access include steep relief, lack of road infrastructure, and steep banks. After heavy rain, streams may rise rapidly, and the associated swift currents and floating debris can destroy water points.	Most of the streams in this category originate near population centers, so expect high levels of contamination. Precautions must be taken to protect equipment against floods. Contingency plans for supplemental water supplies are necessary because local quantities during the dry season may be insufficient.

Table C-1. Surface Water Resources (continued)

Map Unit No. (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water locally plentiful (continued)			Selected station numbers, rivers, and water quality characteristics are listed below. **Pacific Ocean Basin (I)**: **59**, Rio Villalobos at Villalobos (1430N09033W), pH 8.1, TDS 817 mg/L, dissolved oxygen of 0.29 percent and hardness 93 mg/L; **62**, Rio Grande de Mita at Las Lechuzas (1422N08938W), pH 8.1, TDS 220 mg/L, and hardness 73 mg/L; and **63**, Rio Grande de Mita at Las Cruces (1419N08938W), pH 8.0, TDS 239 mg/L, and hardness 94 mg/L.		
5 Fresh water scarce or lacking	Coastal streams, lagoons, swamps, and estuaries. Two of these sources are listed below. **Pacific Ocean Basin (I)**: Canal de Chiquimulilla (1355N09107W). **Caribbean Sea Basin (II)**: Rio Dulce (1549N08845W).	Large to enormous quantities of brackish to saline water are available year-round.	Water ranges from brackish to saline in coastal area streams, swamps, lagoons, and estuaries. Brackish water in coastal swamps is of poor quality and contains large amounts of organic materials, iron, and magnesium. During tidal inflow, coastal streams become more saline. During tidal outflow and floods, water can become fresh to slightly brackish. Estuaries typically contain saline water.	Access and development of water points are limited by road infrastructure, ground cover, and soil conditions. Associated floods or tidal surges from storms may destroy water points.	Precautions must be taken to protect equipment from bank slumping and water level fluctuations. Equipment must also be protected from corrosion incurred by exposure to salts. Desalination equipment is required to treat brackish and saline water.

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

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

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

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

Rio Cahabon..............................1525N08936W

Geographic coordinates for Guatemala that are given as 1525N08936W equal 1525' north 8936' west and can be written as a latitude of 15 degrees and 25 minutes north and a longitude of 89 degrees 36 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Coordinates are approximate. Basin numbers are shown in parentheses; stream-gaging station numbers are shown in bold. Geographic coordinates for rivers are generally at the river mouth.

Note:
- $CaCO_3$ = calcium carbonate
- ft^3/s = cubic feet per second
- gal/min = gallons per minute
- km^2 = square kilometers
- L/min = liters per minute
- m^3/s = cubic meters per second
- mg/L = milligrams per liter
- Mm^3 = million cubic meters
- pH = hydrogen-ion concentration
- TDS = total dissolved solids

Conversion Chart:

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

Table C-2. Ground Water Resources

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful	Unconfined Quaternary alluvium consisting of unconsolidated sand and gravel interbedded with silt and clay. Mainly located in coastal plains, stream valleys, and interior basins. Alluvium thickness in the Departamento de Escuintla (1410N09100W)[3] ranges up to 200 m.	Very small to very large quantities of ground water are available in the Pacific Coastal Plain (1410N09115W), in some of the large river valleys, and in a few basins throughout the country. Quantities decrease during the dry season, which is November through April everywhere except in the north where it is December through April. During this season, the water table drops 1 to 3 m. Yields from 18 drilled wells in the Departamento de Escuintla (1410N09100W) in the Pacific coastal alluvium range from 10 to 50 L/s with an average yield of 20 L/s. Specific capacities range from 1 to 5 L/s/m. Locally, yields range from 35 to 95 L/s with specific capacities of about 2 L/s/m. Yields from seven wells drilled in the Altiplano (1430N09100W) (includes departments of Quezaltenango, Totonicapan, Solola, Chimaltenango, Sacatepequez, and Guatemala) alluvium range from 3 to 58 L/s with an average yield of 30 L/s. Yields range from 5 to 25 L/s from the alluvium of the upper Rio Motagua basin (1544N08814W). Specific capacities range from 0.1 to 17 L/s/m. Transmissivities in the Pacific coastal alluvium range from 150 to 2,000 m^2/d and from 100 to 2,500 m^2/d in the Altiplano (1430N09100W).	Fresh water is available from the alluvial aquifers. TDS for the Pacific coastal alluvium range from 150 to 250 mg/L and pH ranges from 6 to 7. The water quality of the Altiplano (1430N09100W) alluvium is generally good with conductivity values between 200 and 400 micromhos/cm; exceptions are in areas contaminated by the thermal springs of volcanic origin where conductivities range from 1,500 to 2,000 micromhos/cm. Shallow ground water is often biologically contaminated near settlements. Near the coast, fresh water is underlain by brackish or saline water. Locally, fresh-water lenses exist in the deeper aquifers. Contamination from pesticides can be expected in agricultural areas.	Accessibility, siting, and drilling of wells are easy. Depth to water ranges from 1 to 6 m. Pumping levels are between 10 and 30 m in the Pacific Coastal Plain (1410N09115W), 20 and 135 m in the Altiplano (1430N09040W), and 20 to 100 m in the upper Rio Motagua basin (1544N08814W). Because saltwater zones underlie the fresh-water zones in the coastal plains, caution should be exercised in pumping to prevent saltwater intrusion. Wells should be screened due to the unconsolidated nature of the material.	In the Pacific Coastal Plain, the aquifer is easily replenished by rainfall averaging 200 cm/yr and through recharge occurring at the foothills of the volcanic mountains to the north. Suitable for tactical wells, small submersible pump wells, and hand-pump wells. Supports irrigation and municipal water supply wells.
2 Fresh water locally plentiful	Karst and fractured Cretaceous limestone. Dissolution and fracturing have greatly enhanced the porosity and permeability of the limestone. Mainly located in Peten Lowlands (1650N09000W), in Peten Highlands (1620N08925W), and in the Sierra de Los Cuchumatanes (1535N09125W) and Sierra de Chama (1540N09030W).	Meager to very large quantities of ground water are available from the limestone aquifers. The largest quantities of ground water are available in areas that have the greatest limestone dissolution and fracturing. Quantities decrease during the dry season.	Fresh water is available from the limestone aquifers. The water increases from hard to very hard in the dry season. Brackish water occurs locally where gypsum is interbedded with the limestones. Shallow ground water is often biologically contaminated near settlements.	Accessibility is difficult in densely forested areas. Steep slopes in the central part may hinder siting. Siting and drilling are difficult because of localized dissolution of the karst limestones and the hardness of rock. Depths to water range from 3 m in the lowlands to 30 m in the hills and mountains.	Most areas are suitable for tactical wells, small submersible pump wells, and hand-pump wells. Quantities are decreasing in areas that have been deforested.

Table C-2. Ground Water Resources (continued)

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful	Tertiary and Quaternary volcanic ash, cinder, sand, and lava flows of the Pacific volcanic belt. Mainly located in the southern Central Highlands (1515N09030W). Fracturing has greatly enhanced the porosity and permeability of the aquifers. Ground water is mainly obtained from pore spaces, porous layers, and fractures. Thickness of the fallen ash flow materials rarely exceeds 10 m. The thickness of the ash flow deposits is highly variable due to the underlying pre-existing topography and can reach up to 100 m per depositional unit. The Quaternary lava flows originated from a chain of over 30 volcanoes aligned in an east-west direction mainly along the lower edge of the Sierra Madre (1435N09100W). These flows consist of basaltic, andesitic, and rhyolitic lavas deposited in the form of sands, bombs, ash, and lahars that are interbedded with volcanic-ejected materials. Thickness varies from a maximum of 500 m at the base of cinder cones to about 1,500 m near the summits. Due to the high permeability of the flows, the aquifer is easily recharged. The Tertiary tuffs and lava deposits are intensely fractured due to rapid cooling and have good permeability. Hydrologically, this is the most important unit in the volcanic Altiplano (1430N09040W); it is a highly used aquifer. Scattered hot springs occur throughout the area.	Very small to very large quantities of ground water are available from the volcanic aquifers. Locally, wells from 75 to 300 m deep yield between 25 and 100 L/s of ground water. **Quaternary Pyroclastic Deposits**. Wells drilled exclusively in pyroclastic deposits in the Altiplano (1430N09040W) yield between 2 and 50 L/s at mean depths of about 180 m. Specific capacities vary between 0.02 and 4.4 L/s/m. Wells in the Quezaltenango Valley (1445N09140W) yield between 20 and 50 L/s at mean depths of 150 m with specific capacities of 1 to 4 L/s/m. Wells in the Chimaltenango Valley (1440N09055W) yield between 5 and 20 L/s at mean depths of 160 m with specific capacities of 0.1 to 2 L/s/m. Transmissivity is highly variable in the pyroclastics and ranges between 50 and 750 m^2/d in the Guatemala Valley (1440N09030W) and between 100 and 300 m^2/d in the Quezaltenango Valley (1445N09140W). **Quaternary Lava Deposits**. In general, wells drilled in the lava deposits in various zones of the Altiplano (1430N09040W) yield between 10 and 45 L/s at mean depths of 150 m with specific capacities of 0.8 L/s/m. Wells drilled in the Rio Oitua basin (1430N08942W) between Ipala (1437N08937W) and Suchitan (1425N08948W) yield between 15 and 40 L/s at depths up to 150 m with specific capacities of 1 to 10 L/s/m. **Tertiary Tuffs and Lavas**. Within this unit are springs of high productivity, like Ojo de Agua (1421N09019W) in the Guatemala Valley (1440N09030W) which yields between 250 and 500 L/s and issues from fractured andesitic lava in contact with pyroclastic material of low permeability.	Fresh water is in unconsolidated aquifers. Locally, the ground water may be high in sulfates and chlorides. The water quality of the hot springs is brackish. **Quaternary Pyroclastic Deposits**. The ground water quality in the Quaternary Pyroclastic deposits is generally fresh with electrical conductivity values ranging from 200 to 400 micromhos/cm. **Quaternary Lava Deposits**. The ground water quality in the Quaternary lavas is generally fresh with electrical conductivity values <500 micromhos/cm. **Tertiary Tuffs and Lavas**. The ground water quality in the Tertiary deposits is generally fresh with electrical conductivity values generally <500 micromhos/cm. Only in locally hydrothermally active areas is the ground water saline. The quality of drinking water in the Guatemala City (1438N09031W) area in 1997 is given below for the following wells. Well #1 Alameda Norte, 4/26/95, Cl 2.47 mg/L, SO_4 113 mg/L, total P .282 mg/L, total Na 2.59 mg/L, turbidity 24 mg/L, biochemical oxygen demand after 5 days 0.4 mg/L, fecal coliform <3 MPN/100 mL; Well #2 Jardines de Minerva, 5/24/95, Cl 24.7 mg/L, SO_4 8.2 mg/L, total P .282 mg/L, total Na 5.93 mg/L, turbidity 8 mg/L, biochemical oxygen demand after 5 days 6.9 mg/L, chemical oxygen demand 21.5 mg/L, fecal coliform <3 MPN/100 mL.	Accessibility is difficult because of steep mountain slopes. Drilling is difficult in the hard rocks. Depth to water ranges from 10 to 150 m in the unconsolidated aquifers and from 167 to 300 m in the consolidated aquifers. Wells should be cased, and screens are necessary in volcanic ash. **Quaternary Pyroclastic Deposits**. Pumping levels are between 20 and 160 m in the Altiplano (1430N09040W), between 60 and 90 m in the Quezaltenango Valley (1445N09140W), between 75 and 165 m in the Chimaltenango Valley (1440N09055W), and between 1 and 120 m in the Rio Oitua basin (1430N08942W). **Quaternary Lava Deposits**. Pumping levels are between 1 and 120 m in the Rio Oitua basin (1430N08942W). **Tertiary Tuffs and Lavas**. The fractured zone where most of the ground water circulation takes place is within 500 m of the land surface. Wells drilled in this unit in various zones of the Altiplano (1430N09040W) have depths of generally 150 m. Pumping levels range from 35 to 90 m in the Ipala Valley (1437N08937W) and from 30 to 90 m in the Guatemala Valley (1440N09030W). In the Guatemala City metropolitan area (1438N09031W), only one well managed by EMPAGUA was abandoned due to poor water quality. Nine wells were abandoned due to the presence of fines and structural or equipment failures through 1993.	Most areas are suitable for tactical wells, small submersible pump wells, and hand-pump wells. About 64 percent of the water supply for the Guatemala metropolitan area (1438N09031W) is from ground water.

Table C-2. Ground Water Resources (continued)

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful (continued)		Wells drilled in the Ipala valley (1437N08937W) yield from 12 to 30 L/s with specific capacities of about 1 L/s/m. Wells drilled in the Guatemala Valley (1440N09030W) yield from 0.4 to 1.8 L/s with specific capacities from 2.2 L/s/m in the south to 28 L/s/m in the north. In the Guatemala City metropolitan area (1438N09031W), the Guatemala Municipal Water Supply Public Corporation (EMPAGUA) manages 121 ground water wells in the metropolitan area. (July 1995). Region North 1 has 63 wells with a total withdrawal capacity of 540 L/s, Yields range from 1.26 to 25.23 L/s. Region North 2 has five wells with a total withdrawal capacity of 60 L/s. Yields range from 1.89 to 18.93 L/s. Central Region has 20 wells with a total withdrawal capacity of 548 L/s. Yields range from 6.31 to 63.08 L/s. Region East 1 has 15 wells with a total withdrawal capacity of 360 L/s. Yields range from 2.52 to 50.47 L/s. Region South 1 has six wells with a total withdrawal capacity of 65 L/s. Yields range from 6.31 to 17.03 L/s. Region South 2 has one well with a withdrawal capacity of 18 L/s. Region South 3 has 11 wells with a withdrawal capacity of 1,142 L/s. Yields range from 31.54 to 320.15 L/s. Ojo de Agua (1421N09019W) wells are also located in Region South 3.	Well #3 Roosevelt Hospital, 4/26/95, Cl 1.98 mg/L, SO_4 256 mg/L, total P .636 mg/L, total Na 4.19 mg/L, turbidity 24 mg/L, biochemical oxygen demand after 5 days 1.3 mg/L, chemical oxygen demand 5.0 mg/L, fecal coliform <3 MPN/100 mL; Well #4 Molino de la Flores, 5/24/95, Cl 5.4 mg/L, SO_4 7.7 mg/L, total P .117 mg/L, total Na 1.24 mg/L, turbidity 4 mg/L, biochemical oxygen demand after 5 days 10.2 mg/L, chemical oxygen demand 15.3 mg/L, fecal coliform <3 MPN/100 mL; Well #5 Ojo de Agua, 5/24/95, Cl 5.9 mg/L, SO_4 4.3 mg/L, total P .133 mg/L, total Na 1.40 mg/L, turbidity 0 mg/L, biochemical oxygen demand after 5 days 7 mg/L, chemical oxygen demand 21.5 mg/L, fecal coliform <3 MPN/100 mL.		
4 Fresh water locally plentiful	Paleozoic age igneous and metamorphic rocks consisting of granite, basalt, gneiss, schist, serpentine, and some volcanic rocks. Mainly located in the central part of the Central Highlands (1515N09030W) along a belt 20 to 60 km wide that extends east to west across the country. These rocks are generally impermeable with little porosity. Ground water is primarily from fractures.	Meager to small quantities of ground water are available from the igneous and metamorphic aquifers.	Water quality is fresh from these aquifers. Shallow ground water is often biologically contaminated near settlements.	Accessibility is difficult due to steep slopes in the mountains. Drilling is difficult in the hard rocks. Depth to water ranges from 3 to 150 m. Wells should be cased near the surface.	Suitable for hand-pump wells where depth to water is <100 m. Some areas are suitable for tactical wells and submersible pump wells. Successful wells may depend upon encountering water-bearing fractures.

Table C-2. Ground Water Resources (continued)

Map Unit No. (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
5 Fresh water locally plentiful	Tertiary and Cretaceous sedimentary aquifers consisting of sandstone interbedded with shale, conglomerates, and limestones. Mainly located in plains, hills, and mountains in central Guatemala, in the southern and northern Peten (1650N09000W), and in northern Alta Verapaz (1540N09000W). Ground water is primarily from solution fissures, bedding planes, joints, and pore spaces. Due to very low permeability, this unit is not considered a regional aquifer.	Very small to large quantities of ground water are available from the sedimentary aquifers. Drilled wells near the Port of Livingston (1550N08845W) on Amatique Bay (1555N08845W) yield 6 L/s with specific capacity of 0.08 L/s/m.	Fresh water is available locally. The ground water may be brackish where gypsum beds are present. Shallow ground water is often biologically contaminated near settlements.	Accessibility is difficult on steep slopes. Depth to water ranges from 3 to 150 m. Wells should be cased and screened. Port of Livingston (1550N08845W) wells are drilled to 150 m and have static water levels of 10 m.	Some areas are suitable for tactical wells and small submersible pump wells. Most areas are suitable for hand-pump wells if depth to water is <100 m. Successful wells may depend upon encountering water-bearing fractures.
6 Fresh water scarce or lacking	Unconsolidated Quaternary sediments, primarily sand, located along the Pacific (1410N09115W) and Caribbean coasts (1515N08930W). Ground water is from pore spaces in the unconsolidated sediments.	Very small to very large quantities of non-fresh water are available.	Brackish to saline water is available from the unconsolidated aquifers. Saltwater intrusion of seawater into the unconsolidated sediments contaminates the ground water. Fresh-water lenses float on the saline water in many places.	Accessibility may be difficult in wet and densely forested areas along the coast. Siting and drilling wells are difficult because of the presence of saltwater underlying the fresh-water zones in the coastal areas. Depth to water ranges from 1 to 6 m. Caution should be exercised to prevent saltwater intrusion. Wells should be screened due to the unconsolidated nature of the material.	If desalinization or reverse osmosis water purification of the water is provided, these areas are suitable for tactical wells, small submersible pump wells, and hand-pump wells. Overpumping of the fresh-water lenses can lead to saltwater intrusion.

[1]Quantitative Terms:

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

[2]Qualitative Terms:

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

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

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

Departamento de Escuintla.......................1410N09100W

Geographic coordinates for Departamento de Escuintla that are given as 1410N09100W equal 1410' north 9100' west and can be written as a latitude of 14 degrees and 10 minutes north and a longitude of 91 degrees 0 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates are approximate. Geographic coordinates for rivers are generally at the river mouth.

Table C-2. Ground Water Resources (continued)

Note:

$CaCO_3$	= calcium carbonate	mL	= milliliters
Cl	= chloride	MPN	= most probable number
cm/yr	= centimeters per year	N	= nitrogen
gal/min	= gallons per minute	Na	= sodium
L/min	= liters per minute	NaCl	= sodium-chloride
L/s	= liters per second	P	= phosphorus
L/s/m	= liters per second per meter	pH	= hydrogen-ion concentration
m^2/d	= square meters per day	SO_4	= sulfate
mg/L	= milligrams per liter	TDS	= total dissolved solids

Conversion Chart:

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