Water Resources Assessment of Ecuador

UNITED STATES SOUTHERN COMMAND

US Army Corps of Engineers
Mobile District and
Topographic Engineering Center

SEPTEMBER 1998

Preface

In 1995 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 Ecuador. This assessment has two objectives. One objective is to provide an analysis of the existing water resources of Ecuador and identify some opportunities available to the Government of Ecuador to maximize the use of these resources. The other objective is to provide Ecuador and U.S. military planners with accurate information for planning various joint military training exercises and humanitarian civic assistance engineer exercises such as the New Horizons series.

This report collates information from many different sources that enable the reader to better understand the current situation of Ecuador's abundant water resources. This general assessment will enable the Government of Ecuador to make a more detailed analysis of the use of water resources so that it can continue its development of a comprehensive water resources management plan.

Topics covered in this assessment are as follows:

?? the Introduction and Country Profile topics explain the mission of the assessment team and provide some basic information on Ecuador and a list of the agencies contacted;
?? the Current Use of Water Resources topic discusses use of the water resources by various sectors of the country. Included in this section are discussions on water supply, water quality, hydropower, waterway transportation, flood control, and legislative framework;
?? the Existing Water Resources topic contains an analysis of the general availability of surface and ground water resources in Ecuador. This section is designed to be used with the surface and ground water resources maps in Appendix A;
?? the Recommendations topic presents recommendations for basic technical engineering training and for watershed protection.

A team consisting of the undersigned water resources specialists from the U.S. Army Corps of Engineers Mobile District and the U.S. Army Topographic Engineering Center conducted the water resources investigations during 2 weeks in January 1997 and subsequently prepared the report.

James O. Buckalew
Water Resources Engineer
Telephone: 251-694-3863
Facsimile: 251-690-2727
Internet: james.o.buckalew@sam.usace.army.mil

Maurice James, P.E.
Hydrology and Hydraulic Design Specialist
Telephone: 251-690-3109
Facsimile: 251-690-3208
Internet: maurice.james@sam.usace.army.mil

Lisa Scott, Hydrologist
Telephone: 703-428-6895
Facsimile: 703-428-8176
Internet: laura.c.dwyer@usace.army.mil

Paul Reed, Hydrologist
Telephone: 703-428-7206
Facsimile: 703-428-8176
Internet: paul.e.reed@usace.army.mil

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

Officials Consulted

Name	Organization (Acronym)	English Translation
Dr. Eugenio Bayancela Ing. Fernando Solis Ms. Kim Johnston	Cooperative for American Relief to Everywhere (CARE)	
Mr. Ken Farr Mr. Tom Geiger Mr. Fausto Maldonado Ms. Maria Augusta Fernandez Mr. Jaime Paredes	U.S. Agency for International Development (USAID)	
Ing. Gustavo Gomez Dr. Ing. Remigio Galarraga Ing. Anibal Vega	Instituto Nacional de Meteorologia y Hidrologia (Ministerio de Energia y Minas) (INAMHI)	National Institute of Meteorology and Hydrology
Ing. Eric Cadier	Institute Francais de Recherche Scientifique Pour le Developpement en Cooperation (ORSTOM)*	French Scientific Research Institute for Cooperative Development
Ing. Othon Zevallos	Comision Asesora Ambiental (CAA)	Environmental Advisement Commission
Mr. Tomas Munoz Martin	Banco Interamericano de Desarrollo (BID)	International Development Bank
Ing. Luis Carrera	Ambiente y Desarrolla Sostenible (AMDESCO)	Environmentally Sustainable Development
Ing. Diego Gonzalez Ing. Jorge Perez	Subsecretaria de Saneamiento Ambiental (SSA)	Under Secretary for Sanitation and Environment
Ing. Patricio Vega Davila Ing. Ivan Calero Hidalgo Ing. Patricio Vivero Silva	Consejo Nacional de Recursos Hidricos (CNRH)	Council of Hydrologic Resources
Ing. Homero Castanier Ing. Rebecca Cabezas Ing. Mercelo Encalada	Proyecto de Fortalecimiento y Ampliacion de los Servicios Basicos de Salud en el Ecuador (FASBASE)	Fortification and Expansion Project of the Basic Health Services in Ecuador

*Origin of acronym is unknown.

Officials Consulted, Continued

Name	Organization (Acronym)	English Translation
Ing. Jorge Villavicencio R., Coronel Tecnico Carlos Ernesto Cobos M., General de Brigada	Cuerpo de Ingenieros de la Fuerza Terrestre (CEE)	Ecuadorean Army Corps of Engineers

Contents

Title **Page**

Contents, Continued

Figures

Tables

Appendix

List of Acronyms and Abbreviations

Acronyms

CARE	Cooperative for American Relief to Everywhere
CNRH	Consejo Nacional de Recursos Hidricos (National Council of Hydrologic Resources)
ETAPA	Empresa Publica Municipal de Telefonos, Agua Potable y Alcantarillado
FASBASE	Fortalecimiento y Ampliacion de los Servicios Basicos de Salud en el Ecuador
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
INAMHI	Instituto Nacional de Meteorologia e Hidrologia
INECEL	Instituto Ecuatoriano de Electrificacion (national electric company)
INERHI	Instituto Ecuatoriano de Recursos Hidraulicos
PAHO	Pan American Health Organization
SSA	Subsecretaria de Saneamiento Ambiental *in the* Ministerio de Desarrollo Urbano y Vivienda
USACE	U.S. Army Corps of Engineers (referred to in text as *Corps*)
USAID	U.S. Agency for International Development
USSOUTHCOM	United States Southern Command

Abbreviations

Ca	calcium
$CaCO_3$	calcium carbonate
Cl^-	chloride
CN	carbon-nitrogen
Fe	iron
gal/min	gallons per minute
km^2	square kilometers
L/min	liters per minute
m^3/s	cubic meters per second
Mg	magnesium
mg/L	milligrams per liter
mm	millimeters
Mm^3	million cubic meters
MW	megawatts
NaCl	nitrogen-chloride
pH	potential of hydrogen
SO_4	sulfate
SSC	suspended sediment concentrations
TDS	total dissolved solids (the sum of all dissolved solids in water or waste water)

I. Introduction

This assessment is a resource document intended to support current and potential investments in the water resources of Ecuador. Provisions within this assessment describe the existing major water resources in the country, identify special water resources needs and opportunities, document ongoing and planned water resources development activities, and suggest practicable approaches to short- and long-term water resources development.

Responsibility for overseeing the water resources of Ecuador is shared by several government agencies and institutions. The U.S. Army Corps of Engineers assessment team met and consulted with the most influential of these organizations in deciding priorities and setting goals for the use of Ecuador's water resources. The following is a list of these organizations and their primary areas of responsibility.

Agency	Area of Responsibility
Instituto Ecuatoriano de Electrificacion (INECEL)	INECEL, the national electric company, makes assessments of water resources for development of hydropower. INECEL maintains a network of hydrologic and meteorological gages in most basins of the Andes.
Comision de Estudios para el Desarrollo de la Cuenca del Rio Guayas (CEDEGE)	CEDEGE is a regional committee established to study the Guayas basin. This basin is considered very important in terms of water resources needs. The basin has major problems with water supply for agricultural and industrial production. It also has flooding problems in the lower valleys and drought problems in the coastal areas. A current study is considering the feasibility of transferring water to the dry coastal areas near Guayaquil. The Guayas basin has one multipurpose project, the Daule-Peripa Dam. The dam provides hydropower, irrigation water, and water supply. It has a 35-megawatt capacity, is 60 to 80 meters high, and contains about 60 million cubic meters of water.
Centro de Rehabilitacion de Manabi (CRM)	CRM is a development agency for rehabilitation of Manabi province. It has two projects with impoundments: the Poza Honda on the Rio Portoviejo and La Esperanza on the Rio Chone. These dams were constructed from 1984 to 1985 for water supply and irrigation. The dams do not have hydropower plants.
Programa de Desarrollo Regional del Sur del Ecuador (PREDESUR)	PREDESUR manages the basins adjacent to Peru in the southern part of the country in the provinces of Loja, Zamora, and El Oro.
TAHUIN	TAHUIN manages a multipurpose small earth dam in the coastal area of El Oro.
Centro de Recuperacion Economica del Azuay (CREA)	CREA is the center for economic development in Azuay province. Its jurisdiction also includes Canar and Morona-Santiago.
Empresa Publica Municipal de Telefonos, Agua Potable y Alcantarillado (ETAPA)	ETAPA is responsible for management of water and environmental resources in the province of Canton and in the city of Cuenca.
Subsecretaria de Saneamiento Ambiental	SSA supports development of water supply and sanitation for municipalities. In rural areas, SSA implements waste treatment systems and small water

Agency	Area of Responsibility
in the Ministerio de Desarrollo Urbano y	supply systems. The central government funds 70 percent of the development of the rural facilities. The communities share the cost of the
Vivienda (SSA)	remaining 30 percent. The communities often provide their support with "in-kind services" such as nontechnical services. This is similar to a program established by USAID in the mid-1980's. Currently, SSA has a pilot program to strengthen basic services, which is funded by the World Bank. Maintenance for these systems will be funded by a "water tax." About 1,500 communities have been identified to have a need for this program.
Pan American Health Organization (PAHO)	PAHO is involved in five demonstration projects that primarily deal with technological advice. It is seeking technology in low-cost small water supply systems. PAHO does not fund source investigations but funds planning and design. PAHO also provides materials for education through their center, CEPIS, in Lima, Peru.
U.S. Agency for International Development (USAID)	USAID's activity in development of water resources was substantially reduced in the mid-1990's, due to reduced funding. This is basically due to reduced funding. Just prior to 1995, USAID phased out its rural water development program, and it does not foresee development of a program in the near future. USAID does not develop irrigation systems.
Fortalecimiento y Ampliacion de los Servicios Basicos de Salud en el Ecuador (FASBASE)	FASBASE is an independent organization functioning under the Ministry of Public Health with the basic mission of developing water supply and sanitary projects in communities. This includes training in operation and maintenance. The agency is partner with SSA, CRM, and the provincial Office of Public Health in Guayas. FASBASE uses local nongovernment officials under contract and shares costs with the communities. Generally, the agency is successful in developing some type of water supply system but often needs to transport the water 10 to 20 kilometers to deliver it to the communities.
Consejo Nacional de Recursos Hidricos (CNRH)	CNRH is the agency responsible for permitting development of water supply systems in Ecuador. The CNRH regulates and coordinates requests for development of projects for domestic, agricultural, and industrial water supply. The agency is relatively new and has inherited the hydrologic and water quality data bases from INERHI, the previous agency. In the mid-1990's, the Government of Ecuador eliminated INERHI and created CNRH. Due to limited funding, CNRH has been unable to fully implement a program at this time.

II. Country Profile

A. Geography

Ecuador is situated in the northwestern part of the South American Continent. Its borders are Colombia to the north, Peru to the east and south, and the Pacific Ocean to the west. The total land area of the country including the Galapagos Islands is 272,456 square kilometers. The Andes Mountains naturally divides Ecuador's mainland into three geographic regions: the Costa (coastal plain), the Sierra (Andes Mountains), and the Oriente (Amazon basin). A fourth region is the Galapagos Islands. See figures 1 and 2 for general geographic information.

Figure 1. Vicinity Map

The Costa

The Costa region is the belt between the Pacific Ocean and the western side of the Andes Mountains (extending up to about 2,000 meters above sea level). With 180 kilometers, the region is widest near the Santa Elena Peninsula and narrowest with 30 kilometers along the western border of the Azuay province. Near the northern and southern extremities of the region, the Sierra highlands approach the coast. The Costa comprises about 26 percent of Ecuador.

The Pacific coast of the Costa is about 850 kilometers long with a tidal range of 2 to 3 meters between low and high tide. This range is considered moderate when compared to other Pacific coastal regions on the South American Continent.

The rivers and streams that drain the Costa originate on the western slopes of the Sierra and empty into the Pacific Ocean. Many streams, particularly in the Rio Guayas basin, have formed alluvial fans composed of loose topsoil carried from the slopes of the Andes Mountains. The principal drainage systems are the Rio Guayas in the south and the Rio Esmeraldas in the north. In the north, the Rio Cayapas system drains the rain forest. Both northern rivers are navigable in their lower courses by small light craft. The Rio Guayas system is the largest and most important of the region's rivers. From its mouth to the city of Guayaquil, the Rio Guayas is less of a natural river and more of a commercially developed waterway. Above Guayaquil, it divides into the Rio Daule, the Rio Babahoyo, and a multitude of tributaries. These streams enrich the Guayas basin with soils carried down from the Sierra, making the Rio Guayas basin Ecuador's most fertile agricultural zone.[1]

Guayaquil, on the Rio Guayas near the Golfo de Guayaquil, is Ecuador's largest city. It is also the largest port on the western Pacific coast of South America.

The Sierra

The Sierra region comprises about 34 percent of Ecuador. Its principal features are the two parallel ridges of the Andes. The western ridge, the Cordillera Occidental, extends approximately north to south the entire length of the country. The eastern ridge, the Cordillera Central, is generally 40 to 60 kilometers east of the Cordillera Occidental. Between the two ridges are a series of upland valleys with elevations ranging from 2,000 to 3,000 meters. These upland valleys descend in elevation from north to south. Most of the region's population lives in these valleys. Within these high inter-Andean valleys, except for urban areas, agriculture is the principal industry. Quito, Ecuador's capital, is in the northern Sierra in the Pichincha province. At the southern end of the

Sierra, the valleys open into the Costa and Oriente region. East of the Cordillera Central begins the downward slope to the Amazon basin.

The Oriente

The Oriente region, the easternmost region, comprises about 38 percent of Ecuador and consists principally of an alternately flat and gently undulating expanse of tropical rain forest. The population consists primarily of tribal people. Since oil was discovered in the northern region during the 1960's, this region has become increasingly important economically. The discovery of oil led to the construction of roads and pipelines for delivery of oil, along with facilities to process the crude oil. The rivers and streams originating on the eastern slopes of the Sierra are part of the Rio Amazon basin.

The Galapagos Islands

The Galapagos Islands region, the fourth and smallest region, comprises about 2 percent of Ecuador and lies approximately 1,050 kilometers west from the mainland. It consists of the Galapagos Islands that comprise the Archipielago de Colon. The island group extends about 400 kilometers east to west and has an overall land area of about 8,060 square kilometers. Only five of the several hundred islets and reefs have permanent populations, and over half the people live on San Cristobal Island. Rainfall is moderated by ocean currents, but sufficient amounts are received above altitudes of 300 meters to support tree life and some crops.

Figure 2. Country Map

B. Population Distribution

The total population of Ecuador at the time of the 1990 census was 9,577,568. In 1996 it was projected that an annual growth rate of 1.96 percent would bring the estimated total population in 1996 to about 11,500,000. The population is divided between the Costa (50 percent) and Sierra (47 percent) regions with most of the remaining 3 percent in the sparsely populated Oriente region. The population of the provinces and their capitals (when available), based on the 1990 census, is listed in table 1.

Table 1. Population Distribution

Province	Capital	Population of Province	Population of Capital	Area (km^2)
Azuay	Cuenca	506,090	194,981	8,639
Bolivar	Guaranda	155,088	–	3,254
Canar	Azogues	189,347	–	3,516
Carchi	Tulcan	141,482	–	3,699
Chimborazo	Riobamba	364,682	94,505	5,637
Cotopaxi	Latacunga	276,324	–	5,287
El Oro	Machala	412,572	144,197	5,988
Esmeraldas	Esmeraldas	306,628	98,558	15,216
Archipielago de Colon (Galapagos)	Puerto Baquerizo Moreno	9,785	–	8,060
Guayas	Guayaquil	2,515,146	1,508,444	20,902
Imbabura	Ibarra	265,499	–	4,986
Loja	Loja	384,698	94,305	10,793
Los Rios	Babahoyo	527,559	–	6,254
Manabi	Portoviejo	1,031,927	132,937	18,400
Morona-Santiago	Macas	84,216	–	29,140
Napo	Tena	103,387	–	35,280
Pastaza	Puyo	41,811	–	29,520
Pichincha	Quito	1,756,228	1,100,847	16,599
Sucumbios	Nueva Loja	76,952	–	18,150
Tungurahua	Ambato	361,980	124,166	2,896
Zamora-Chinchipe	Zamora	66,167	–	20,240
Total		9,577,568		272,456

Note: Dash indicates that information is not available.

C. Economy

Ecuador has rich agricultural areas and substantial oil resources. The coastal areas and the central highlands are the principal regions for agriculture, while the Amazon lowlands contain most of the country's oil resources. In 1993 the agricultural sector of the economy--crops, livestock, forestry, and fisheries--employed almost 31 percent of the labor force and provided 43 percent of the country's exports. The primary export products were petroleum (39 percent), bananas (17 percent), shrimp (16 percent), coffee (6 percent), and cocoa (3 percent). The largest part of the gross national product is produced by the services industry (48 percent), followed by manufacturing industries (39 percent) and agriculture (13 percent).

III. Current Use of Water Resources

A. Water Supply

Water supply in Ecuador is a very serious problem, even though the country has an average annual rainfall of 1,200 millimeters. The uneven distribution of rainfall and population are the major reason for the country’s water supply problems. Some areas receive only 250 millimeters of rainfall per year, and others receive as much as 6,000 millimeters per year. Some regions are without rainfall for months. Most of the population occupies the mountain regions and the Guayas watershed in the Pacific coastal lowlands. In contrast 80 percent of the available water supply in the country is in the sparsely populated Amazon basin. Only 10 percent of the total available water in the country is used, and of this, 97 percent is used for irrigation and 3 percent for domestic and industrial purposes.[2] The percentage of industrial/commercial water usage is unknown.

The National Council of Hydrologic Resources (CNRH) is the agency responsible for permitting development of water supply systems in Ecuador. The CNRH regulates and coordinates requests for development of projects for domestic, agricultural, and industrial water supply. The agency is relatively new and has inherited the hydrologic and water quality data bases from the Instituto Ecuatoriano de Recursos Hidraulicos (INERHI), the agency previously responsible for development of water projects. In the mid-1990's, the Government of Ecuador eliminated INERHI and created CNRH. The CNRH is developing a master plan for utilization of water resources, but their program is not fully operational. It is anticipated that, once this program is complete, CNRH will be the central source for water resources information. Currently, development of domestic water supply systems is accomplished by many different agencies with very little coordination. However, the need for adequate potable water is of such magnitude that sufficient development opportunities are available for all agencies. The limiting factor is the lack of financial resources.

1. Domestic Uses and Needs

Less than 3 percent of the water used in Ecuador is for domestic purposes. Most of the water used for domestic purposes comes from surface water sources. A significant need for domestic water supply systems exists in rural areas, especially along the coast and within the drought-stricken areas of the Loja, Manabi, and El Oro provinces. However, most large metropolitan areas have good water supply systems. The Ministry of Urban Development and Housing, which previously carried out development of water supply and waste treatment systems for municipalities, is currently transferring this responsibility to the local municipalities.

The Quito water supply system is a complex connected system of reservoirs, wells, and pipelines. Quito has its own water management department. Part of the water supply for Quito is transported via pipeline about 60 kilometers from a reservoir on the Rio Papallacta on the eastern (Amazon) side of the mountains. U.S. Agency for International Development (USAID), Cooperative for American Relief to Everywhere (CARE), and the Government of Ecuador are sponsoring a project to develop a basin management plan for water supply to Quito.

In Cuenca, the local utility company Empresa Publica Municipal de Telefonos, Agua Potable y Alcantarillado (ETAPA) manages and develops water supply for the city and surrounding urban and rural areas. ETAPA also has a water quality research laboratory at the University of Cuenca. ETAPA is presently inventorying all streams in the area to determine minimum flows. Competition for use of the water is very high. The upper basin of the Rio Machangara has two dams, the Lallrago and the Chanlud. Cuenca has two large wastewater treatment plants. Some 200 small private treatment plants are also in its metropolitan area.

A great need exists for the development of small water supply systems throughout Ecuador. Many existing well systems need to be repaired and/or reconstructed. FASBASE representatives indicate that only 50 percent of the more than 900 small water supply systems, shown in the Pan American Health Organization (PAHO) report, "Sectoral Analysis," function continuously.[3] Also, in 1995 an earthquake destroyed most of the well systems within the Cotopaxi province. The USAID and CARE organizations have previously financed the drilling of wells within Cotopaxi. A CARE program, the Programa de Manejo de Recobras Costeras, has been designated to help save the mangroves. As a part of this program, CARE is working with the Subsecretaria de Saneamiento Ambiental *in the* Ministerio de Desarrollo Urbano y Vivienda (SSA) and PAHO to assist local communities in development of water supply systems in the coastal areas. They are also working with the University of Cuenca to develop a sand filtration system for small water supply projects. Countrywide, the Ecuadorean Army Corps of Engineers has purchased a new drill rig to support development of water well systems for the public. However, a critical need for water supply systems still exists. The PAHO conference held in January 1997 in Quito developed a plan to achieve 100-percent coverage of water supply in rural areas by the year 2005. The cost will be partially funded by a grant from Spain. The estimated cost for the program is $400 million, and additional funding is being sought from other agencies such as the International Development Bank and World Bank.

The provinces of Loja, El Oro, and Manabi are experiencing a severe drought. Experts interviewed attribute the drought to climatic changes that are occurring in the region west of the 80 degree longitude. This region is already semiarid, becoming more so, and said to be undergoing the process of desertification.[4] Prior to the drought, the water level in the aquifer was at depths of only 15 to 20 meters, but now it is at depths of 80 to 100 meters. Many wells no longer provide water, and it is too expensive to drill wells to the greater depths for small communities. The Government of Ecuador has declared the drought in the province of Loja a national disaster. The major rivers in the province of Loja are considered perennial, and communities located away from the streams have serious water supply problems. These remote communities depend on small streams and shallow wells that have been virtually dry since the drought began. In the province of Manabi, water must be hauled in by truck at great expense. In addition to the water shortage due to the drought, ground water quality problems arise from the excessive naturally occurring iron in the ground water, which clogs the well screens and seriously reduces the yields of the wells.[5]

The highlands have experienced a mass influx of people from the drought-stricken areas in southern Ecuador. The influx of people and the associated poor agricultural practices have increased the demand for water for domestic and agricultural purposes. The layer of fertile soil in these areas is thin and easily disturbed by the agricultural practices of the new settlers. These practices result in a loss of the natural vegetation and an increase in erosion, thereby reducing the amount of rainfall available for recharge of the aquifers. Most of Ecuador's deforestation, estimated at 200 to 300 hectares per year, occurs in these highland areas. Increasing population densities in these areas will continue to diminish and threaten the remaining natural vegetation, of which only 3 percent remains. To protect the remainder of the original rain forest, CARE is managing a project to develop ecological land management techniques for the high Andean region in the middle basin areas. The purpose of the project is to develop an ecological compatible water supply for the region's existing population which will discourage future migration into these areas.[6]

The need for wastewater treatment systems is also an important concern throughout Ecuador. However, this issue must take a lower priority than the development of water supply sources. USAID has an ongoing program to construct wastewater treatment systems for small communities. The

Army currently has a contract with a French firm to provide hydrologic and hydraulic engineering support for the development of these treatment systems.

2. Industrial/Commercial Uses and Needs

The petroleum industry is drawing new settlements into the Santa Domingo vicinity, making it the highest growth area in the country. This area is very rich in agricultural resources and has an abundant supply of water, but contamination is increasing. Information on industrial uses and needs is very limited. Three percent of the water usage in the country is for domestic and industrial purposes.

3. Agricultural Uses and Needs

Irrigation accounts for 97 percent of the water used in Ecuador. The demand for irrigation water is high and increasing yearly, especially in the Andes region and in the arid coastal plains. Agricultural production in the Andes is mostly for internal use, and production along the coast is generally for exportation. Significant losses of surface soils occur throughout the country because of deforestation, overuse, and poor cultivation practices. These losses are very significant in the Andes region.

Information on ground water use for agriculture in the country is very limited. Most irrigation systems use surface water. Current cultivation and irrigation practices have reduced or removed vegetation and eroded valuable top soils. Sediments from erosion of top soils have caused problems in streams and reservoirs. Increased sediment loads in streams have induced changes in the topography. According to CNRH officials, current irrigation practices have caused the soils in the Imbabura area to become hard and compacted.

About 10 percent of the country is considered to be desert, but this appears to be increasing because of climatic changes. Experts interviewed during the site visit indicated that their studies show the average annual rainfall is decreasing 2 to 18 millimeters per year in many places. More than 100 years ago, the western coast of the Guayas province produced significant agricultural products. Now it is very arid, and farming requires expensive irrigation. Studies by CNRH suggest that climatic changes are turning some provinces, such as Manabi, Loja, and El Oro, into deserts.[7]

Several Ecuadorean officials noted the need for technical assistance and training for development of more efficient irrigation systems. Twenty percent of the agricultural products use irrigation systems that are very inefficient. Many do not have intake and distribution systems that allow control, and most systems are open-channel systems, with as much as 90 percent of the water lost. Past development costs have totaled $300 to $1,200 per hectare for irrigation and flood control systems. However, along the western coast of the Guayas province, irrigation costs are now more than $100,000 per hectare. The best areas for development of irrigation systems are in valleys of the Andes using small reservoirs.

CARE is developing methods to improve irrigation systems using vegetation coverage and organic agriculture to make the current cultivated lands more productive and operational year-round. The focus is concentrating on preservation and management of existing small irrigation systems in the highlands. These efforts intend to reduce the need to cultivate new lands.

More than 80 percent of the shrimp and 90 percent of the bananas produced in Ecuador come from the delta areas around the Bay of Guayaquil. Ecuador’s shrimp mariculture industry is the world’s second largest. The development of this industry while economically beneficial has been associated with the decline in mangrove forests. Some sources attribute the shrimp mariculture industry with responsibility for the loss of more than 42,000 hectares of mangroves since its inception in 1969.[8]

B. Hydropower

Ecuador is experiencing significant shortages of electricity. To address this situation, the Government has routinely imposed 4- to 6-hour brownouts in selected areas throughout the country, with times and locations rotated daily. This scarcity of power is due to drought-induced water shortages affecting hydroelectric generation on the Rio Paute. Sedimentation of reservoirs has further exacerbated the problem. For example, the Amaluza Dam has a capacity of 1,200 megawatts and 120 million cubic meters of storage and produces about 60 percent of the country’s electricity. However, the storage volume of the reservoir that supports the Amaluza Dam has been reduced 25 percent to 90 million cubic meters since operation began. Originally constructed with 5 generation units, the dam now operates 10 units. This increase in generating capability and concurrent rise in power demand, coupled with the reduced storage capacity and volume, has resulted in significant reservoir drawdown to very low levels during the dry season. Although plans to develop another project upstream of the Amaluza Dam have been completed, the project has yet to be funded.

Table 2 lists the major hydropower plants which provide the bulk of the country's electricity.

Table 2. Hydropower Plants

Name	River	Capacity (megawatts)
Agoyan	Rio Pastaza	170
Amaluza Dam	Rio Paute	1,200
Daule Peripa	Rio Pastaza	35 (currently generating 10)
Pisayambo (new)	Rio Guayas	300
	Total	1,705

C. Stream Gage Network

The Instituto Nacional de Meteorologia e Hidrologia (INAMHI) maintains the hydrologic data base for the country. INAMHI's basic function is to gather, record, and maintain data. Reports of data similar to the USGS publications are published annually, and summaries of data are published periodically.

Based on information provided by INAMHI, 125 hydrologic stations exist throughout the country. These stations measure stage, and some also measure discharge. Many of these stations have more than 20 years of reliable data. Ecuador also has more than 193 meteorological stations of various types. Almost all measure rainfall, and many include climatological information. These stations are maintained by several different agencies, but INAMHI is the central repository for the data. Since deforestation is becoming critical, especially in the Amazon basin, and soil loss has increased greatly in deforested areas, additional stations are needed to monitor the impacts of deforestation.

Maintenance of the existing network of hydrologic stations is difficult. Most stations have older equipment, such as strip charts. Some of the sparsely populated regions have limited data. Other regions that are difficult to access, such as the highlands and the jungle, need remote or telemetric stations. INAMHI has a contract with an American company to implement some pneumatic equipment with French-manufactured telemetric stations. These stations generally measure rainfall, temperature, water level, relative humidity, wind, and solar radiation.

University of Cuenca officials have collected a large amount of meteorological data in the Canar and Azuay provinces. This information is presented in monthly rainfall maps. The Paute basin has 44 gage stations. The university has just completed a classification study of the surface areas in the Paute basin, and the next phase is to begin research of five irrigation sites that represent the five different zones of the basin. A Geographic Information System for hydrologic data in the Cuenca region is also being planned.

D. Waterway Transportation

Ecuador has two major navigation ports, Guayaquil and Puerto Bolivar. Dredging in the port of Guayaquil maintains a 6- to 10-meter depth and Puerto Bolivar uses the natural depth. The Rio Guayas can be navigated about 60 to 80 kilometers upstream from Guayaquil. Internal navigation is not significant, and vessels on the rivers vary in size according to the depths and widths allowed by the natural flow in the rivers. Only small crafts are used for most commercial navigation in the Amazon regions. Commercial movement of goods over the waterways is managed by private enterprise. In some highly remote areas, the only mode of transportation is by small private boats.

E. Flood Control

The basin with the most significant flood damage is the Rio Guayas basin. This basin has 40 percent of the population and major agricultural activities. Significant flooding problems occur in the upper delta areas of the Bay of Guayaquil. Some preliminary studies suggest that impoundments in the upper basin would help reduce the flood peaks, but other local protection work is also needed in the lower basin between the Babahoyo and Canar rivers. Floods cause significant agricultural, commercial, and residential damage annually during the wet season (November through May). Reduction of flooding in this area would greatly enhance the local agricultural production of rice, corn, and bananas.

In recent years, damages from flooding have increased. This is partially caused by the changes in hydrologic characteristics of the basins resulting from deforestation. Industrial, residential, and agricultural development have also added to the population in the high-risk flood areas of the low alluvial plains. Much work is needed in providing flood-warning systems and defining flooding potential in the valleys and coastal regions.

Near Cuenca, ETAPA is planning a flood control dam on the Rio Tomebamba at Pond Surorchid. The dam will be about 100 meters long and 30 meters high, store up to 13,000 cubic meters, and provide a minimum flow of 1.3 cubic meters per second. Currently, the Rio Tomebamba, the main stream that flows through the city of Cuenca, discharges from 450 to 150,000 liters per second, with the higher flows causing significant damage.[9]

F. Water Quality

Surface water contamination from domestic sources occurs nationwide, especially near heavily populated areas. However, many sources indicate that surface water contamination has increased significantly in recent years. Also, brackish to saline water is encountered in coastal lagoons and river deltas.

The Ministry of Environment is working with a $15 million program funded by the World Bank to strengthen environmental management practices in the country. This program includes plans for environmental management of the Golfo de Guayaquil, the Amazon basin areas affected by oil exploration, and management of about 10 to 12 urban areas such as Quito, Guayaquil, and Cuenca.

Water pollution is eliminating many potential and existing water resources. Most contamination is from domestic waste, agricultural chemicals (especially along the coast), and oil production in the Amazon basin. Gold mining also creates pollution problems in certain areas. Large plantations use great quantities of agricultural chemicals; pollutants from these chemicals have begun to reach the gulf and impact the shrimp farms. Most all streams and surface water systems have problems with pesticides.

Domestic waste is a major problem on the Galapagos Islands. This domestic waste is percolating into the ground water system. The Government of Ecuador is presently constructing waste treatment plants in most major cities on the islands. Ground water on the Island of Santa Cruz is slightly brackish because of the shallow well depths and the high cost of drilling deeper.[10] About 50 percent of the potable water on the islands comes from captured rainwater.

Deforestation and inadequate land use practices have accelerated soil erosion, thereby increasing sediment loads in rivers and streams. The heavy sediment loads injected into the streams have greatly decreased the storage capacity of many reservoirs and have induced significant geomorphic changes in most streams.

G. Legislative Framework

At present, the Government of Ecuador defines water rights based on historic use. Current water law in Ecuador requires that a fee be charged for water used for irrigation and industrial purposes. Each province has its own agency for collection of these fees. A new law is being developed which will allow projects to be funded through the fee system. This will include hydropower, water supply, and flood control. It will also allow a "minimum return" to be established and include some environmental regulation aspects.

The CNRH is developing a new water law that will strengthen the existing law and will address water quality issues. The law will allow the private sector to participate. It will be designed to encourage better management practices in using and developing water resources. A law to privatize management of water resources is also being considered.

IV. Existing Water Resources

A. General

Ecuador relies on both surface and ground water for water supplies, with most coming from surface water sources. Agricultural irrigation consumes the majority with domestic and industrial use comprising only 3 percent. Only 61 percent of the population has access to potable water in Ecuador. For domestic purposes, urban areas mainly rely on surface water and rural areas mainly rely on ground water. Urban areas have more accessibility to water supply and sanitation services than rural areas. In areas with inadequate access to safe water supplies, waterborne diseases are the greatest health hazard. Seventy-eight percent of the urban population and only 39 percent of the rural population have access to water supply services.

Rivers are the major sources of fresh surface water. Even though fresh surface water is abundant, water pollution is a serious problem, especially near populated areas. Biological and chemical contamination of surface water supplies is widespread, and water supply conditions are frequently aggravated by the increasing population growth and land use demands. Major pollution sources are commercial agriculture, manufacturing plants, mining activities, and petroleum operations.

Sufficient supplies of fresh ground water are available throughout most of the country. Biological and chemical contamination of shallow wells is a major concern. Deep wells can provide good sources for domestic water supply. Many rural and small water supplies rely on ground water resources.

Access to water resources is feasible in urban areas where the highway and road network is most extensive. However, in undeveloped rural areas, access is hindered by the lack of all-weather roads and adverse terrain conditions.

B. Surface Water Resources

Ecuador has an average annual rainfall of 1,200 millimeters, but it is unevenly distributed. The cool Pacific Ocean currents significantly impact the weather in the coastal areas west of 80 degrees longitude. This region is very arid and appears to become more so each year. The weather patterns in the Andes Mountains and eastern lowlands regions are significantly different from each other and from the coastal areas. From January to April, it is humid and rainy in the coastal region or Costa; while in October and November, very little precipitation occurs. This pattern is referred to as the Pacific system. In the east or Oriente, heavy tropical rains usually occur in July and August. In the mountain region or Sierra, the influence of both the coastal and Amazon weather patterns produces two wet seasons, February to March and June to August. Rains in the mountains are generally light in intensity but long in duration.

Ecuador can be divided into five major climatic regions according to precipitation. These are the Amazonian lowlands, the intermontane highlands, the coastal lowlands, the Santa Elena-Manta watershed, and the Galapagos Islands. Over the last hundred years, some areas of the country have experienced significant reductions of as much as 10 millimeters in average annual rainfall because of climatic changes and deforestation.

Topography and seasonal precipitation control the distribution of surface water resources. Table A-1 and figure A-1 in Appendix A provide detailed information of surface water availability. Access to water sources is possible in flood plains and along roads but is difficult in remote areas.

Ecuador has 272,456 square kilometers of total land area. Overall, Ecuador has 40,000 cubic meters of water per person per year; however, it is very unevenly distributed. For example, average annual rainfall for Quito and the south is only 300 millimeters, but the average annual rainfall for the northern valleys is greater than 1,000 millimeters. The greatest amounts of available water are in the sparsely populated Amazon basin.

The Rio Napo basin has the greatest rainfall. It is also the cocoa production region. In 1987 an earthquake coupled with heavy rainfall created landslides that resulted in heavy loss of surface soils in this region. Large amounts of sediment were injected into the rivers, creating temporary dams and altering the course of the river several times. An active volcano further aggravates erosion of surface soils by keeping the surface unstable.

The Oriente region, which is about 29 percent of the country, has a sufficient water supply. In this area, flooding is the most significant problem with respect to water resources. This region is sparsely populated, and in large parts of the area, streams are the most practical means of transportation.

Mountain springs and rivers can be used for water supply, but in the lower part of the basin, they are contaminated with agricultural chemicals. The intermontane valley communities generally use spring waters. In the Oriente, a combination of springs and rivers are used for water supply. In the jungle areas, primary sources for domestic use are rivers, shallow wells, and captured rainwater. Some contamination exists in streams near oil development activities.

An estimated 200 to 300 hectares of forest are lost annually because of deforestation.[11] Most of the loss occurs in the northwest part of the country. USAID has contracted CARE to develop ecological management techniques for an area in the northwest part of the country. Deforestation affects the climate and water quality and causes runoff.

The principal drainage features include perennial and intermittent streams, wetlands, small lakes, and reservoirs. Large and small perennial streams are common throughout the country's interior. Along the Pacific coast and on the Galapagos Islands, streams are intermittent. Small lakes are common in the valleys of the Andes Mountains. The most significant impoundments are in the Andean mountain ranges.

The most significant drainage basins in Ecuador are listed in table 3. The Galapagos Islands are listed as one drainage area because the individual islands have similar characteristics. However, each island is its own drainage unit. Flows in the major rivers of the Galapagos Islands basins provide water year-round in the valleys and lower plains. Table 3 presents average annual rainfall and average annual discharge for the most significant rivers in these basins.

Most of the population is in the mountain region and in the Guayas watershed in the Pacific coast area. The major watersheds in the country are the Guayas, the Esmeraldas which drains to the west, and the Amazon (Napo, Pastaza, and Santiago) which drains east.

Some tributaries in the upper areas of the drainage basins, in the southern provinces along the coast, and in the Andean valleys may have no flow during the dry months of the year. Monthly maximum flows on the Galapagos Islands streams typically range from two to five times the average annual flow, and minimum monthly flows range from one-third to one-sixth of the average annual flow.

Table 3. Major Drainage Basins

River Name	Receiving Body	Area (km^2)	Average Annual Precipitation (mm)	Average Discharge (m^3/s)
Guayas	Golfo de Guayaquil	32,112	1,662	835
Esmeraldas	Pacific Ocean	20,401	1,980	680
Catamayo	Pacific Ocean	6,717	999	93
Mira	Pacific Ocean	6,495	1,788	210
Cayapas-Onzole	Pacific Ocean	6,024	3,326	403
Zapotal	Pacific Ocean	5,561	465	21
Jubones	Pacific Ocean	4,054	898	59
Puyango	Pacific Ocean	3,694	1,222	72
Balao	Pacific Ocean	3,417	1,335	63
Arenillas	Pacific Ocean	2,725	861	21
Jipijapa	Pacific Ocean	2,638	371	5
Chone	Pacific Ocean	2,483	1,070	26
Canar	Pacific Ocean	2,384	1,327	53
Taura	Pacific Ocean	2,348	1,196	30
Portoviejo	Pacific Ocean	2,231	737	12
Verde	Pacific Ocean	2,169	2,038	43
Jama	Pacific Ocean	2,095	821	5
Cojimies	Pacific Ocean	1,617	1,425	18
Muisne	Pacific Ocean	1,285	2,639	53
Mataje	Pacific Ocean	684	3,052	35
Carchi	Pacific Ocean	348	1,215	6
Napo	Amazon basin	30,948	3,388	424
Santiago	Amazon basin	26,176	3,127	661
Pastaza	Amazon basin	24,296	3,255	2,051
Churaray	Amazon basin	17,159	2,883	801
Aguarico	Amazon basin	11,065	2,175	900
Tigre	Amazon basin	6,492	2,742	265
Morona	Amazon basin	6,481	1,603	632
Mayo-Chinchipe	Amazon basin	2,844	3,354	453
San Miguel-Putumayo	Amazon basin	6,539	3,388	424
Galapagos Islands	Pacific Ocean	–	–	–

Note: Dash indicates that information is not available.

Large rivers and reservoirs provide fresh water year-round. Water supplies from small streams and reservoirs are seasonally abundant. Natural water resources in Ecuador are augmented by manmade water resources which include dams and reservoirs. Table 4 displays the major dams and reservoirs in the country.

Table 4. Major Dams/Reservoirs			
Name	**River**	**Reservoir Volume ($10^3 m^3$)**	**Purpose**
San Marcos	Rio Boqueron	40,000	Irrigation
El Carrizal	Rio Carrizal	400,000	Flood control and irrigation
Daule-Peripa	Rio Daule	6,000,000	Hydroelectricity, irrigation, flood control, and water supply
Pisayambo	Rio Pisayambo	100,000	Hydroelectricity
Poza Honda	Rio Portoviejo	100,000	Irrigation and water supply
Agoyan	Rio Pastaza	1,850	Hydroelectricity
San Vincente	Rio Nuevo	25,000	Irrigation
El Azucar	Rio Azucar	12,000	Irrigation
Daniel Palacios	Rio Paute	120,000	Hydroelectricity
El Labrado	Rio Chulco	6,000	Hydroelectricity and irrigation
Tahuin	Rio Arenillas	220,000	Irrigation, flood control, and water supply

*International Commission on Large Dams, *World Register of Dams*, 1984.

C. Ground Water Resources

According to Ecuadorean officials, information on ground water is limited, and significant research is needed to develop a reliable data base. Sufficient supplies of fresh ground water are generally available throughout most of Ecuador. Springs and deeper wells provide the most reliable and important sources of ground water for drinking water supplies. In the highland valleys, the aquifers are small. At present, a regulatory agency for ground water does not exist, but the new agencies are working toward developing appropriate regulations.

The most abundant ground water supplies are available in alluvium typically consisting of sands and gravels. These aquifers are found in the Rio Guayas basin of the Costa region and along rivers in the Oriente region. Yields in the Rio Guayas basin have been noted to be as much as 7,900 liters per minute. Other important sources of ground water supplies are also found in the Oriente region in aquifers of unconsolidated and consolidated sediments, principally of sandstone and conglomerates.

Accessibility of ground water sources is best near populated and agriculturally developed areas. In areas without roads, the dense vegetation and marshy ground make accessibility difficult. However, in the Rio Guayas basin, accessibility is good except for marshy ground areas.

Groundwater supplies are developed from aquifers. An aquifer may be imagined as a huge natural reservoir or system of reservoirs in rocks whose capacity is the total volume of pores or openings 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. Ground water 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. An aquifer is a saturated bed, formation, or group of formations which yields water in sufficient quantity 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. In certain rock masses such as certain 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. However, if a borehole is drilled at a location where the bedrock is compact and the rock is highly fractured with water flowing through the fractures, then the borehole could yield sufficient water to be economically useful.

Since it is difficult or impossible to predict precise locations that will have fractures in the bedrock, photographic analysis can be employed to assist in selecting more suitable well site locations. Other methods are available but are generally more expensive. Geologists use aerial photography in combination with other information sources to map lithology, faults, fracture traces, and other features that aid in well site selection. In hard rock, 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. Onsite verification of probable fractures further increases the chances of siting successful wells.

Ground water is generally safer than untreated surface water supplies; however, many shallow aquifers are becoming contaminated. Without treatment, most traditional water sources are becoming unfit for human consumption. Biological contamination of shallow aquifers by pathogens due to improper disposal of human and animal wastes is a common problem. The problem affects areas surrounding even the smallest villages. The water table surface generally follows land contours, and contamination plumes typically move downslope from populated areas.

Aquifers consisting of fractured or brecciated lava flows are particularly susceptible to contamination because water is transmitted rapidly in the subsurface with little or no filtering out of contaminants. Fracture systems may also transport the contamination in directions other than directly downslope. In areas of unconsolidated sediments, water produced from depths of less than 10 to 20 meters should be expected to be contaminated. Shallow-perched aquifers in relatively unweathered volcanics are frequently contaminated. Water obtained from wells next to streams is also likely to be contaminated. Though ground water quality is generally good, notable exceptions exist for areas of saline or brackish water near the coast and adjacent to mangroves.

Steel casing for well construction is recommended throughout the country. Wells completed with other types of casing materials may suffer excessive damage or deformation during seismic events.

SSA has conducted resistivity studies from about 500 wells to determine the best areas to drill for water. This information is in a data base of geohydrologic profiles that identifies quantity, quality, chemicals, and geophysical characteristics. From this data base, SSA can predict production rates.

D. Water Conditions by Map Unit

The surface water resources map, figure A-1 in Appendix A, divides the country into map units 1 through 4 based on water quantity and quality. Map unit 1 depicts areas where fresh surface water is perennially plentiful in very large to enormous quantities. Map unit 2 depicts areas where fresh surface water is seasonally plentiful in large to enormous quantities. The seasons and locations are as follows: from January through May in areas of the coastal plains; from October through June in the intermontane area between the Cordillera Occidental and Cordillera Oriental; and from March through June and September through November along the eastern slopes of the Cordillera Oriental. Fresh water is available in small to large quantities during the low-water seasons, when perennial sources diminish and intermittent sources go dry for extended periods. Map unit 3 depicts areas where fresh water is scarce or lacking but initially fresh with a transition to predominately brackish water. Small to large quantities are available from January to April in response to rainfall from intermittent streams. These areas are generally dry the rest of the year. Map unit 4 depicts areas where fresh surface water is scarce or lacking. Brackish to saline water is available year-round in large to enormous quantities in coastal estuaries and swamps.

The surface water resources map, figure A-1 in Appendix A, divides the country into four physiographic regions labeled A, B, C, and D. They are the coastal plains, Andes Mountains, eastern lowlands, and Galapagos Islands regions. A physiographic region is based on surface water physical characteristic boundaries and may overlap several river basins. These four physiographic regions cross several provincial boundaries.

The ground water resources map, figure A-2 in Appendix A, divides the country into map units 1 through 6, based on water quantity, quality, and aquifer characteristics. Map unit 1 depicts areas where fresh water is generally plentiful in small to large quantities from alluvium. Map unit 2 depicts areas where fresh water is generally plentiful in moderate quantities and large quantities are locally available. Map unit 3 depicts areas where fresh water is locally plentiful in small to moderate quantities. Map unit 4 depicts areas where fresh water is locally plentiful in very small to small quantities and where brackish water may occur locally. Map unit 5 depicts areas where fresh water is either scarce or lacking with meager to small quantities locally available. Map unit 6 depicts areas where fresh water is either scarce or lacking with small to large quantities of brackish water available.

The ground water resources map divides the country into four hydrogeologic regions depicted as regions I through IV. They are the Costa, Sierra, Oriente, and Galapagos Islands regions. A hydrogeologic region is based on aquifer or geologic formation boundaries and may contain one or more aquifers or formations. These four hydrogeologic regions cross several provincial boundaries.

In the text, surface and ground water quantity and quality for each province are described by the following terms:

Quantitative Terms:

Enormous	= >400,000 liters per minute (100,000 gallons per minute)
Very large	= >40,000 to 400,000 liters per minute (10,000 to 100,000 gallons per minute)
Large	= >4,000 to 40,000 liters per minute (1,000 to 10,000 gallons per minute)
Moderate	= >400 to 4,000 liters per minute (100 to 1,000 gallons per minute)
Small	= >40 to 400 liters per minute (10 to 100 gallons per minute)
Very small	= >4 to 40 liters per minute (1 to 10 gallons per minute)
Meager	= ≤4 liters per minute (1 gallon per minute)

Qualitative Terms:

Fresh water	= maximum total dissolved solids (TDS)* ≤1,000 milligrams per liter; maximum chlorides ≤600 milligrams per liter; and maximum sulfates ≤300 milligrams per liter
Brackish water	= maximum TDS* >1,000 milligrams per liter but ≤15,000 milligrams per liter
Saline water	= TDS* >15,000 milligrams per liter

*The sum of TDS is the concentration of minerals in water. Most of the dissolved minerals are inorganic salts also described as *salinity*. The World Health Organization guideline for the maximum recommended level of drinking water quality for TDS is 1,000 milligrams per liter. Fresh water quality does not mean that the water is readily potable; purification for biological and chemical contamination may still be required.

See tables A-1 and A-2 and figures A-1 and A-2 for detailed information on surface water and ground water map units.

E. Water Conditions by Province

The following data was compiled for each province from information contained in Appendix A, (Surface Water Resources, figure A-1 and table A-1; and Ground Water Resources, figure A-2 and table A-2) and from *Mapa Hidrogeologico Nacional De La Republica Del Ecuador*, 1986 edition. The information presented below is a general and regional overview of the province derived from the country scale study (Appendix A). Locally, the conditions described may differ. For all areas that appear to be suitable for tactical and hand pump wells, additional detailed study and investigation is necessary to describe the water resources of a particular province adequately before beginning a well drilling program. Specific well data was limited and for many areas was unavailable. Surface water and ground water map units are presented in descending order from most to least desirable units. Provinces are described from north to south by each physiographic region in the following order: A. Coastal plains, B. Andes Mountains, C. Eastern lowlands, and D. Galapagos Islands. It may be beneficial to have figures A-1 and A-2 from Appendix A available for reference while reviewing this section.

Esmeraldas

a. General. About 3 percent of Ecuador's total population lives in the province of Esmeraldas; about 32 percent of this population resides in the provincial capital of Esmeraldas. The population of the province in 1990 was 306,628. Esmeraldas is in the northwest section of Ecuador and borders the country of Colombia and the Pacific Ocean. Esmeraldas has a land surface area of 15,216 square kilometers and occupies about 6 percent of the country's total land mass. Fresh surface water is perennially plentiful for almost the entire province. Fresh ground water is locally plentiful for about two-thirds of the province. Many wells in this province are along the coast and tend to be brackish.

b. Surface Water. Map units 1, 2, and 4 are represented within the province of Esmeraldas. Map unit 1, where fresh water is perennially plentiful, occupies about 90 percent of the province and covers most of the land mass within the province. Map unit 2 occupies about 5 percent of the province along its eastern border lying at the base of the western flanks of the Cordillera Occidental. Here, fresh water is seasonally plentiful from January through May with flows tapering off the rest of the year. Map unit 4 occupies about 5 percent of the province and represents a zone of mangrove swamps surrounding the delta of the Rio Santiago in the northeast corner of the province. Here, fresh water is scarce or lacking, but brackish to saline water is perennially available due to the tidal influx of sea water mixing with streamflow.

c. Ground Water. Map units 1, 3, 4, 5, and 6 are represented within the province of Esmeraldas. Wells in the province have varying total dissolved solids (TDS) ranging from 225 to 2,250 milligrams per liter. Iron contamination in wells is a major concern in the province. Lack of roads and dense vegetation limit access to ground water sources in some areas. About 70 percent of the province lies equally within map units 3 and 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies about 10 percent in the northern and southern parts of the province. The aquifers are alluvial, consisting of sands and gravels with lesser amounts in silts, clays, sandstones, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. The San Tadeo Formation in map unit 1 consists of lahars, fanglomerates, and mudflows with TDS typically ranging between 255 and 280 milligrams per liter. The Undifferentiated Quaternary Formation in map unit 1 consists of sands, sandstones, clays, and conglomerates. Well exploration is recommended in this map unit due to the potential for high yields and good water quality.

Map unit 3 occupies about 35 percent of the province in the lower elevations. The aquifers consist of sandstones and conglomerates with lesser amounts in tuffs, clays, silts, mudstones, and limestones. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The Onzole Superior Formation within this map unit consists of argillite interbedded with lesser amounts of sandstones and lenses of conglomerate. TDS values in this formation range between 1,350 and 2,250 milligrams per liter. The Viche Formation within map unit 3 consists of clayey silt with calcareous lenses, conglomerates, and sandstones. TDS values of the Viche Formation range between 540 and 2,100 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 35 percent of the province and trends northeast-southwest through the province. The aquifers consist of recent volcanics, cataclastic rocks, pyroclastic rocks, porphyries, diabases, quartzites, limestones, and mudstones. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 10 percent of the province in scattered locations throughout. The aquifers consist of intrusive and extrusive igneous rocks composed of granites, granodiorite, rhyolite, and massive metamorphic rocks, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Map unit 6 occupies less than 10 percent of the province in a few scattered locations along the coast. The provincial capital Esmeraldas and the community of San Lorenzo are within this map unit. The aquifers consist of unconsolidated clastic rocks. They generally have high permeability, producing small to large quantities of brackish to saline water. Fresh water is scarce or lacking in map unit 6. These aquifers are generally associated with mangroves. The Manglar Formation in map unit 6 consists of mud clays (lodos arcillosos) and silts. TDS values are between 225 and 2,100 milligrams per liter. Well exploration is not recommended in this area due to the potential of poor water quality.

Pichincha

a. General. Pichincha has about 18 percent of the total population of Ecuador; about 63 percent of this population resides in Quito, the national and provincial capital. The population of the province in 1990 was 1,756,228. The province of Pichincha is in the north-central section of Ecuador. Pichincha has a land surface area of 16,599 square kilometers and occupies about 6 percent of the country's total land mass. Fresh surface water is equally divided between perennially plentiful in the lower elevations and along the river valleys, and seasonally plentiful in the upper elevations of the province. Fresh ground water is locally plentiful in about two-thirds of the province and generally plentiful in the western part of the province.

b. Surface Water. Map units 1 and 2 are present within the province of Pichincha, each occupying about 50 percent. Map unit 1 is mostly in the western part where fresh water is perennially plentiful. Map unit 2 is mostly in the eastern part where fresh water is seasonally plentiful in most streams. Quito, the national capital, lies in map unit 2. In the moderately sloped areas which lie at the base of the western flanks of the Cordillera Occidental, fresh water is seasonally plentiful, generally from January through May with flows tapering off the rest of the year. The interior of the Andes Mountains region of eastern Pichincha is characterized by gorge-like streams with steep rugged slopes. Here, fresh water is seasonally plentiful generally from October through June with runoff diminishing or fluctuating drastically the rest of the year.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Pichincha. Wells in the province have yields varying from 60 to 4,500 liters per minute (about 16 to 1,200 gallons per minute). TDS values in the province range between 53 and 2,925 milligrams per liter. Lack of roads and dense vegetation limit access to ground water sources in some areas. Map units 1 and 3 occupy most of the province where fresh water is generally or locally plentiful. Many wells are in map unit 1.

Map unit 1, the most favorable area for wells, occupies about 35 percent in the western part of the province in the Costa region. The aquifers are alluvial from the San Tadeo Formation. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Wells in this formation have yields from 240 to 4,500 liters per minute (about 60 to 1,200 gallons per minute). TDS values range between 53 and 320 milligrams per liter. Well exploration is recommended in map unit 1 due to the potential for high yields and good water quality.

Map unit 3 occupies about 25 percent of the province in the higher elevations of the Cordillera Occidental mountain range. The aquifers consist of recent volcanic rocks with lesser amounts of sands, clays, and silts. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water with an average yield of 900 liters per minute and average TDS value of 300 milligrams per liter. The Cangahua Formation in map unit 3 consists of volcanic rocks. Wells in this formation have yields from 60 to 900 liters per minute (about 16 to 240 gallons per minute). The higher yields are probably the result of fractures in the formation. TDS values range from 283 to 2,925 milligrams per liter. The national capital of Quito is in this area. Most areas within this map unit are suitable for tactical and hand pump wells.

Map unit 4 occupies about 35 percent of the province and is along the western and eastern slopes of the Cordillera Occidental mountain range. The aquifers consist of recent volcanics, cataclastic rocks, pyroclastic rocks, porphyries, diabases, quartzites, limestones, and mudstones. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies less than 5 percent in the north-central and eastern parts of the province. The aquifers consist of granite and granodiorite, which produce meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Manabi

a. General. Manabi has about 11 percent of the total population of Ecuador; about 13 percent of this population resides in the provincial capital of Portoviejo. The population of the province in 1990 was 1,031,927. The province of Manabi is in the coastal section of western Ecuador. Manabi has a land surface area of 18,400 square kilometers and occupies about 7 percent of the country's total land mass. Fresh surface water is seasonally plentiful in over half of the province. Fresh ground water is locally plentiful for half of the province. Fresh ground water in the lower elevations along the coast is scarce or lacking. A persistent drought from 1994 to 1997 drastically diminished the flow duration and discharge in many of the intermittent streams in the Andes Mountains region.

b. Surface Water. Map units 1, 2, 3, and 4 are represented within the Manabi province. Map unit 1 occupies about 20 percent in the central and northern parts of the province. The hydroelectric plant, Daule Peripa, is on the Rio Daule in this province. Map unit 2 occupies about 60 percent of the province. It includes areas where fresh water is seasonally plentiful in most streams, generally from January through May. Flows decrease the rest of the year. Map unit 3 occupies about 20 percent of the province. It is in the arid western part of the province where fresh to brackish water is seasonally available in most streams, generally from January through April, with flows tapering off the rest of the year. Map unit 4 occupies less than 1 percent of the province in the tidal flats around the mouth of the Rio Chico. Here fresh water is scarce or lacking, but brackish to saline water is perennially available because the tidal influx of sea water mixes with the streamflow.

c. Ground Water. Map units 1, 3, 4, 5, and 6 are represented within the province. Map units 3 and 4 cover about 70 percent of the province where fresh water is locally plentiful. Existing wells have yields varying from 90 to 120 liters per minute (about 24 to 32 gallons per minute). TDS values vary from only 64 to 6,000 milligrams per liter. Iron contamination in wells is a major concern in the province.

Map unit 1, the most favorable area for wells, occupies about 5 percent of the province in the northeastern part. The aquifers of the San Tadeo Formation are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. One well in this formation has a yield of 120 liters per minute (about 32 gallons per minute). TDS values in this formation range between 64 and 240 milligrams per liter. Well exploration is recommended here due to the potential for high yields and good water quality.

Map unit 3 occupies about 35 percent of the province and trends northeast-southwest throughout the province with the largest area occurring in the east. The aquifers consist of sandstones and conglomerates with lesser amounts in tuffs, clays, silts, mudstones, and limestones. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The Angostura Formation consists of sandstones, conglomerates, and calcareous sandstones with TDS values ranging between 450 and 2,635 milligrams per liter. The Borbon Formation consists of sandstones, clays, conglomerates, and calcareous sandstones. TDS values for this formation range from 98 to 1,200 milligrams per liter. The Tablazos Formation is greater than 150 meters thick and consists of sandstones, conglomerates, and calcareous sediments. Wells completed in the Tablazos Formation are artesian with yields from 60 to 840 liters per minute. The Viche Formation consists of clayey silt with calcareous lenses, conglomerates, and sandstones. One well in this map unit has a TDS value of 615 milligrams per liter. The San Mateo Formation consists of sandstones, conglomerates, and clays. TDS values range between 450 and 6,000 milligrams per liter. In the area around San Lorenzo, the well depths average approximately 20 meters with average depth to water at 5 meters. Average TDS value is 3,000 milligrams per liter. Yields average 60 liters per minute. Manta, a major port community, is in this map unit. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 35 percent of the province in scattered locations throughout. The aquifers consist of siltstones, lutites, sandstones, conglomerates, clays, shales, breccias, diabases, and pyroclastic rocks. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. The Onzole Y Charapoto Formation within this map unit consists of siltstones, lutites, sandstones, and conglomerates. TDS values range between 360 and 2,250 milligrams per liter. The Cayo Formation consists of clays, shales, breccias, and conglomerates. TDS values of two wells are 2,800 and 3,200 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 20 percent of the province in an area paralleling the coast and trending northeast-southwest. The aquifers consist of lutites, calcareous siltstones, and clays of the Dos Bocas Formation, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Map unit 6 occupies about 5 percent of the province in a few scattered locations along the coast. Two of these areas are in the lower reaches of the Rio Chone and the Rio Chico. The provincial capital Portoviejo is within this map unit. The aquifers are in the Undifferentiated Quaternary Formation, consisting of sands, sandstones, clays, and conglomerates. They generally have high permeability, producing small to large quantities of brackish to saline water, with fresh water scarce or lacking. TDS values range from 1,200 to 2,475 milligrams per liter. Well exploration is not recommended in these coastal areas due to the potential of poor water quality.

Los Rios

a. General. Los Rios has about 6 percent of the total population of Ecuador; the provincial capital is Babahoyo. The population of the province in 1990 was 527,559. The province of Los Rios is in the west-central section of Ecuador. Los Rios has a land surface area of 6,254 square kilometers and occupies about 2 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Los Rios. Map unit 1 occupies about 40 percent of the province located in the broad flood plains of the major rivers. Fresh water is perennially plentiful in this area. Map unit 2 occupies about 60 percent of the province and represents the areas outside of the major river valleys. This map unit has fresh water that is seasonally plentiful in most streams, generally from January through May, with flows tapering off the rest of the year.

c. Ground Water. Map units 1, 4, and 5 are represented within the province of Los Rios. Wells in the province have yields varying from 60 to 3,000 liters per minute (about 16 to 800 gallons per minute). TDS values in the province range between 50 and 680 milligrams per liter.

Map unit 1, the most favorable area for wells and with fresh water generally plentiful, occupies about 90 percent of the province. Babahoyo, the capital of the province, is within this map unit along the Rio Babahoyo. Generally, the aquifers are alluvial, consisting of sands and gravels with lesser amounts in silts, clays, sandstones, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. The Pichilingue Formation in this map unit consists of terrace and river sediments. One well in this formation has a yield of 1,500 liters per minute (about 400 gallons per minute). TDS values range between 50 and 680 milligrams per liter. The Undifferentiated Quaternary Formation in this map unit consists of sands, sandstones, clays, and conglomerates. Wells in these sediments have yields between 60 and 3,000 liters per minute. TDS values range between 64 and 450 milligrams per liter. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 4 occupies more than 5 percent of the province in two small areas along the eastern edge. The aquifers consist of diabases, andesites, and volcanic sediments of the Macuchi Formation. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies less than 5 percent of the province in one area along its eastern edge. The aquifers consist of intrusive rocks composed of granites and granodiorite, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Guayas

a. General. Guayas has about 26 percent of the total population of Ecuador; about 60 percent of this population resides in the provincial capital of Guayaquil. The population of the province in 1990 was 2,515,146. The province of Guayas is in the southwest section of Ecuador. Guayas has a land surface area of 20,902 square kilometers and occupies about 8 percent of the country's total land mass.

b. Surface Water. Map units 1, 2, 3, and 4 are represented within the province of Guayas. Map unit 1 occupies about 25 percent of the province. It is in the Rio Chimbo valley and in the interfluvial marshes and flood plains of the Rio Daule, Rio Chimbo, and Rio Babahoyo. It is also representative of several major streams that flow west into the Golfo de Guayaquil. In this map unit, fresh water is perennially plentiful. Guayaquil is located in this area. Map unit 2 occupies about 35 percent of the province. It represents the areas outside of, but adjacent to, the Rio Daule and the Rio Babahoyo interfluvial valleys. Here fresh water is seasonally plentiful in most streams, generally from January through May, with flows tapering off the rest of the year. Map unit 3 occupies about 30 percent of the province, generally in the arid western part from the Cerros de Colonche Range to the coast and in the uplands of Isla Puna. In this map unit, fresh to brackish water is seasonally available in most streams, generally from January through April. Streams are generally dry the rest of the year. Map unit 4 occupies about 10 percent of the province. It represents a zone of tidal estuaries encompassing the Rio Guayas Delta below the confluence of the Rio Babahoyo and the Rio Daule where fresh water is scarce or lacking. Brackish to saline water is perennially available in this area due to the tidal influx of sea water mixing with streamflow.

c. Ground Water. Map units 1, 3, 4, 5, and 6 are represented within the province of Guayas. Wells in the province have yields varying from 60 to 7,920 liters per minute (about 16 to 2,100 gallons per minute). TDS values in the province may be as low as 60 milligrams per liter and as high as 6,000 milligrams per liter. Along the coast, large banana plantations are heavy users of ground water. In these areas, the aquifers are very shallow and easy to access.

Map unit 1, the most favorable area for wells and with fresh water generally plentiful, occupies about 40 percent of the province in the eastern part. Generally, the aquifers are alluvial, consisting of sands and gravels with lesser amounts in silts, clays, sandstones, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. The Pichilingue Formation in this map unit consists of terrace and river sediments. TDS values range between 158 and 400 milligrams per liter. The Undifferentiated Quaternary Formation in this map unit consists of sands, sandstones, clays, and conglomerates. Wells in this formation have yields between 60 and 7,920 liters per minute. TDS values range between 165 and 890 milligrams per liter. Many wells are within this map unit. Well exploration is recommended due to the potential for high yields and good water quality.

Map unit 3 occupies about 30 percent of the province and is generally located within the Peninsula de Santa Elena. The aquifers consist of sandstones and conglomerates with lesser amounts in tuffs, clays, silts, mudstones, and limestones. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. In the Peninsula de Santa Elena, average well yield is 180 liters per minute, with average TDS values of 3,000 milligrams per liter. On the Peninsula de Santa Elena, average well depth is 50 meters, and average depth to water is 10 meters. The Zapotal, Progreso, Tablazos, and Complejo Olistostromico Formations are within this map unit. The Zapotal Formation in the Daular area has a thickness of 1,000 meters and consists of sandstones, conglomerates, and clays. TDS values range from 340 to 782 milligrams per liter. The Progreso Formation consists of clays, sandstones, conglomerates, and lutites. One well in this formation has a yield of 60 liters per minute (about 16 gallons per minute). In the San Juan and Progreso areas, the Progreso Formation ranges from 400 to 1,300 meters thick. The Tablazos Formation consists of sandstones, conglomerates, and calcareous banks. Wells in this formation have yields from 60 to 840 liters per minute (about 16 to 220 gallons per minute). TDS values in the Progreso and Tablazos Formations range between 3,500 and 3,800 milligrams per liter. The Complejo Olistostromico Formation consists of allochthon rocks, sandstones, lutites, limestones, and cherts. One well in this formation has a yield of 60 liters per minute. TDS values range between 656 and 6,000 milligrams per liter. Well yields near Rio Verde range from 70 to 757 liters per minute, with TDS values of 256 to 1,730 milligrams per liter. A well near Pedro Carbo has yields of 780 liters per minute. In the San Juan and Progreso areas, wells have yields of 284 to 379 liters per minute. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 10 percent of the province in the western part. The aquifers consist of siltstones, lutites, sandstone, conglomerates, clays, shales, breccias, pyroclastic rocks, and diabases. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 5 percent of the province and is in a small area in the center of the Santa Elena Peninsula. The aquifers consist of lutites, calcareous siltstones, and clays of the Dos Bocas Formation, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within this map unit, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Map unit 6 occupies less than 15 percent of the province and is along the coast of Golfo de Guayaquil and in the lower reaches of the Rio Guayas. The aquifers consist of Quaternary sediments of unconsolidated clastic rocks. They generally have high permeability, producing small to large quantities of brackish to saline water. Fresh water is scarce or lacking. Guayaquil and the major port community of Puerto Nuevo are within this map unit. The Undifferentiated Quaternary Formation of this aquifer has yields from 240 to 1,560 liters per minute (about 60 to 400 gallons per minute). TDS values range between 240 and 3,500 milligrams per liter. Well exploration is not recommended due to the potential of poor water quality.

El Oro

a. General. El Oro has about 4 percent of the total population of Ecuador; about 35 percent of this population resides in the provincial capital of Machala. The population of the province in 1990 was 412,572. The province of El Oro is in the southwest section of Ecuador. El Oro has a land surface area of 5,988 square kilometers and occupies about 2 percent of the country’s total land mass.

b. Surface Water. A persistent drought from 1994 to 1997 drastically diminished the flow duration and discharge in many of the intermittent streams in the Andes Mountains region. Map units 1, 2, and 4 are represented within the province of El Oro. Map unit 1 occupies less than 10 percent of the province and is representative of several major streams that flow west into the Golfo de Guayaquil. Fresh water is perennially plentiful from these streams. Map unit 2 occupies about 85 percent of the province. It represents areas where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October to June in the Andes Mountains region. Map unit 4 occupies about 5 percent of the province in the tidal flats around the mouth of the Rio Jubones, along with coastal lowlands and offshore islands to the south and west of the mouth. In this map unit, fresh water is scarce or lacking, but brackish to saline water is perennially available due to the tidal influx of sea water mixing with streamflow. Puerto Bolivar, a navigational port, is located in map unit 4.

c. Ground Water. Map units 1, 4, 5, and 6 are represented within the province of El Oro. Wells in the province have yields varying from 184 to 1,500 liters per minute (about 16 to 2,100 gallons per minute). TDS values in the province may be as low as 60 milligrams per liter and as high as 7,600 milligrams per liter. Along the coast, large banana plantations are heavy users of ground water. In these areas, the aquifers are very shallow and easy to access. About 70 percent of the province lies equally within map units 4 and 5. Map unit 4 has fresh water locally plentiful, while map unit 5 has fresh water scarce or lacking.

Map unit 1, the most favorable area for wells, occupies about 20 percent of the province in the western part. The aquifers are alluvial, consisting of sands and gravels with lesser amounts in silts, clays, sandstones, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Machala, the capital of the province, is within this map unit. Wells are generally shallow (15 to 20 meters); however, because of a drought from 1994 to 1997, these wells have dried up. Water is available in deep aquifers between 100 and 200 meters, but due to the lack of equipment and funding, these aquifers have not been exploited. The Undifferentiated Quaternary Formation in this map unit consists of sands, sandstones, clays, and conglomerates. Wells in this formation have yields between 600 and 1,500 liters per minute (about 158 to 395 gallons per minute). TDS values range between 184 and 800 milligrams per liter. Many wells have been drilled in this map unit. Further exploration is recommended due to the potential for high yields and good water quality.

Map unit 4 occupies about 35 percent of the province in the eastern part. The aquifers consist of lavas, pyroclastic rocks, agglomerates, diabases, andesites, and volcanic sediments. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 35 percent of the province in the higher elevations. The aquifers consist of intrusive rocks consisting of granites and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Map unit 6 occupies less than 10 percent of the province and is along the coast of the Golfo de Guayaquil. The aquifers consist of Quaternary sediments of unconsolidated clastic rocks. They generally have high permeability, producing small to large quantities of brackish to saline water. Fresh water is scarce or lacking in map unit 6. The Undifferentiated Quaternary Formation of this aquifer has TDS values ranging between 334 and 7,600 milligrams per liter. Well exploration is not recommended in this area due to the potential of poor water quality.

Loja

a. General. Loja has about 4 percent of the total population of Ecuador; about 25 percent of this population resides in the provincial capital of Loja. The population of the province in 1990 was 384,698. The province of Loja is in the south-central section of Ecuador bordering Peru. Loja has a land surface area of 10,793 square kilometers and occupies about 4 percent of the country's total land mass.

b. Surface Water. A persistent drought from 1994 to 1997 drastically diminished the flow duration and discharge in many of the intermittent streams in the Andes Mountains region. Map units 1, 2, and 3 are represented within the province of Loja. Map unit 1 occupies about 10 percent of the province, which represents several major streams that flow west into Peru. Fresh water is perennially plentiful from these streams. Map unit 2 occupies about 80 percent of the province. It covers the most land mass in the province and represents areas where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October through June in the Andes Mountains region. Flows taper off the rest of the year. Map unit 3 occupies about 10 percent of the province. Several isolated zones in the southern part of this province have fresh to brackish water seasonally available in most streams, generally from January through April. However, the prolonged drought has drastically diminished runoff or dried out many of the smaller intermittent streams.

c. Ground Water. Map units 3, 4, and 5 are represented within the province of Loja. Springs in the province have TDS values between 5 and 435 milligrams per liter. Wells in the province are generally shallow (15 to 20 meters); however, because of a drought from 1994 to 1997, these wells have dried up. Water is available in deep aquifers of 100 to 200 meters depth; but due to the lack of equipment and funding, these aquifers have not been exploited. Dense vegetation and steep slopes may limit access in many areas. About 70 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 3 occupies about 5 percent of the province in a small area at the northeastern edge. The aquifers are in the Tarqui Formation, consisting of tuffs, riolitic agglomerates, and andesites. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. This formation contains springs with TDS values ranging between 60 and 360 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 70 percent of the province and occurs throughout. The aquifers typically consist of lavas, pyroclastic rocks, agglomerates, graywackes, lutites, conglomerates, and andesites. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. The Zapotillo Formation in map unit 4 consists of graywacke, black lutites, and conglomerates. This formation contains springs with TDS values ranging between 240 and 435 milligrams per liter. The Celica Formation in map unit 4 consists of massive green andesites. This formation contains springs with TDS values ranging between 5 and 380 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 25 percent of the province on the eastern edge and in two small locations in the north and south. The aquifers consist of intrusive rocks consisting of granites and granodiorites; some areas in the Zamora Formation consist of schists, quartzites, and gneisses, producing meager to small quantities of fresh water. Loja, the capital of the province, is within this area. These aquifers have very poor hydrologic properties and are almost impermeable.

Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Zamora-Chinchipe

a. General. Zamora-Chinchipe has less than 1 percent of the total population of Ecuador, with the provincial capital city at Zamora. The population of the province in 1990 was 66,167. The province of Zamora-Chinchipe is in the southeast corner of Ecuador. Zamora-Chinchipe has a land surface area of 20,240 square kilometers and occupies about 7 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Zamora-Chinchipe. Map unit 1, which occupies the Rio Chinchipe and Rio Zamora valleys, covers about 30 percent of the province, where fresh water is perennially plentiful. Map unit 2 covers about 70 percent of the province. It represents the areas outside of these two river valleys, where fresh water is seasonally plentiful in most streams, generally from March through June and September through November. Flows taper off the rest of the year.

c. Ground Water. Map units 3, 4, and 5 are represented within the province of Zamora-Chinchipe. Dense vegetation and steep slopes may limit access in many areas. About 80 percent of the province lies within map unit 5 where fresh water is scarce or lacking.

Map unit 3 occupies about 5 percent of the province in a small area at the northern edge. The aquifers are in the Tarqui Formation and consist of tuffs, riolitic agglomerates, and andesites. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 15 percent of the province scattered on the eastern side. The aquifers typically consist of sandstones, lutites, limestones, and minor amounts of pyroclastic sediments, quartzites, tuffs, slates, and clays. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 80 percent of the province in the higher elevations throughout. Most of the aquifers are in the Zamora Formation and consist of schists, quartzites, and gneisses. Other aquifers in areas of intrusive rocks consist of granites and granodiorites, producing meager to small quantities of fresh water. Zamora, the capital of the province, is within this area. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Azuay

a. General. Azuay has about 5 percent of the total population of Ecuador; about 39 percent of this population resides in the provincial capital of Cuenca. The population of the province in 1990 was 506,090. The province of Azuay is in the south-central section of Ecuador. Azuay has a land surface area of 8,639 square kilometers and occupies about 3 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Azuay. Map unit 1, where fresh water is perennially plentiful, occupies about 10 percent of the province in the Rio Paute basin, which originates in a series of crater lakes west of Cuenca but otherwise has little representation in Azuay. The hydroelectric plant Amaluza is located on the Rio Paute in this province. Map unit 2 occupies about 90 percent of the province. It represents areas where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October through June in the Andes Mountains region. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Azuay. Springs in this province have TDS values ranging between 135 and 675 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 60 percent of the province lies within map unit 3 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 5 percent of the province along the western boundary. The aquifers are alluvial in the Undifferentiated Quaternary Formation, consisting of sands, sandstones, clays, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in map unit 1 due to the potential for high yields and good water quality.

Map unit 3 occupies about 60 percent in the central part of the province. The aquifers typically consist of lutites, sandstones, conglomerates, and volcanic sediments. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. Many springs exist in this area. Cuenca, the capital of the province, is within this area along the Rio Paute. Map unit 3 yields small to moderate quantities of fresh water locally. The Tarqui Formation in map unit 3 consists of tuffs and riolitic agglomerates in andesite. This formation contains springs with TDS values ranging between 135 and 675 milligrams per liter. The Moraspamba Formation in map unit 3 consists of intercalated lutites and sandstones with conglomerates. This formation has springs with TDS values ranging between 320 and 390 milligrams per liter. The Ayancay Group Formation in this area consists of alternating sandstones, conglomerates, and clays. This formation contains springs with TDS values ranging between 350 and 420 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 25 percent of the province and occurs in the lower elevations along the western boundary. The aquifers typically consist of volcanic sediments, agglomerates, lava flows, diabases, and andesites. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. The Macuchi Formation in map unit 4 consists of diabases and andesites with volcanic sediments. This formation contains springs with TDS values ranging between 370 and 420 milligrams per liter. Drilling would probably be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 10 percent of the province in the northeastern part. The aquifers typically consist of andesites, phyllites, schists, granites, and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Canar

a. General. Canar has 2 percent of the total population of Ecuador. Its provincial capital is Azogues. The population of the province in 1990 was 189,347. The province of Canar is in the south-central section of Ecuador and has a land surface area of 3,516 square kilometers, which is about 1 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Canar. Map unit 1, where fresh water is perennially plentiful, occupies about 10 percent of the province. It is representative of several major streams, most notably the Rio Canar, that flow west out of the Andes Mountains. Map unit 2 occupies about 90 percent of the province. It represents areas where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October through June in the Andes Mountains region. Flows taper off the rest of the year. Two dams, the Lallrago and the Chanlud, are on the Rio Machangara in map unit 2.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Canar. Dense vegetation and steep slopes may limit access in many areas. About 40 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies about 10 percent of the province along the western boundary. The aquifers are alluvial in the Undifferentiated Quaternary Formation, consisting of sands, sandstones, clays, and conglomerates. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 3 occupies about 40 percent of the province in the central part. The aquifers from unconsolidated and consolidated clastic sediments typically consist of lutites, sandstones, conglomerates, and volcanic sediments. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. Many springs are in this map unit. Azogues, the capital of the province, and the community of Canar are within this map unit, which yields small to moderate quantities of fresh water locally. The Tarqui Formation in map unit 3 consists of tuffs and riolitic agglomerates in andesite. This formation contains springs with TDS values ranging between 275 and 350 milligrams per liter. The Undifferentiated Quaternary Formation in map unit 3 consists of sands, clays, and silts. TDS values range between 290 and 380 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 40 percent of the province in the west and in the east. The aquifers typically consist of volcanic sediments, agglomerates, diabases, and andesites. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 10 percent of the province along the eastern boundary. The aquifers typically consist of andesites, phyllites, schists, granites, and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Chimborazo

a. General. Chimborazo has about 4 percent of the total population of Ecuador; about 26 percent of this population resides in the provincial capital of Riobamba. The population of the province in 1990 was 364,682. The province of Chimborazo is in the central section of Ecuador, has a land surface area of 5,637 square kilometers, and occupies about 2 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Chimborazo. Map unit 1, where fresh water is perennially plentiful, occupies about 10 percent of the province primarily in the Rio Cebadas gorge, which drains northward between the Cordillera Occidental and the Cordillera Oriental. Map unit 2 occupies about 90 percent of the province. It represents areas where fresh water is seasonally plentiful in most streams, generally from October through June, with flows tapering off the rest of the year.

c. Ground Water. Map units 3, 4, and 5 are represented within the province of Chimborazo. Springs and wells in the province have TDS values ranging between 60 and 1,425 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 60 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 3 occupies about 25 percent of the province and is scattered in small areas throughout. The aquifers from unconsolidated and consolidated clastic sediments typically consist of andesites, agglomerates, and volcanic sediments. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. Riobamba, the capital of the province, is within this area. The Cangahua Formation in map unit 3 consists of volcanic sediments. Wells in this formation have yields from 60 to 900 liters per minute (about 16 to 240 gallons per minute). This formation contains springs with TDS values ranging between 223 and 345 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 60 percent of the province and occurs throughout. The aquifers typically consist of volcanic sediments. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. The Macuchi Formation in map unit 4 consists of diabases and andesites with volcanic sediments. This formation contains springs with TDS values ranging between 135 and 1,425 milligrams per liter. The Sicalpa Formation in map unit 4 consists of agglomerates and pyroclastic-andesitic lavas. This formation contains springs with TDS values ranging between 340 and 740 milligrams per liter. Recent volcanic sediments in map unit 4 consist of lavas, andesitic tuffs, breccias, and ash. This formation contains springs with TDS values ranging between 96 and 950 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 15 percent of the province in an elongated area in the southeast part. The aquifers are within the Paute Group Formation and consist of andesites, phyllites, and schists, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Two springs in this aquifer have TDS values of 125 and 270 milligrams per liter. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Bolivar

a. General. Bolivar has about 2 percent of the total population of Ecuador. Its provincial capital is Guaranda. The population of the province in 1990 was 155,088. The province of Bolivar is in the central section of Ecuador, has a land surface area of 3,254 square kilometers, and occupies about 1 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Bolivar. Map unit 1, where fresh water is perennially plentiful, occupies about 10 percent of the province. It is in a small area in the northwest part of the province near the Rio Zapotal headwaters and represents the Rio Chimbo in the southern part of the province. Map unit 2 occupies about 90 percent of the province. It represents areas where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October through June in the Andes Mountains region. Flows taper off the rest of the year.

c. Ground Water. Map units 3, 4, and 5 are represented within the province of Bolivar. Springs have TDS values ranging between 64 and 340 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 70 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 3 occupies about 10 percent of the province in a small area in the center. The aquifers from this area are of the Cangahua Formation and consist of volcanic sediments. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. Guaranda, the capital of the province, is within this map unit. This area contains springs with TDS values ranging between 184 and 223 milligrams per liter. One well has a yield of 300 liters per minute with TDS values of 240 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 70 percent of the province and occurs throughout. The aquifers typically consist of volcanic sediments, metamorphic rocks, and some sedimentary rocks. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. The Macuchi Formation in map unit 4 consists of diabases and andesites with volcanic sediments. This formation contains springs with TDS values ranging between 64 and 206 milligrams per liter. Recent volcanic sediments in map unit consist of lavas, andesitic tuffs, breccias, and ash. This formation contains springs with TDS values ranging between 86 and 340 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 20 percent of the province and occurs in small scattered areas throughout. The aquifers consist of granites and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Tungurahua

a. General. Tungurahua has about 4 percent of the total population of Ecuador; about 34 percent of this population resides in the provincial capital of Ambato. The population of the province in 1990 was 361,980. The province of Tungurahua is in the central section of Ecuador, has a land surface area of 2,896 square kilometers, and occupies about 1 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Tungurahua. Map unit 1, where fresh water is perennially plentiful, occupies about 25 percent of the province. Map unit 1 occurs in the mountain valleys of the Rios Ambato, Cebadas, Cutuchi, and Pastaza. The hydroelectric plant Agoyan is located on the Rio Pastaza in this province. Map unit 2 occupies about 75 percent of the province and represents the areas outside of the major river gorges. Here fresh water is seasonally plentiful in most streams. Fresh water is generally available from October through June along the western slopes of the Cordillera Oriental and from March through June and September through November along the eastern slopes of the Cordillera Oriental. Flows taper off the rest of the year.

c. Ground Water. Map units 3, 4, and 5 are represented within the province of Tungurahua. Some springs in the province have TDS values between 86 and 585 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 40 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 3 occupies about 30 percent of the province in the western half. The aquifers from this area are of the Cangahua Formation and consist of volcanic sediments. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The average well yield is 600 liters per minute, with average TDS value of 500 milligrams per liter. The average well depth is 70 meters and average depth to water is 25 meters. Ambato, the capital of the province, is within this area. One well has a yield of 300 liters per minute. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 40 percent of the province and occurs throughout. The aquifers typically consist of volcanic sediments. They produce very small to small quantities of fresh water from localized fracture zones with very low to medium permeability at depths of less than 60 meters. Recent volcanic sediments in map unit 4 consist of lavas, andesitic tuffs, breccias, and ash. This formation contains springs with TDS values ranging between 86 and 585 milligrams per liter. The Pisayambo Formation consists of lavas and pyroclastic sediments with agglomerates. One spring in this formation has a TDS value of 20 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 30 percent of the province along the eastern edge. The aquifers consist of schists, quartzites, and phyllites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Cotopaxi

a. General. Cotopaxi has about 3 percent of the total population of Ecuador. Its provincial capital is Latacunga. The population of the province in 1990 was 276,324. The province of Cotopaxi is in the central section of Ecuador, has a land surface area of 5,287 square kilometers, and occupies about 2 percent of the country’s total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Cotopaxi. Map unit 1, where fresh water is perennially plentiful, occupies about 20 percent of the province in the mountain valleys of the Rio Cutuchi and the Rio Toachi. Map unit 2 occupies about 80 percent of the province. It represents the areas outside of these river valleys where fresh water is seasonally plentiful in most streams, generally from January through May in the coastal plains region and from October through June in the Andes Mountains region. Flows taper off the rest of the year. The hydroelectric plant Pisayambo is located on the Rio Pisayambo in this province.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Cotopaxi. Wells and springs have TDS values between 28 and 1,456 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 60 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies about 5 percent of the province near its western border. The aquifers are alluvial, consisting of sands, clays, and silts. These aquifers are unconfined and confined with medium to high permeability, producing small to large

quantities of fresh water. TDS values range between 79 and 135 milligrams per liter. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 3 occupies about 30 percent of the province and is in the mountain valleys of the Rio Cutuchi and Rio Toachi. The aquifers consist of recent volcanic rocks with lesser amounts of sands, clays, and silts. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The Cangahua Formation in map unit 3 consists of volcanic rocks. The average well yield is 600 liters per minute. Wells in this formation have TDS values ranging between 435 and 1,456 milligrams per liter, with an average TDS value of 500 milligrams per liter. The average well depth is 70 meters, and average depth to water is 25 meters. Latacunga, the capital of the province, is within this area. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 60 percent of the province. The aquifers consist of lavas, pyroclastic sediments with agglomerates, diabases, andesites, and volcanic sediments. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. The Macuchi Formation in map unit 4 consists of diabases and andesites with volcanic sediments. This formation contains TDS values from springs ranging between 28 and 435 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 5 percent of the province in a small area along the southern boundary. The aquifers consist of granites and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Imbabura

a. General. Imbabura has about 3 percent of the total population of Ecuador. The provincial capital is Ibarra. The population of the province in 1990 was 265,499. Imbabura is in the north-central section of Ecuador, has a land surface area of 4,986 square kilometers, and occupies about 2 percent of the country’s total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Imbabura. Map unit 1, where fresh water is perennially plentiful, occupies about 30 percent of the province and represents several major streams that comprise the Rio Mira and Rio Guayllabamba watersheds. Map unit 2 occupies about 70 percent of the province. It represents the areas outside of these river basins where fresh water is seasonally plentiful in most streams, generally from October through June. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Imbabura. TDS values are between 60 and 1,650 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 60 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 5 percent of the province in the western part. The aquifers are alluvial, consisting of lahars, fanglomerates, and mudflows. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 3 occupies about 20 percent of the province occurring in a few scattered areas. The aquifers consist of recent volcanic rocks with lesser amounts of sands, clays, and silts. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The Cangahua Formation in map unit 3 consists of volcanic rocks. Wells in this formation have TDS values ranging between 60 and 1,650 milligrams per liter. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 60 percent of the province and occurs throughout. The provincial capital Ibarra lies within this map unit. The aquifers consist of lavas, pyroclastic sediments with agglomerates, diabases, andesites, breccias, and ash. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Recent volcanic sediments in map unit 4 consist of lavas, andesitic tuffs, breccias, and ash. Two wells in this formation have TDS values of 315 and 585 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 15 percent of the province occurring in a few scattered areas. The aquifers consist of granites and granodiorites, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Carchi

a. General. Carchi has about 2 percent of the total population of Ecuador. The provincial capital is Tulcan. The population of the province in 1990 was 141,482. The province of Carchi is in the north-central section of Ecuador bordering Colombia, has a land surface area of 3,699 square kilometers, and occupies about 1 percent of the country’s total land mass.

b. Surface Water. Map unit 1, where fresh water is perennially plentiful, occupies about 95 percent of the province. Map unit 2 occupies about 5 percent of the province in a small strip along the ridge line of the Cordillera Oriental, which forms the eastern border with the province of Sucumbios. Just west of the ridge line, fresh water is seasonally plentiful, generally from October through June. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 3, 4, and 5 are represented within the province of Carchi. Wells in the province have TDS values between 24 and 533 milligrams per liter. Dense vegetation and steep slopes may limit access in many areas. About 80 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 5 percent of the province in the northwestern corner. The aquifers are alluvial, consisting of lahars, fanglomerates, and mudflows. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 3 occupies about 10 percent of the province and occurs in two small areas in the eastern part. The aquifers consist of volcanic sediments and glacier deposits. These aquifers are local and discontinuous with low to medium permeability, producing small to moderate quantities of fresh water. The Cangahua Formation in map unit 3 consists of volcanic sediments. Wells in this formation have TDS values ranging between 24 and 533 milligrams per liter. Tulcan, the capital of the province, is within this area. Most areas within map unit 3 are suitable for tactical and hand pump wells.

Map unit 4 occupies about 80 percent of the province. The aquifers consist of lavas, andesites, breccias, and ash, producing very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Recent volcanic deposits in map unit 4 consist of lavas, andesitic tuffs, breccias, and ash. Two wells in this formation have TDS values of 45 and 128 milligrams per liter. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies more than 5 percent of the province along the eastern edge. The aquifers consist of granites, granodiorites, schists, quartzite, phyllites, and gneisses, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Sucumbios

a. General. Sucumbios has less than 1 percent of the total population of Ecuador. Its provincial capital is Nueva Loja. The population of the province in 1990 was 76,952. The province of Sucumbios is in the northeast section of Ecuador, has a land surface area of 18,150 square kilometers, and occupies about 7 percent of the country’s total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Sucumbios. Map unit 1, where fresh water is perennially plentiful, occupies about 95 percent of the province. Map unit 2 occupies a small strip along the ridge line of the Cordillera Oriental, which forms the western border with Carchi province. Just east of the ridge line, fresh water is seasonally plentiful, generally from March through June and September through November. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 2, 4, and 5 are represented within the province of Sucumbios. Lack of roads and dense vegetation limit access to ground water sources. About 50 percent of the province lies within map unit 2 where fresh water is plentiful.

Map unit 1, the most favorable area for wells, occupies less than 30 percent of the province. It is along the Rio Napo (north bank), the Rio Aguarico, the Rio Cuyabeno, the Rio Putumayo, and the Rio San Miguel. The aquifers are alluvial, consisting of sands, gravels, and cobble. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Nueva Loja, the capital of the province, is within this map unit. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 2 occupies about 50 percent of the province occurring in the upper reaches of the Amazon River basin. The aquifers consist of clays, sandstones, breccias, and conglomerates, producing moderate quantities of fresh water with large quantities available locally. In the vicinity of Lago Agrio, groundwater may be contaminated from oil production. Well exploration is favorable in this area due to the potential for high yields and overall good water quality.

Map unit 4 occupies about 10 percent of the province and occurs in the western part. The aquifers consist of calcareous lutites, limestones, and sandstone. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 10 percent of the province and occurs along the western boundary. The aquifers consist of granites, schists, quartzite, phyllites, and gneisses, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Napo

a. General. Napo has about 1 percent of the total population of Ecuador. Its provincial capital is Tena. The population of the province in 1990 was 103,387. The province of Napo is in the east-central section of Ecuador, has a land surface area of 35,280 square kilometers, and occupies about 13 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Napo. Map unit 1, where fresh water is perennially plentiful, occupies about 80 percent of the province. Map unit 2 occupies about 20 percent of the province in most of the highlands in the western part. In this map unit, fresh water is seasonally plentiful in most streams, generally from March through June and September through November along the eastern slopes of the Cordillera Oriental. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 2, 4, and 5 are represented within the province of Napo. Lack of roads and very dense vegetation limit access to ground water sources. About 60 percent of the province lies within map unit 2 where fresh water is generally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 20 percent of the province. It is along the Rio Napo, the Rio Tiputini, and the Rio Conanco (north bank). The aquifers are alluvial, consisting of sands, gravels, and cobble. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in map unit 1 due to the potential for high yields and good water quality.

Map unit 2 occupies about 60 percent of the province and is in the upper reaches of the Amazon River basin. The aquifers consist of clays, sandstones, breccias, and conglomerates, producing moderate quantities of fresh water with large quantities available locally. Aquifers have low to medium permeability. Some aquifers are locally discontinuous. Well exploration is favorable in this area due to the potential for high yields and good water quality.

Map unit 4 occupies about 10 percent of the province in the western part along the eastern slopes of the mountain range. The aquifers consist of calcareous lutites, limestones, volcanic sediments, and sandstone. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Tena, the capital of the province, is within this map unit. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 10 percent of the province in the higher elevations of the western parts. The aquifers consist of granites, granodiorites, clays, limonites, conglomerates, and sandstones, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures or conglomerates and sandstone in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Pastaza

a. General. Pastaza has less than 1 percent of the total population of Ecuador. Its provincial capital is Puyo. The population of the province in 1990 was 41,811. The province of Pastaza is in the east-central section of Ecuador, has a land surface area of 29,520 square kilometers, and occupies about 11 percent of the country's total land mass.

b. Surface Water. Map units 1 and 2 are represented within the province of Pastaza. Map unit 1, where fresh water is perennially plentiful, covers almost the entire land mass within the province. Map unit 2 occupies a small area in the westernmost corner of the province along the eastern slopes of the Cordillera Oriental. Here, fresh water is seasonally plentiful in most streams, generally from March through June and September through November. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 2, 4, and 5 are represented within the province of Pastaza. Lack of roads and very dense vegetation limit access to ground water sources. About 70 percent of the province lies within map unit 2 where fresh water is generally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 20 percent of the province. It is along the Rio Conanco (south bank), the Rio Curaray, the Rio Pindoyaco, the Rio Conambo, the Rio Bobonaza, and the Rio Pastaza (north bank). The aquifers are alluvial, consisting of sands, gravels, and cobble. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. The community of Montalvo is within this map unit along the Rio Bobonaza. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 2 occupies about 75 percent of the province and occurs in the upper reaches of the Amazon River basin. The aquifers consist of clays, sandstones, breccias, and conglomerates, producing moderate quantities of fresh water with large quantities available locally. Springs with yields of 60 liters per minute are near Santa Clare. Puyo, the capital of the province, is within this area. Wells near Puyo have TDS values ranging from 75 to 450 milligrams per liter. Well exploration is favorable in this map unit due to the potential for high yields and good water quality.

Map unit 4 occupies a very small area of the province and occurs in the western part along the eastern slopes of the Cordillera Oriental. The aquifers consist of calcareous lutites, limestones, volcanic sediments, and sandstone. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies less than 5 percent of the province in two small areas in the higher elevations of the western parts. The aquifers consist of granites, granodiorites, clays, limonites, conglomerates, and sandstones, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures or conglomerates and sandstone in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

Morona-Santiago

a. General. Morona-Santiago has about 1 percent of the total population of Ecuador. Its provincial capital is Macas. The population of the province in 1990 was 84,216. The province of Morona-Santiago is in the southeast section of Ecuador, has a land surface area of 29,140 square kilometers, and occupies about 11 percent of the country's total land mass.*

b. Surface Water. Map units 1 and 2 are represented within the province of Morona-Santiago. Map unit 1, where fresh water is perennially plentiful, occupies about 50 percent of the province and is spread throughout. Map unit 2 occupies about 50 percent of the province. It occurs in most of the highlands in the western part of the province. Here fresh water is seasonally plentiful in most streams, generally from March through June and September through November along the eastern slopes of the Cordillera Oriental. Flows taper off the rest of the year.

c. Ground Water. Map units 1, 2, 4, and 5 are represented within the province of Morona-Santiago. Springs and wells in the province have TDS values ranging between 45 and 180 milligrams per liter. Lack of roads and very dense vegetation limit access to ground water sources. About 40 percent of the province lies within map unit 4 where fresh water is locally plentiful.

Map unit 1, the most favorable area for wells, occupies less than 10 percent of the province, along the Rio Pastaza (south bank), the Rio Macuma, the Rio Cangaime, and the Rio Santiago. The aquifers are alluvial, consisting of sands, gravels, and cobble. These aquifers are unconfined and confined with medium to high permeability, producing small to large quantities of fresh water. Well exploration is recommended in this area due to the potential for high yields and good water quality.

Map unit 2 occupies about 20 percent of the province and occurs in the upper reaches of the Amazon River basin in the northern part. The aquifers consist of clays, sandstones, breccias, and conglomerates, producing moderate quantities of fresh water with large quantities available locally. Springs with yields of 60 liters per minute are near Macas. A spring in this formation contains a TDS value of 45 milligrams per liter. Well exploration is favorable in this area due to the potential for high yields and good water quality.

Map unit 4 occupies about 40 percent of the province and is in the western part of the province along the eastern slopes of the mountain range. The aquifers consist of calcareous lutites, limestones, volcanic sediments, clays, sandstones, lutites, slates, limestones, and quartzites. They produce very small to small quantities of fresh water from localized fracture zones at depths of less than 60 meters. The Grupo Limon Formation in map unit 4 consists of clays, sandstones, lutites, slates, limestones, and quartzites. This formation contains springs and a few wells with TDS values ranging between 53 and 180 milligrams per liter. Macas, the capital of the province, is within this area. Drilling would most likely be difficult in the hard volcanic rock. Successful wells may depend upon encountering fractures in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration.

Map unit 5 occupies about 30 percent of the province and occurs generally in the western part with some scattered areas throughout. The aquifers consist of granites, granodiorites, schist, quartzites, phyllites, and gneisses, producing meager to small quantities of fresh water. These aquifers have very poor hydrologic properties and are almost impermeable. Successful wells may depend upon encountering fractures or conglomerates and sandstone in the borehole during drilling. Remote sensing to locate fracture zones should improve chances of successful well exploration. These areas are the least desirable for future well exploration due to their low-yield potential. Some areas within map unit 5, generally along fractures at depths of less than 60 meters, are suitable for tactical and hand pump wells.

*Surface area calculations are based on Ecuador's claim to the disputed boundary with Peru, which includes territory north of the 5? S meridian and west of the Rio Maranon and the Rio Santiago.

Galapagos

a. General. Galapagos has less than 1 percent of the total population of Ecuador. Its provincial capital is Puerto Baquerizo Moreno. The population of the province in 1990 was 9,785. The province of Galapagos consists of an island group in the Pacific Ocean about 1,000 kilometers west of the mainland. The Galapagos Islands have a land surface area of 8,060 square kilometers and occupy about 3 percent of Ecuador's total land mass.

b. Surface Water. Map units 3 and 4 are represented in the islands. Map unit 3, where rainfall is most likely to occur, occupies hilly areas mostly in the interiors of the islands at elevations greater than 700 meters. In these upland areas, fresh to brackish water is seasonally available in the form of overland runoff (well-defined drainage channels are lacking) or from intermittent ponds and catchments. Usually, the runoff will infiltrate the ground surface before reaching the beaches. This generally occurs from January through April, with dry conditions dominating the rest of the year. Map unit 4, where fresh water is scarce or lacking due to lack of rainfall, mostly occupies island perimeters at elevations of less than 700 meters. In these low-lying areas, brackish to saline water is seasonally available from intermittent ponds and depressions, generally from January through April, with dry conditions dominating the rest of the year.

c. Ground Water. Map units 4 and 6 are represented within the Galapagos Islands. Map unit 4 is in the highest elevations of the islands with very small to small quantities of fresh water locally available from volcanic deposits.

Map unit 6 occupies more than 80 percent of the province in the coastal areas. Puerto Baquerizo Moreno, the capital of the province, is in this area. Small to large quantities of brackish to saline water are available from alluvial and volcanic aquifers. A thin fresh water lens lies above the brackish/saline water. Extreme care should be exercised during well drilling in these areas. The borehole should not extend below the fresh water lens into the brackish/saline water underneath. Over pumping from fresh water wells in this area will cause saltwater intrusion, which permanently ruins the well. Saltwater intrusion is a major problem in this area. Well exploration is not recommended in this area due to the potential for poor quality water.

V. Recommendations

A. General

Almost all government agencies, private companies, and individuals that were interviewed during the country visit expressed interest in technical assistance and support. They were keenly aware of the need for increased planning, developing, and managing of water resources. The following reflects a composite of the needs identified by the Corps' assessment team and by Ecuadorean government officials.

B. Technical Training and Assistance

Ecuadorean government officials recognize the need to further develop their technical capabilities in defining flood-prone areas, developing flood-warning systems, collecting and analyzing ground water data, and implementing flood plain management programs. The U.S. Army Corps of Engineers has several software programs for managing water resources. These programs are considered state-of-the-art tools internationally. Many of Ecuador's engineers are aware of the Corps' Hydrologic Engineering Center (HEC) at Davis, California, and are familiar with several of the HEC-developed software programs. Perhaps best known is the HEC-2 program that is used to calculate water surface profiles. In addition to the HEC-2 program, other HEC software includes data storage and management, reservoir regulation, sediment transport, river hydraulics, statistical hydrology, and surface water hydrology.

The U.S. Army Corps of Engineers has provided training in the application of the HEC-2 program to engineers in other Latin American countries, and the user manuals and associated documents have been translated into Spanish. Ecuadorean government officials indicated an interest in obtaining the software, manuals, and training for their engineers. Appropriate training is critical to the overall success of a water resources management plan.

C. Watershed Management

A common concern of most Ecuadorean government officials and technical experts is the impact of deforestation on the environment and on water resources. Development of comprehensive watershed and basin management plans are 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 alternate uses of water and land resources,

(2) identifying conflicts and trade offs among competing uses, and

(3) making changes through informed decisions.

The planning should include short-term measures (i.e., erosion stabilization, bridge protection, flood warning systems, small water supply systems, hydrologic and meteorological stations); interim measures (i.e., flood control actions, sediment control programs, flood plain management, small reservoirs); and long-term measures (i.e., reforestation, large impoundment for flood control, hydropower, and water supply).

D. Small Surface Impoundments

In the areas where development of ground water has been unsuccessful, the construction of small impoundments for surface water supply should be considered. Design of these impoundments would not be difficult, and construction techniques would be very similar to local construction techniques. The main factors are selecting a suitable site, sizing the embankment, and designing the outlet structures.

VI. Summary

Although surface and ground water resources in Ecuador are generally abundant, they are unevenly distributed. The uneven distribution of rainfall and population are the major reasons for the country's water supply problems. This situation leads to increased competition for limited resources. The increased competition can be attributed to population growth and commercial development, along with changes in river hydrology caused by deforestation, desertification, drought, and unwise land use practices along the high slopes of the Andes Mountains. In addition, the severe drought in the Manabi province and in the Rio Paute basin are the cause for electricity shortages in the country. Water pollution caused by human waste, agricultural residues, and other solid wastes is also a problem throughout Ecuador. This pollution affects public health and has a negative influence on hydrologic resources such as rivers, lakes, and ground water. The increased demands and the impacts of pollution present challenges to the managers of Ecuador's water resources. Throughout our meetings with the managers, the recognition of the task before them and a willingness to address the issues were evident.

The recommendations offered in this report regarding technical training, watershed management, and small surface impoundments present opportunities to improve Ecuador's water resources situation in the short term. If adopted, these actions can have positive long-term impacts. Many of the other issues discussed in this report require long-term institutional commitments to affect change. Ultimately, the key to successful implementation of any plan is the ability of the various government agencies to work together toward common goals.

Endnotes

[1]George Thomas Kurian, *Geo-Data, World Geographical Encyclopedia*, Detroit, Michigan: Gale Research, 1989, pp. 126-129.

[2]Personal communications with Ing. Marcelo Encalada T., Ing. Homero Castanier, and Ing. Rebecca Cabezas, Proyecto de Fortalecimiento y Ampliacion de los Servicios Basicos de Salud en el Ecuador (FASBASE), Quito, January 1997.

[3]Interview with Ing. Homero Castanier, FASBASE, Quito, 20 January 1997.

[4]Interview with Ing. Othon Zevallos, Director, Comision Asesora Ambiental, January 1997.

[5]Personal communications with U.S. Agency for International Development (USAID) officials, Quito, January 1997.

[6]Personal communications with USAID officials, January 1997.

[7]Interview with Consejo Nacional de Recursos Hidricos engineers, Quito, January 1997.

[8]Donald D. Robadue, Jr. and Luis Arriaga, *Ecuador's Coastal Resources Management Program*, Kingston, Rhode Island: University of Rhode Island, Coastal Resources Center, 1993.

[9]Personal communications with Empresa Publica Municipal de Telefonos, Agua Potable y Alcantarillado, Quito, January 1997.

[10]Interview with FASBASE engineers, Quito, January 1997.

[11]Personal communications with USAID officials, January 1997.

Bibliography

Estudios de Geografia, "El Agua en el Ecuador, Clima, Precipitacion, Escorrentia." Vol. 7, Pierre Pourrut, editor, 1995.

International Commission on Large Dams. *World Register of Dams*. 1984.

Kurian, George Thomas. *Geo-Data, World Geographical Encyclopedia*. Detroit, Michigan: Gale Research, 1989.

Ministerio de Agricultura y Ganderia, Programa Nacional de Regionalizacion Agraria, Ecuador. *Elementos Basicas para la Planificacion de los Recursos Hidricos, Ecuador*. 1979.

Ministerio de Desarrollo Urbano y Vivienda, Subsecretaria de Saneamiento Ambiental. *Requerimientos de Perforacion de Pozos en el Ecuador*. August 1993.

Ministerio de Obras Publicas y Urbanismo, Centro de Estudios y Experimentacion de Obras Publicas. *Plan Nacional de Recursos Hidraulicos de la Republica del Ecuador, Informe General*. 1989.

Nelson, Gomez E. *Atlas del Ecuador, Geografia y Economia, Mapas del Mundo*. Edition 3, May 1994.

MAPS:

Calidad de la Informacion Hidrologia. Hoja No. 8, Map No. 8-2, Scale 1:2,000,000, 1979.

Calidad de la Informacion Pluviometrica. Hoja No. 8, Map No. 8-1, Scale 1:2,000,000, 1979.

Caudales Especificos de Estiaje DCC 30. Hoja No. 5, Scale 1:1,000,000, 1979.

Deficit Hidrico Medio Anual (Necesidad Teorica del Riego). Hoja No. 9, Scale 1:1,000,000, 1979.

Deficit Hidricos Medios Mensuales de la Costa y de la Sierra. Hoja No. 10, Scale 1:4,000,000, 1979.

Escorrentia Media Anual: Periodo 1964-1982. Scale 1:1,000,000, no date.

Evapotranspiracion Potencial Media Anual, Formula de Thornthwaite. Hoja No. 2, Scale 1:1,000,000, 1979.

Evapotranspiracion Real Media Anual, Metodo de Thornthwaite: 1964-1982. Scale 1:1,000,000, no date.

Isoyetas Medias Anuales e Histogramas Mensuales: Periodo 1964-1973. Hoja No. 1, Scale 1:1,000,000, 1979.

Isoyetas Medias Anuales e Histogramas Mensuales: 1964-1982. Scale 1:1,000,000, no date.

Mapa Hidrogeologico Nacional. Hoja No. 6, Scale 1:1,000,000, 1979.

Map Base de Ubicacion de Estaciones Hidrometeorologicas, Division de Sistemas Hidrograficos. Scale 1:1,000,000, no date.

Modulos Especificos Anuales. Hoja No. 4, Scale 1:1,000,000, 1979.

Numero de Meses Secos, Hoja No. 11, Scale 1:1,000,000, 1979.

Zonas Prioritarias Para la Investigacion y Explotacion de Aguas Subterraneas. Hoja No. 7, Scale 1:1,000,000, 1979.

APPENDIX A

Water Resources Areal Appraisal

Ecuador

First edition

Prepared by: Operations Division
U.S. Army Topographic Engineering Center, Alexandria, Virginia

Prepared for: U.S. Army Engineering District, Mobile, Alabama
U.S. Southern Command, Miami, Florida

Preface

Water Resources Areal Appraisals summarize water resources information for a selected country or region. They are useful to water planners as overviews of available water resources on a country or regional scale. The appraisal includes two topics—Surface Water Resources and Ground Water Resources—with text, tables, and figures. It also includes a bibliography, a glossary, and a list of place names. The text presents a summary of the water resources topics while the table presents more detailed and quantitative data. Table entries are represented graphically as map units on the figure (map graphic). The table and figure should be used together for a comprehensive understanding of the water resources topic.

The Surface Water Resources topic presents surface water features as potential sources of water. The table for this topic details the quality, quantity, and seasonality of significant water features within each region of the country of interest and describes accessibility to these potential water sources. The figure (map graphic) divides the country into surface water resources regions, depicting where fresh water is perennially available, seasonally available, and scarce or lacking. Where they exist, brackish and saline water sources are also described. Major physiographic region boundaries and selected stream gaging stations are also depicted.

The Ground Water Resources topic describes the availability of ground water as a usable water source throughout the study area. The table for this topic details the predominant characteristics for each region of the country of interest, such as aquifer materials, aquifer thickness, depth to water, yields, and water quality. The table also presents information useful to the siting, designing, and construction of new wells. The figure (map graphic) divides the country into regions with similar ground water characteristics. Individual well locations are generally not portrayed because of the small map scale of the product.

This Ecuador appraisal supports the U.S. Army Corps of Engineers Mobile District's water resources assessment program and, in turn, directly supports the U.S. Southern Command's humanitarian civic assistance water development program. Information provided is the most recent available from published sources in the United States and from published and unpublished sources in Ecuador through January 1997. Principal authors of this appraisal are Paul E. Reed and Lisa M. Scott.

Request for Water Resources Areal Appraisal or other water resource information should be addressed to the U.S. Army Topographic Engineering Center, Operations Division, 7701 Telegraph Road, Alexandria, Virginia 22315-3864.

Contents

Tables

Figures

List of Place Names

Place Name	Geographic Coordinates
Amazon drainage basin	0200S07830W
Andes Mountains	0200S06700W
Cerros de Colonche (mountains)	0200S08020W
Coastal plains (physiographic region)	0100S08000W
Costa (hydrogeologic region)	0100S08000W
Eastern lowlands (physiographic region)	0100S07700W
El Oro (province)	0330S07950W
Esmeraldas (province)	0050N07915W
Galapagos Islands	0000 09030W
Isla Puna	0250S08008W
Loja (province)	0410S07930W
Manabi (province)	0040S08050W
Oriente (hydrogeologic region)	0200S07700W
Rio Babahoyo	0210S07952W
Rio Daule	0210S07952W
Rio Guayas basin	0236S07954W
Rio Guayllabamba	0028N07925W
Rio Mira	0136N07901W
Rio Mira basin	0136N07931W
Rio Pastaza	0236S07638W
Rio Paute	0243S07815W
Sierra (hydrogeologic region)	0200S07830W

Note:
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) and Western (W) Hemisphere. For example:

Amazon drainage basin 0200S07830W

Geographic coordinates for the Amazon drainage basin that are given as 0200S07830W equal 2? 0' N, 78? 30' W and can be written as a latitude of 2 degrees and 0 minutes south and as a longitude of 78 degrees and 30 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

Water Resources Areal Appraisal
Ecuador

1. Introduction

Ecuador, with a 1990 population of 9,577,568 (about 55 percent urban and 45 percent rural) relies on surface and ground water sources for domestic water supplies. Heavy amounts of precipitation over most of Ecuador's land surface provide high amounts of surface runoff and groundwater recharge. This is the cause for the country's overall high specific runoff value of greater than 160 centimeters, a figure several times higher than the world average of 30 centimeters per year. Of the total water used nationally per year, 97 percent is for agriculture and irrigation and only about 3 percent is for domestic and industrial purposes. About 61 percent of the total population has access to potable water supplies. About 78 percent of the urban populations in comparison to about 39 percent of the rural populations have some type of potable water service. Of the urban system sources, about 65 percent is from surface water, about 33 percent is from ground water, and about 2 percent is from a mixture of surface and ground water. Of the rural system sources, the scenario is almost inversely proportional: about 64 percent is from ground water, about 34 percent is from surface water, and about 2 percent is from a mixture of surface and ground water.

Although fresh surface water is plentiful in most parts of Ecuador, the sources are generally not readily potable. Ecuador faces the typical water pollution problems that plague developing countries worldwide. Biological and chemical contaminations of surface water are serious problems that are increasing with population growth and with land use demands. Water and sewage purification systems are inadequate and overburdened.

Fresh ground water is generally available in most of Ecuador, but is unevenly distributed. Ground water resources are unevenly exploited. The principal use of ground water is for domestic purposes. Shallow wells are possibly biologically or chemically contaminated, especially near populated or agricultural areas. Access is difficult in most of Ecuador because of rugged terrain, dense vegetation, marshy areas, and lack of roads.

2. Surface Water Resources

Streams are the major surface water sources in most of Ecuador. Reservoirs, lakes, swamps, and canals are also important sources but are limited to certain areas. The highest concentrations of biological contamination in surface water occur near populated areas. Chemical contamination of surface water occurs primarily near manufacturing zones; in and near large cities; and in areas of commercial agriculture, mining districts, and petroleum operations. See table A-1 and figure A-1 for further details.

Fresh water is perennially available in very large to enormous quantities in the eastern lowlands, in the coastal plains in the northwest, in the interfluvial zone between the Rio Daule and the Rio Babahoyo, and from individually delineated streams. Large streams are the predominant surface water sources. Some other sources in these regions are reservoirs, natural lakes, and lowland swamps. These fresh water supplies are generally not readily potable. They require treatment due to prevalent biological contamination in most areas and due to chemical contamination from contaminated overland runoff in urban areas. Other causes for chemical contamination are:

(1) the dumping of industrial waste into the waterways near manufacturing zones;

(2) the leaching of residual pesticides in large-scale commercial farming areas, and

(3) the hydrocarbon pollution from leaks and spills associated with the extraction, processing, and delivery of petroleum.

Fresh water is seasonally available in large to enormous quantities from most of the intermontane areas of the Andes Mountains and from parts of the coastal plains south of the equator. Large streams are the predominant surface water sources. Additional sources are irrigation canals, highland lakes, and reservoirs. The occurrence and duration of seasonal runoff vary according to orographic effects and precipitation patterns. These fresh water supplies are generally not readily potable. They require treatment due to prevalent biological contamination in most areas and due to chemical contamination from contaminated overland runoff in urban areas. Industrial waste dumped into the waterways near mining operations is also a cause for chemical contamination of fresh water supplies.

Fresh to brackish water is available in small to large quantities primarily from intermittent streams from January through April. This hydrologic pattern typifies arid areas along the coastal plains west and north of the Cerros de Colonche range, on most of Isla Puna, and in parts of the southwest near the border with Peru. The fresh water supplies are generally not readily potable and require treatment due to prevalent biological contamination in populated areas and due to chemical contamination from contaminated overland runoff in urban areas. Hydrocarbon pollution from leaks and spills associated with extraction and processing of petroleum also causes chemical contamination.

Brackish to saline water is available in large to enormous quantities in coastal estuaries. On the Galapagos Islands, it is available in small to large quantities in ponds and depressions. In the estuaries, quality ranges from brackish during high flow to saline during low flow, when the extension of tidal influences causes total dissolved solids concentrations to rise farther inland. Biological contamination is high in the estuaries and in the stagnant ponds and depressions of the Galapagos Islands. Chemical contamination occurs primarily from hydrocarbon pollution caused by leaks and spills associated with petroleum delivery.

The best potential access to water points is near populated areas, near agriculturally developed areas, and along major transportation routes, such as all-weather roads and navigable rivers. The most difficult type of access is in areas with lowland swamps and dense vegetation in the coastal plains and eastern lowlands, and in the steep terrain of the Andes Mountains. The best potential for development of water points is along canal levees, streams, lakes, and reservoirs with stable banks.

3. Ground Water Resources

Fresh ground water is generally available in most of Ecuador, but it is unevenly distributed. Ecuador can be divided into four major hydrogeologic regions—the Costa (coastal plain), the Sierra (Andes Mountains), the Oriente (Amazon basin), and the Galapagos Islands.[1, 2] Each region has distinctive water characteristics and availability. See table A-2 and figure A-2 for further details.

The Costa region covers about 26 percent of Ecuador. Meager to large quantities of fresh to brackish water are available from alluvial aquifers. These aquifers are locally to regionally extensive with low to high permeability. Because of limited recharge due to lack of rainfall, the availability of fresh water is seasonal in the southwestern part of this region.

The Sierra region covers about 34 percent of the country. Meager to moderate quantities of fresh water are available from local and discontinuous aquifers found in unconsolidated, consolidated, and fractured rocks of the Andes Mountains. Because of limited recharge due to lack of rainfall, the availability of fresh water is seasonal in the higher elevations of this region.

The Oriente region covers about 38 percent of the country. Meager to large quantities of fresh water are available from locally to regionally extensive aquifers in permeable to semipermeable sedimentary rocks and volcanics.

The Galapagos Islands region comprises about 2 percent of the country. Small quantities of fresh water are available from isolated fracture zones in volcanic deposits in the upper elevations of the larger islands; however, saltwater intrusion is a concern.

In 1973 Ecuador had 2,915 hand-dug wells with an average depth of 28 meters and an average yield of 13.2 liters per minute; 154 drilled wells with an average depth of 96 meters and an average yield of 240 liters per minute.[3] Ground water resources are primarily being exploited in the Rio Guayas basin of the Costa region and in the intermontane basins of the Sierra region. Wells in the El Oro and Loja provinces are generally shallow (15 to 20 meters). However, persistent droughts from 1994 to 1997 caused these wells to become dry. Water is available in deep aquifers, but lack of equipment and funding leave these aquifers unexploited.[4] The amount of ground water exploitation varies from extensive near cities to limited in the mountains and small villages. In the Oriente and in the Galapagos Islands, exploitation of ground water resources is limited.

The principal use of ground water is for domestic purposes. Shallow wells are possibly biologically or chemically contaminated, especially near populated or agricultural areas. In the Oriente region, ground water is possibly contaminated by oil production seepage. In the Sierra and Costa regions, it may be contaminated by leakage from the pipeline that crosses the Andes Mountains and extends to the Pacific Ocean. In the Esmeraldas and Manabi provinces, iron contamination in the wells is a major concern.[5] Access is difficult in most of Ecuador because of rugged terrain, dense vegetation, marshy areas, and lack of roads.[6, 7]

The Costa region includes the Isla Puna and most of the drainage basins that empty into the Pacific Ocean. Small to large quantities of fresh ground water are available from regionally extensive alluvial aquifers with high permeability in the Rio Guayas and Rio Mira basins. In the Rio Guayas basin, exploitation of ground water resources is high. Small to large quantities of brackish water are available in the mangrove areas along the coast. Small to moderate quantities of fresh water are available in unconsolidated and consolidated clastic sediments in the western part of this region. These aquifers are local and discontinuous with low to medium permeability and are locally brackish. Very small to small quantities of fresh water are available from isolated fracture zones in sedimentary, metamorphic, and volcanic deposits with very low to medium permeability.[8]

The Sierra region encompasses the Andes Mountains. Springs are common in this region. Small to moderate quantities of fresh water are available from alluvium, unconsolidated and consolidated sandstones, and conglomerates in the intermontane valleys of the upper Rio Pastaza, upper Rio Guayllabamba, and upper Rio Paute. Very small to small quantities of fresh water are generally available from isolated fracture zones in volcanic deposits, limestones, mudstones, igneous rocks, and metamorphic rocks. These aquifers are local and discontinuous with very low to medium permeability. Localized thermal springs can be found in the active volcanic region, especially near the border with Colombia. Exploitation of ground water resources varies from very little in the mountains to moderate in the river valleys.[9]

The Oriente region encompasses the part of the Amazon drainage basin that is in Ecuador. Fresh ground water is generally available within this region. Small to large quantities of fresh water are generally plentiful in the alluvial aquifers with high permeability associated with the deposits nearest to the rivers of this region. Moderate quantities of fresh water are generally plentiful in the plains between the rivers and in the upper headwaters of the rivers. These local and discontinuous aquifers are composed of unconsolidated and consolidated sandstones and conglomerate deposits and have low to medium permeability. Meager to small quantities of fresh water are generally available from isolated fracture zones with very low to medium permeability in volcanic deposits, limestones, mudstones, igneous rocks, and metamorphic rocks in the western part of the region. Very small to small quantities of fresh water are locally plentiful from lutites, sandstones, limestones, slates, pyroclastic sediments, and quartzites in the higher elevation along the western border. Very few wells have been drilled in the Oriente region because of abundant surface water supplies.[10]

In the Galapagos Islands, small quantities of fresh water are available from isolated fracture zones in volcanic deposits at higher elevations. Small to large quantities of brackish water are available along the coast. Salt water intrusion is a major concern throughout all of these islands.[11]

Endnotes

[1]Ministerio de Recursos Naturales y Energeticos, *Mapa Hidrogeologico Nacional de la Republica del Ecuador*, Map, Scale 1:1,000,000, Quito, 1983.

[2]*The Economist*, "Ecuador, Clean-up time," Vol. 329, No. 7838, London, England, 20-26 November 1993, p. 50.

[3]Fritz van der Leeden, *Water Resources of the World*, Port Washington, New York: Water Information Center, Inc., 1975, p. 402.

[4]Per conversation with Dr. Eugenio Bayancela, Proyecto PROMUSTA-CARE Ecuador, and Ing. Hid. Homero Castanier, FASBASE, Quito, January 1997.

[5]Per conversation with Dr. Eugenio Bayancela and Ing. Hid. Homero Castanier, January 1997.

[6]Library of Congress, Science and Technology Division, *Draft Environmental Report on Ecuador*, Washington, DC, September 1979, pp. 32-33.

[7]Ministerio de Recursos Naturales y Energeticos, pp. 5-7.

[8]Ministerio de Recursos Naturales y Energeticos, pp. 5-7.

[9]Ministerio de Recursos Naturales y Energeticos, pp. 5-7.

[10]Ministerio de Recursos Naturales y Energeticos, pp. 5-7.

[11]Ministerio de Recursos Naturales y Energeticos, pp. 5-7.

Table A-1. Surface Water Resources

Map Unit (See Fig. A-1)	Sources	Quantity[1]	Quality[2]	Remarks
1 Fresh water perennially plentiful	Perennial lakes, reservoirs, and streams generally <16 km apart. Marshes and swamps are scattered throughout the eastern lowlands (0100S07700W)[3], and they are concentrated in the interfluvial basin north of the Rio Daule and the Rio Babahoyo confluence (0210S07952W).	Very large to enormous quantities are available year-round. Annual minimum discharges from selected stream gaging stations are given below, followed by the year of record: **1** Rio Teaone (Tiaone) above Rio Esmeraldas confluence (0056N07941W), 44,040 L/min, 1994; **3** Rio Mira at Lita (0050N07828W), 1,843,415 L/min, 1972; **4** Rio Apaqui below Rio Minas confluence (0032N07747W), 42,060 L/min, 1994; **5** Rio Guayllabamba near Rio Cubi confluence (0008N07827W), 1,783,950 L/min, 1972; **6** Rio Guachala above Rio Granobles confluence (000IN07809W), 91,500 L/min, 1994; **7** Rio San Pedro near Machachi (0028S07833W), 67,680 L/min, 1994; **8** Rio Toachi near Las Pampas (0026S07857W), 305,400 L/min, 1994; **9** Rio Daule at Pichincha (0101S07949W), 327,058 L/min, 1972; **10** Rio Daule at La Capilla (0142S08000W), 2,126,280 L/min, 1994; **11** Rio Quevedo near Quevedo (0101S07928W), 530,460 L/min, 1994; **12** Rio Vinces at Vinces (0133S07944W), 170,000 L/min (approximate minimum discharge during 10-year period of record ending in 1972); **13** Rio Zapotal above Rio Lechugal confluence (0123S07921W), 505,800 L/min, 1994;	Sources are fresh with TDS generally <200 mg/L, but treatment for biological and chemical pollutants is required to attain potability. Biological contamination occurs in water bodies throughout most of the country, except in headwater streams and highland lakes in the high mountain elevations. Biological contamination increases in the vicinities of populated areas, where solid wastes and sewage pollute the waterways and result in concentrations of pathogenic microorganisms. Chemical contamination from industrial waste is prevalent in waterways near manufacturing zones in Ambato (0115S07837W), Cuenca (0253S07859), Esmeraldas (0059N07942W), and Latacunga (0056S07837W). At these locations, heavy metals and phenolic substances are at alarming levels. Other sources of chemical contamination are: (1) the residual pesticides used in the large-scale commercial farming areas in the watershed of the Rio Esmeraldas (0034N07928W); (2) the hydrocarbon pollution caused by leaks and spills associated with petroleum refining and its delivery along the lower Rio Esmeraldas; and (3) the hydrocarbon pollution associated with extraction and delivery of petroleum in the provinces of Napo (0025S07655W) and Sucumbios (0020N07725W). Stream gaging stations that monitor water quality are given below with sampling date and resulting values derived from sampled parameters. When and where available, SSC are given with corresponding stream discharge measurements:	Access to and development of water supply points are influenced by topography and ground cover. Access by land is difficult throughout the eastern lowlands and in most of the northwest coastal areas because of swamps, dense tropical forests, and unstable banks. Navigable waterways could provide access via the Rio Napo, the Rio Pastaza, the Rio Macuma, the Rio Namagoza, and the Rio Zamora in the eastern lowlands and via the Rio Esmeraldas and the Rio Santiago in the northwest coastal areas. Access by land is also restricted in the interfluvial lowlands north of the Rio Daule and Rio Babahoyo confluence, although roads on irrigation canal levees provide limited access in these areas. In the interfluvial lowlands, navigable waterways could provide access via the Rio Babahoyo and the Rio Vinces. Access by land is generally best near urban areas, where numerous all-weather roads exist and permanent bridges cross streams. In the rugged terrain of the Andes Mountains, where bridges span deep gorges and roads parallel steep banks, access and development are difficult due to long vertical distances separating bridges or roads from surface water bodies.

Table A-1. Surface Water Resources (Continued)

Map Unit (See Fig. A-1)	Sources	Quantity[1]	Quality[2]	Remarks
1 Fresh water perennially plentiful (continued)		**14** Rio Chimbo below Rio Pangor confluence (0156S07900W), 183,000 L/min, 1994; **15** Rio Chimbo near Bucay (0212S07908W), 857,460 L/min, 1994; **16** Rio Canar near Rio Raura confluence (0233S07907W), 249,753 L/min, 1972; **17** Rio Canar at Puerto Inca (0233S07933W), 234,120 L/min, 1994; **18** Rio Jubones below Rio San Francisco (0318S07930W), 300,540 L/min, 1994; **19** Rio Jubones above Pasaje (0320S07949W), 1,046,584 L/min, 1972; **20** Rio Tumbez near Marcabeli (0349S07956W), 304,920 L/min, 1994; **21** Rio Tomebamba near Monay (0253S07858W), 123,540 L/min, 1994; **22** Rio Paute near Rio Dudas confluence (0241S07835W), 1,379,588 L/min, 1972; **23** Rio Cebadas near Cebadas (0153S07838W), 338,520 L/min, 1994; **25** Rio Cutuchi above Rio Yanayacu confluence (0104S07836W), 111,060 L/min, 1994; and **26** Rio Misahualli near Cotundo (0051S07747W), 125,760 L/min, 1994.	**2** Rio Esmeraldas below Rio Sade confluence (0031N07925W), 15 Apr 94, TDS 73 mg/L, pH 7.2, temperature 24 ?C, SSC 375 mg/L at 119,246,400 L/min; **5** Rio Guayllabamba near Rio Cubi confluence, 13 Mar 94, SSC 575 mg/L at 5,183,820 L/min; **10** Rio Daule at La Capilla, 25 Jan 94, TDS 79 mg/L, pH 7.2, temperature 27.4 ?C, SSC 30 mg/L at 6,140,140 L/min; 10 Nov 94, TDS 79 mg/L, pH 7.1, temperature 27 ?C, SSC 132 mg/L at 2,970,960 L/min; **11** Rio Quevedo near Quevedo, 23 Feb 94, TDS 95 mg/L, pH7.5, temperature 27.2 ?C, SSC 155 mg/L at 21,225,840 L/min; **12** Rio Vinces at Vinces, 26 Jan 94, TDS 57 mg/L, pH 7.3, temperature 15.8 ?C, SSC 100 mg/L at 17,368,560 L/min; **14** Rio Chimbo below Rio Pangor confluence, 2 Nov 94, TDS 94 mg/L, pH 7.5, temperature 18 ?C, SSC 131 mg/L at 338,820 L/min; **15** Rio Chimbo near Bucay, 20 Jan 94, TDS 94 mg/L, pH 7.6, temperature 22.8 ?C, SSC 958 mg/L 2,407,500 L/min; 1 Nov 94, TDS 107 mg/L, pH 7.5, temperature 21.7 ?C, SSC 128 mg/L at 670,080 L/min; **16** Rio Canar near Rio Raura confluence, 14 Apr 94, TDS 144 mg/L, pH 7.2, temperature 16.5 ?C, SSC 682 mg/L at 5,695,440 L/min; **17** Rio Canar at Puerto Inca, 13 Jan 94, TDS 96 mg/L, pH 7.4, temperature 23 ?C, SSC 678 mg/L 2,322,360 L/min; 13 Apr 94, TDS 109 mg/L, pH 7.4, SSC 2,603 mg/L at 7,926,720 L/min;	

Table A-1. Surface Water Resources (Continued)

Map Unit (See Fig. A-1	Sources	Quantity[1]	Quality[2]	Remarks
1 Fresh water perennially plentiful (continued)			**20** Rio Tumbez near Marcabeli, 16 Feb 94, SSC 469 mg/L at 9,376,440 L/min; **20** Rio Tumbez near Marcabeli, 16 Feb 94, SSC 469 mg/L at 9,376,440 L/min; **23** Rio Cebadas near Cebadas, 27 0ct 94, TDS 68 mg/L, pH 7.2, temperature 13.4 ?C, SSC 286 mg/l at 712,200 L/min; **24** Rio Pastaza at Banos (0123S07825W),16 Apr 94, TDS 11 mg/L, pH 7.3, temperature 17.4 ?C; 22 0ct 94, TDS 95 mg/L, pH 7.7, temperature 14.8 ?C, SSC 253 mg/L 2,677,320 L/min; **25** Rio Cutuchi above Rio Yanayacu confluence, 25 Mar 92, SSC 6,981 mg/L at 479,160 L/min; 14 Apr 94, TDS 142 mg/L, pH 7.2, temperature 16.2 ?C; and **26** Rio Misahualli near Cotundo, 20 Mar 94, TDS 94 mg/L, pH 7.5, temperature 21.3 ?C, SSC 936 mg/L at 564,420 L/min.	
2 Fresh water seasonally plentiful	Perennial and intermittent lakes, reservoirs, canals, and streams generally <16 km apart.	Large to enormous quantities are available seasonally as follows: January through May in most interior areas of the coastal plains (0100S08000W), including the western slopes of the Cordillera Occidental (0130S07855W); October through June along intermontane slopes and valleys of the Andes Mountains (0200S07840W); and March through June and September through November along the eastern slopes of the Cordillera Oriental (0130S07820W). Small to large quantities are available during the various low water seasons, when runoff into perennial sources diminishes drastically and intermittent sources dry out for extended intervals.	Sources are generally fresh, but treatment for biological and chemical pollutants is required to attain potability. Biological contamination occurs in water bodies throughout most of the country, except in headwater streams and highland lakes in the high mountain elevations. Biological contamination increases in the vicinities of populated areas, where solid wastes and sewage pollute the waterways and result in concentrations of pathogenic microorganisms. Chemical contamination from industrial waste is prevalent in waterways near manufacturing zones in the cities of Quito and Riobamba, where heavy metals and phenolic substances are at alarming levels. Other sources of chemical contamination are the high levels of residual mercury associated with the gold amalgamation process in the provinces of Azuay	Access to and development of intake sites are influenced by topography and ground cover. Access is restricted along the eastern slopes of the Cordillera Oriental by dense vegetation; in the intermontane areas of the Andes Mountains by steep slopes and banks; and along the coastal lowlands in the vicinity of the Golfo de Guayaquil (0300S08030W) by soft soils and shifting channels.

Table A-1. Surface Water Resources (Continued)

Map Unit (See Fig. A-1	Sources	Quantity[1]	Quality[2]	Remarks
2 Fresh water seasonally plentiful (continued)			(0305S07920W), El Oro (0330S07950W), and Zamora-Chinchipe (0415S07850W).	
3 Fresh water scarce or lacking	Intermittent streams generally >16 km apart.	Small to large quantities are available January through April primarily from small, intermittent streams. Flows occur generally in short intervals responding to rainfall. Streams are generally dry during the rest of the year.	Runoff generally becomes brackish during sustained flows, when TDS concentrations tend to increase. Stream flow is generally turbid and high in sediment. Biological contamination occurs near populated areas. Chemical contamination occurs as hydrocarbon pollution from spills associated with the extraction and refining of petroleum in the province of Guayas (0200S08000W) on the Peninsula de Santa Elena (0215S08050W).	Access to streams is feasible in coastal plains and hills, but development of intake sites is impractical. Occasional flash floods during the wet season quickly infiltrate unconsolidated streambeds, making capture of water difficult. During sustained flows, frequent maintenance of intake equipment would be required, as high sediment loads cause accelerated silting and wear of intake equipment.
4 Fresh water scarce or lacking	Coastal estuaries and swamps on the mainland and Isla Puna (0250S08008W); ephemeral streams, small ponds, and volcanic rock depressions on the Galapagos Islands (0030S09030W).	Small to enormous quantities are available. Small to large quantities are generally available on the Galapagos Islands. Large to enormous quantities are available on the mainland and on Isla Puna.	Water is generally brackish to saline. During low stream flow into coastal estuaries, tidal currents overtake weaker riverine currents, thus creating backwater conditions. This causes saline concentration of water to migrate upstream into adjacent lowlands. Estuarine flow is generally turbid and high in sediment. Biological contamination is high in estuarine zones and in stagnant ponds and depressions of the Galapagos Islands. Chemical contamination occurs as hydrocarbon pollution from spills and leaks associated with the delivery of petroleum in the delta of the Rio Guayas (0222S07950W).	Access by land is not feasible in estuarine zones because of water-logged surface conditions. In the northwest coastal areas, navigable waterways could provide access via the Rio Santiago, and south of the Rio Daule and Rio Babahoyo confluence via the Rio Guayas. Development of intake points is impractical along estuaries and in coastal swamps because of unstable banks. Portable reverse-osmosis desalination equipment would be necessary.

[1]Quantitative Terms:

Enormous	= >400,000 L/min (100,000 gal/min)
Very large	= >40,000 to 400,000 L/min (10,000 to 100,000 gal/min)
Large	= >4,000 to 40,000 L/min (1,000 to 10,000 gal/min)
Moderate	= >400 to 4,000 L/min (100 to 1,000 gal/min)
Small	= >40 to 400 L/min (10 to 100 gal/min)
Very small	= >4 to 40 L/min (1 to 10 gal/min)
Meager	= $\leq$4 L/min (1 gal/min)

Table A-1. Surface Water Resources (Continued)

[2]Qualitative Terms:

Fresh water	= 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

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

eastern lowlands (0100S07700W)

Geographic coordinates for the eastern lowlands that are given as 0100S07700W equal 1? 0' South 77? 0' can be written as a latitude of 1 degree and 0 minutes south and a longitude of 77 degrees and 0 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country scale map. Coordinates are approximate. Geographic coordinates for rivers are generally at the river mouth.

Note:

gal/min	= gallons per minute
L/min	= liters per minute
mg/L	= milligrams per liter
pH	= hydrogen-ion concentration
SSC	= suspended sediment concentrations
TDS	= total dissolved solids

Table A-2. Ground Water Resources

Map Unit (See Fig. A-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful	Aquifers are associated with unconsolidated clastic rocks of Quaternary age. Alluvium in the Oriente region (Amazon basin, 0200S07700W)[3] consists of highly permeable gravels and sands with lenses of silt and clay. The aquifers in the Costa region (0100S08000W) consist of sands, sandstones, clays, and conglomerates. They are regional but limited in some areas. These aquifers are unconfined and confined with medium to high permeability. Undifferentiated Quaternary sediments in the Costa and Oriente regions consist of sands, sandstone, clays, and conglomerates. This formation is in the provinces of Esmeraldas (0050N07915W), Manabi (0040S08050W), Guayas (0200S08000W), eastern El Oro (0330S07950W), eastern Azuay, (0305S07920W), eastern Canar (0230S07900W), Los Rios (0125S07935W), Cotopaxi (0050S07850W), and Napo (0025S07655W). The San Tadeo Formation in the Costa region of the provinces of Esmeraldas, Manabi, Los Rios and Cotopaxi consists of lahars, fanglomerates, and mudflows. The Pichilingue Formation in the Costa region of the provinces of southwestern Pichincha (0010S07840W), Los Rios, and northern Guayas consists of terrace and river sediments.	Small to large quantities are available. In the Rio Guayas basin (0236S07954W), yields range from 120 to 7,920 L/min. In the Undifferentiated Quaternary sediments, well yields range from 60 to 7,920 L/min. In the San Tadeo Formation, well yields range from 120 to 4,500 L/min. In the Pichilingue Formation, a well had a reported yield of 1,500 L/min. In the Costa region north of Santo Domingo de los Colorados (0015S07909W), average well yield is 360 L/min. In the Costa region south of Santo Domingo de los Colorados and north of Balao (0255S07949W), average well yield is 21,00 L/min. In the Costa region south of Balao, average well yield is 1,200 L/min.	Water is generally fresh in the Costa and Oriente regions. In the Rio Guayas basin, TDS average 364 mg/L. Shallow aquifers may be biologically or chemically contaminated, especially near populated or agricultural areas. TDS values in the undifferentiated Quaternary sediments typically range between 64 and 890 mg/L. TDS values in the San Tadeo Formation range between 53 and 320 mg/L. TDS values in the Pichilingue Formation range between 50 and 680 mg/L. In the Costa region north of Santo Domingo de los Colorados, average TDS value is 350 mg/L. In the Costa region south of Santo Domingo de los Colorados and north of Balao, average TDS value is 400 mg/L. In the Costa region south of Balao, average TDS value is 600 mg/L.	Access is difficult in the Oriente region because of dense vegetation, marshy ground, and lack of roads. Access in the Rio Guayas basin is not difficult, especially near roads, except in marshy areas. Development is possible via shallow hand-dug wells. Ground water is probably at depths of <30 m. In the Costa region north of Santo Domingo de los Colorados, average well depth is 20 m, and average depth to water is 10 m. In the Costa region south of Santo Domingo de los Colorados and north of Rio Balao, average well depth is 55 m and average depth to water is 8 m. In the Costa region south of Balao, average well depth is 60 m, and average depth to water is 3 m.	Ground water is principally used for domestic purposes, except in the Rio Guayas basin where it is also used for agricultural activities. Very few wells have been drilled in the Oriente region due to poor access and low population. Recharge is from rainfall and infiltration from rivers. These areas are suitable for most irrigation wells and municipal water supply wells.
2 Fresh water generally plentiful	Tertiary-Quaternary aquifers in the Oriente region consist of unconsolidated and consolidated clastic sediments, principally sandstone and	Moderate quantities are available with large quantities locally available. Springs with yields of 60 L/min are near Santa Clare (0118S07753W) in the	Water is generally fresh. Wells near Puyo (0128S07759W) in the province of Pastaza have TDS values ranging from 75 to 450 mg/L. A spring in the Plio-Cuaternario	Access is difficult because of dense vegetation and lack of roads. Some aquifers are difficult to locate due to their localized extent.	Ground water is principally used for domestic purposes. Aquifer recharge is from rainfall and infiltration

Table A-2. Ground Water Resources (Continued)

Map Unit (See Fig. A-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water generally plentiful (continued)	conglomerates with lesser quantities of tuffs, clays, and silts. Aquifers have low to medium permeability. Some aquifers are locally discontinuous. The Plio-Cuaternario Formation in the province of Morona-Santiago (0230S07745W) consists of clays, sandstones, breccias, and conglomerates.	province of Pastaza (0155S07700W) and near Macas (0219S07807W) in the province of Morona-Santiago.	Formation had a TDS value of 45 mg/L. Shallow aquifers may be biologically or chemically contaminated, especially near populated or agricultural areas. In the Lago Agrio area (0006N07652W) in the province of Sucumbios (000 07630W), water may be contaminated from oil production.		from rivers. Very few wells have been drilled in the Oriente region due to poor access and low population. These areas are generally suitable for most irrigation wells and municipal water supply wells.
3 Fresh water locally plentiful	Tertiary-Quaternary aquifers generally consist of unconsolidated and consolidated clastic sediments that are principally composed of sandstones and conglomerates with lesser quantities of tuffs, clays, silts, mudstones, and limestones. These aquifers are local and discontinuous with low to medium permeability. Springs are common in the Sierra region (0200S07830W). The Tablazos Formation in the Costa region of the province of Manabi, is >150 m thick and consists of sandstones, conglomerates, and calcareous sediments. Wells completed in the Tablazos aquifer are artesian. The Zapotal Formation in the Daular area (0219S08006W) in the province of Guayas has a thickness of 1,000 m and consists of sandstones, conglomerates, and clays. The Progreso Formation in the San Juan area (0229S08020W) and in the Progreso area (0224S08022W) in the province of Guayas ranges in thickness from 400 to 1,300 m. It consists of clays, sandstones, conglomerates, and lutites. The Undifferentiated	Small to moderate quantities are available. In the Costa region near the mouth of the Rio Colimes (0132S08000W) in the province of Guayas, a well yielded 1,020 L/min. Well yields near Rio Verde (0221S08042W) in the province of Guayas range from 379 to 757 L/min. A well near Pedro Carbo (0150S08014W) in the province of Guayas has yields of 780 L/min. In the San Juan and Progreso area, wells have yields of 284 to 379 L/min. In the Daular area, wells have yields of 379 L/min. Springs in the Sierra region have yields ranging from 60 to 900 L/min. In the Progreso and Complejo Olistostromico Formations, one well in each formation has yields of 60 L/min. In the Cangahua Formation, well yields range from 60 to 900 L/min. In the Tablazos Formation, well yields range from 60 to 840 L/min. In the area around San Lorenzo (0104S08054) in the province of Manabi, average well yield is 60 L/min. In the	Water is generally fresh in the Sierra region and fresh to locally brackish in the Costa region. The aquifers in the Costa region have average TDS values of 892 mg/L, but TDS can be as high as 3,800 mg/L near the coast. In the Sierra region, springs and wells have an average TDS value of 863 mg/L. Shallow aquifers may be biologically or chemically contaminated, especially near populated or agricultural areas. Wells near Rio Verde have TDS values of 256 to 1,730 mg/L, NaCl of 250 to 915 mg/L, Cl of 11 to 41 mg/L, and SO_4 of 104 to 286 mg/L. TDS values in the Progreso Formation range from 594 to 5,658 mg/L. TDS values in the Zapotal Formation range from 340 to 782 mg/L. TDS values in the Onzole Superior Formation range from 1,350 to 2,250 mg/L. TDS values in the Viche Formation range from 540 to 2,100 mg/L. TDS values in the Angostura Formation range from 450 to 2,635 mg/L. TDS values in the Borbon Formation range from 98 to 1,200 mg/L. TDS values in the San Mateo Formation range	Access away from roads in the Sierra and Costa regions is difficult because of dense vegetation and rugged terrain. Development is possible via drilled wells and hand-dug shallow wells. Some of the aquifers are difficult to locate due to their localized extent. Well depths in the Rio Verde area range from 18 to 56 m. Locally, drawdown could be as much as 60 m. In areas surrounding San Juan and Progreso, well depths range from 9 to 49 m. In the Daular area, well depths range from 3 to 14 m. In the area around San Lorenzo, average well depth is 30 m, and average depth to water is 10 m. In the province of Azuay, average well depth is 30 m, and average depth to water is 15 m. In the province of Pichincha, average well depth is 100 m, and average depth to water is 40 m. On the Peninsula de Santa Elena, average well depth is 50 m, and average depth to water is 10 m. In the Cangahua and Undifferentiated Quaternary Formations in the	Ground water is principally used for domestic purposes. Recharge is from rainfall. These areas are suitable for tactical and hand pump water wells. Some areas may be suitable for irrigation wells and municipal water supply wells. Higher yields may be found along fractures.

Table A-2. Ground Water Resources (Continued)

Map Unit (See Fig. A-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful	Quaternary Formation sandstone and lenses of conglomerate. The Viche Formation in the provinces of Esmeraldas and Manabi consists of clayey silts with calcareous lenses, conglomerates, and sandstones. The Angostura Formation in the province of Manabi consists of sandstones, conglomerates, and calcareous sandstones. The Borbon Formation in the province of Manabi consists of sandstones, clays, conglomerates, and calcareous sandstones. The San Mateo Formation in the province of Manabi consists of sandstone, conglomerates, and clays. The Cangahua Formation in the provinces of Carchi (0045N07805W), Imbabura (0022N07825W), Pichincha, Cotopaxi, Tungurahua (0115S07830W), Bolivar (0135S07905W), and Chimborazo (0155S07845W) consists of volcanics. The Complejo Olistostromico Formation in the province of Guayas consists of allochthon rocks, sandstones, lutites, limestones, and cherts. The Tarqui Formation in the provinces of Loja, Zamora-Chinchipe, Chimborazo, Canar, and Azuay consists of tuffs and rhyolitic agglomerates in andesites. The Moraspamba Formation in the province of Azuay consists of intercalated lutites and sandstone with conglomerates.	province of Azuay, average well yield is 120 L/min. In the province of Pichincha, average well yield is 900 L/min. On the Peninsula de Santa Elena (0215S08050W) in the province of Guayas, average well yield is 180 L/min. In the Cangahua and Undifferentiated Quaternary Formations in the provinces of Cotopaxi and Tungurahua, average well yield is 600 L/min.	From 450 to 6,000 mg/L. TDS values in the Cangahua Formation range from 24 to 2,925 mg/L. In the Cangahua and Undifferentiated Quaternary Formations in the provinces of Cotopaxi and Tungurahua, average TDS value is 500 mg/L. TDS values in the Progreso and Tablazos Formations range from 3,500 to 3,800 mg/L. TDS values in the Complejo Olistostromico Formation range from 656 to 6,000 mg/L. TDS values in the Tarqui Formation range from 135 to 600 mg/L. TDS values in the Moraspamba Formation range from 320 to 420 mg/L. In the area around San Lorenzo, the average well TDS value is 3,000 mg/L. In the province of Azuay, the average well TDS value is 600 mg/L. In the province of Pichincha, the average well TDS value is 300 mg/L. On the Peninsula de Santa Elena, average well TDS value is 3,000 mg/L.	provinces of Cotopaxi and Tungurahua, average well depth is 70 m, and average depth to water is 25 m.	
4 Fresh water locally plentiful	Aquifers are very localized and restricted to fracture zones with very low to medium permeability.	Very small to small quantities are available. The springs in the Sierra region	Water is fresh to locally brackish. Most springs and wells are fresh. In the Costa region, TDS	Access is difficult because of rugged mountainous terrain and lack of roads.	Ground water is principally used for domestic and livestock

Table A-2. Ground Water Resources (Continued)

Map Unit (See Fig. A-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
4 Fresh water locally plentiful (continued)	These aquifers principally consist of deposits of recent volcanics, cata-clastic rocks, pyroclastic rocks, porphyry, diabase, quartzite, limestones, and sedimentary rocks. Present in higher elevations on larger islands of the Galapagos Islands (0000 09030W). Springs are common in the Sierra region. The Onzole Y Charapoto Formation in the province of Manabi consists of siltstones, lutites, sandstones, and conglomerates. The Cayo Formation in the province of Manabi and Guayas consists of clays, shales, breccias, and conglomerates. The Zapotillo Y Ciano Formation in the province of Loja (0410S07930W) consists of graywacke, black lutites, and conglomerates. The Celica Formation in the province of Loja consists of massive green andesites. The Macuchi Formation in the provinces of Chimborazo, Bolivar, Cotopaxi, and Canar consists of diabases and andesites with volcanic sediments. The Sicalpa Formation in the provinces of Canar and Chimborazo consists of agglomerates of pyroclastic-andesitic lavas. The Recent Volcanics Formation in the provinces of Canar, Tungurahua, Imbabura, Carchi, and Bolivar consists of lavas, andesitic tuffs, breccias, and ash. The Pisayambo Formation in the province of Tungurahua consists of lavas and pyroclastic sediments. The Grupo Limon Formation in the province	have average yields of 157 L/min. In the Cayo Formation, one well in the Manabi province has yields of 60 L/min. In the Zapotillo Y Ciano Formation, average well yield is 60 L/min.	range from 270 to 6,000 mg/L. Springs and wells in the Sierra region have average TDS values of 552 mg/L. TDS values in the Onzole Y Charapoto Formation range from 360 to 2,250 mg/L. Two wells in the Cayo Formation in the Manabi province had TDS values of 2,800 and 3,200 mg/L. TDS values of springs in the Zapotillo Y Ciano Formation range from 240 to 435 mg/L. TDS values of springs in the Celica Formation range from 5 to 380 mg/L. TDS values of springs in the Macuchi Formation range from 28 to 1,425 mg/L. TDS values of springs in the Sicalpa Formation range from 340 to 740 mg/L. TDS values of wells in the Recent Volcanics Formation range from 45 and 585 mg/L. TDS values of springs in the Recent Volcanics Formation range from 86 to 950 mg/L. One spring in the Pisayambo Formation had a TDS value of 20 mg/L. Springs and wells in the Grupo Limon Formation have TDS values ranging from 53 to 180 mg/L. Shallow aquifers may be biologically or chemically contaminated.	Fracture zones are generally more prevalent near the surface and less likely at depths of >60 m. Successful wells may depend on encountering fractures. In the Zapotillo Y Ciano Formation, average well depth is 25 m, and average depth to water is 10 m.	purposes. Recharge is from rainfall. Some areas, generally located along fractures <60 m deep, may be suitable for tactical and/or hand pump wells.

Table A-2. Ground Water Resources (Continued)

Map Unit (See Fig. A-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
4 Fresh water locally plentiful (continued)	of Morona-Santiago consists of clays, sandstones, lutites, slates, limestones, and quartzites.				
5 Fresh water scarce or lacking	Aquifers in the Sierra, Costa, and Oriente regions consist of intrusive and associated extrusive rocks composed of granites, granodiorite, rhyolite, and massive metamorphic rocks. These rocks have very poor hydrologic properties and are almost impermeable. A few of the aquifers in the Costa and Oriente regions consist of unconsolidated and consolidated sediments. Isolated springs exist along fracture zones. Springs in active volcanic areas are thermal. The Paute Group Formation in the province of Canar consists of andesites, phyllites, and schists.	Meager to small quantities are available. A spring near Palmira in the province of Chimborazo (0205S07843W) has an average yield of 360 L/min.	Water quality is generally fresh. In the Sierra region, TDS of springs generally range from 120 to 420 mg/L. Two springs in the Guamote area in the province of Chimborazo (0156S07843W) have TDS values of 1,125 and 1,425 mg/L. Thermal springs have temperatures ranging from 16 to 49 ?C. Two springs in the Paute Group Formation had TDS values of 125 and 270 mg/L.	Access is difficult because of rugged mountainous terrain. Fractured zones are generally more prevalent near the surface and less likely at depths of >60 m; therefore, the economic drilling depth is generally <60 m.	Ground water is principally used for domestic purposes. Recharge is from rainfall. Some areas are suitable for tactical and/or hand pump wells generally along fractures <60 m deep. Undesirable for future well exploration due to low-yield potential.
6 Fresh water scarce or lacking	In the Costa region, the aquifers are Quaternary sediments of unconsolidated clastic rocks, generally with high permeability. The aquifers tend to have brackish or saline water, and they are sometimes associated with mangroves. The Manglar Formation consists of mud clays and silts. The Undifferentiated Quaternary Formation consists of sands, sandstones, clays, and conglomerates. On the Galapagos Islands, the aquifers are local and discontinuous. They consist of basaltic lava and pyroclastic rocks with low to medium permeability which has been enhanced by fissures.	Small to large quantities of brackish or saline water are available. A well along the Estero Salado (0230S08004W) has yields of 300 L/min of brackish water. In the Undifferentiated Quaternary sediments, well yields range from 240 to 1,560 L/min. Along the Rio Chico (0048S08045W), average well yield is 90 L/min. Along the Rio Chone (0035S08004W), average well yield is 180 L/min.	Water quality is poor (brackish to saline). Saltwater intrusion is a serious problem on the Galapagos Islands and along the Pacific Coast. In the San Lorenzo area in the province of Esmeraldas (0117N07850W), TDS values range from 225 to 2,100 mg/L. TDS values in the Undifferentiated Quaternary Formation range from 240 to 7,600 mg/L. TDS values in the Manglar Formation range from 225 to 2,100 mg/L. Along the Rio Chico, average well TDS values are 1,000 mg/L. Along the Rio Chone, average well TDS values are 800 mg/L.	Mangrove areas along the coast make access very difficult. In the Costa region, depth to water is <30 m. On the Galapagos Islands, a thin fresh water lens exists near sea level, but over pumping will cause saltwater intrusion. Extreme caution should be exercised during drilling to prevent the penetration of the freshwater layer which lies above the saline water. Along the Rio Chone, average well depth is 40 m, and average depth to water is 7 m.	Ground water is principally used for domestic purposes. Recharge is from rainfall and in some coastal areas from infiltration from rivers. Saltwater encroaches from the ocean. Well exploration is not recommended in this area due to the potential of poor water quality. Unsuitable for tactical and hand pump wells.

Table A-2. Ground Water Resources (Continued)

[1] Quantitative Terms:

Enormous = >400,000 L/min (100,000 gal/min)
Very large = >40,000 to 400,000 L/min (10,000 to 100,000 gal/min)
Large = >4,000 to 40,000 L/min (1,000 to 10,000 gal/min)
Moderate = >400 to 4,000 L/min (100 to 1,000 gal/min)
Small = >40 to 400 L/min (10 to 100 gal/min)
Very small = >4 to 40 L/min (1 to 10 gal/min)
Meager = ?4 L/min (1 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 first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or We stern (W) Hemisphere. For example:

Amazon basin (0200S07700W)

Geographic coordinates for the Amazon basin that are given as 0200S07700W equal 2? 0' South 77? 0' West and can be written as a latitude of 2 degrees and 0 minutes south and a longitude of 77 degrees and 0 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country scale map. Coordinates are approximate.

Note:

Ca	= calcium
$CaCO_3$	= calcium carbonate
Cl^-	= chloride
gal/min	= gallons per minute
L/min	= liters per minute
mg/L	= milligrams per liter
NaCl	= sodium-chloride
SO_4	= sulfate
TDS	= total dissolved solids

Conversion Chart:

To Convert	Multiply By	To Obtain
liters per minute	0.264	gallons per minute
liters per minute	15.852	gallons per hour
liters per minute	380.517	gallons per day

Bibliography

Da Ros, Giuseppina. *La Contaminacion de Aguas en Ecuador*: *Una Aproximacion Economica*. Quito: Instituto de Investigaciones Economicas, 1995.

Delavaud, Anne Collin. *Atlas del Ecuador*. Quito: Instituto Geografico Militar, February 1982.

Instituto Ecuatoriano de Recursos Hidraulicos. *Plan Nacional de Riego–Zonas Agricolas del Ecuador*. Map, Scale 1:2,000,000, Quito, 1969.

Instituto Geografico Militar. *Republica del Ecuador–Mapa Fisico*. Map, Scale 1:4,000,000, Quito, 1988.

Instituto Nacional de Meteorologia e Hidrologia–Ministerio de Recursos Naturales y Turismo. *Anuario Hidrologico*. Vol. 9, Quito, 1971.

Leeden, Fritz van der. *Water Resources of the World*. Port Washington, New York: Water Information Center, Inc., 1975.

Library of Congress, Science and Technology Division. *Draft Environmental Report on Ecuador*. Washington, DC, September 1979.

Ministerio de Recursos Naturales y Energeticos. *Mapa Hidrogeologico Nacional de la Republica del Ecuador*. Map, Scale 1:1,000,000, Quito, 1983.

Pan American Health Organization. *Analisis del Sector de Agua Potable y Saneamiento en Ecuador*. Washington, DC, 1994.

Perez, Lic. I.G. *Atlas del Ecuador*. Edition 1, Quito: Ministerio de Relaciones Exteriores, 1995.

Teran, Francisco. *Geografia del Ecuador*. Edition 6, Quito: Ministerio de Education, 1963.

The Economist, “Ecuador, Clean-up time.” Vol. 329, No. 7838, London, England, 20-26 November 1993.

UNESCO, Hydrologic International Program. *Hydrogeological Map of South America*. Scale 1:5000,000, 1996.

Glossary

agglomerate	A rock composed of volcanic fragments of various sizes and degrees of angularity.
allochthon	A mass of rock that has been moved a long distance from its place of origin, commonly by a tectonic process.
alluvial	Pertaining to processes or materials associated with transportation or deposition by running water.
alluvial fan	An outspread, gently sloping mass of alluvium deposited by a stream, especially in an arid or semiarid region where a stream issues from a narrow canyon onto a plain or valley floor.
alluvium	Sediment deposited by flowing water, as in a riverbed, flood plain, or delta.
andesite	A fine- to medium-grained, hard, dense, brown to gray, volcanic igneous rock. Andesite is generally of moderate use for engineering applications.
aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
artesian	Describes ground water which is under sufficient pressure that it can rise above the aquifer containing it. Flowing artesian wells are produced when the pressure is sufficient to force the water above the land surface.
backwater	Water turned back in its course by an obstruction, an opposing current, or the flow of the tide.
basin	A low area toward which streams flow from adjacent hills. Ordinarily, a basin opens either toward the sea or toward a downstream outlet; but in an arid region without an outlet, a basin can be completely surrounded by higher land.
bicarbonate (HCO_3^-)	A negatively charged ion which is the dominant carbonate system species present in most waters having a pH value between 6.4 and 10.3. Excessive concentrations typically result in the formation of scale.
biological contamination	The presence in water of significant quantities of disease-producing organisms.
bog	An area of saturated, spongy ground, consisting primarily of mosses and acidic-decaying vegetation that may develop into peat.
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.

breccia	Gravel-size or larger angular rock fragments in a finer grained material. Breccia is usually a highly unpredictable rock for construction purposes, and it is normally avoided by the military engineer.
canal	A constructed open channel for transporting water from the source of supply to point of use.
cataclastic	Pertaining to the structure produced in a rock by the action of severe mechanical stress during dynamic metamorphism; characteristic features include the bending, breaking, and granulation of the minerals.
chert	A fine-grained sedimentary rock of varying colors usually found as lenses interbedded with limestone or shale. Chert usually has few construction uses.
chemical contamination	Pollution from industrial or synthetic wastes.
clastic	Consisting of fragments of pre-existing rocks.
clay	Geologists use the term to designate the finest sediment grains, a size smaller than silt, but disagreement exists as to the limit, which is arbitrarily set in most cases in a range centering on about 0.002 millimeter diameter.
coastal salt marsh	A tract of soft, wet, low-lying land that at times is flooded with sea water.
confined aquifer	An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than the aquifer itself.
confluence	The point where two streams meet.
conglomerate	Gravel-size or larger, consolidated, rounded to semirounded rock fragments in a finer grained material. Depending upon the degree of cementation, the drillability and ground water potential can vary significantly.
dam	A barrier constructed across a watercourse for one or more of the following purposes: to create a reservoir; to divert water into a conduit or channel; to create a head which can be used to generate power; and to improve river navigability. Dams may be fixed or movable. Dam types include gravity, arch, earth, rock-fill, or a combination of these terms.
delta	A usually triangular alluvial deposit at the mouth of a river. A similar deposit at the mouth of a tidal inlet, caused by tidal currents.
diabase	An intrusive rock consisting essentially of labradorite and pyroxene, and characterized by an ophitic texture.
discharge	Quantity of flow.

draft/drawing	The depth of a vessel's bottom below the water surface. Generally the minimum amount of water depth needed to allow for the safe movement of a vessel in a stream.
drawdown	(1) The magnitude of the change in surface elevation of a body of water as a result of the withdrawal of water. (2) The magnitude of the lowering of the water surface in a well and of the water table or piezometric surface adjacent to the well, resulting from the withdrawal of water from the well by pumping. (3) In a continuous water surface with accelerating flow, the difference in elevation between downstream and upstream points.
ephemeral stream	A stream or reach of stream that flows briefly in direct response to local precipitation and whose channel is above the water table.
estuary	A passage in which the tide meets a river current; an arm of the sea that extends inland to meet the mouth of a river; and the part of a stream that is influenced by the tide of the body of water into which it.
fanglomerate	The material of an alluvial fan in which the rock fragments are only slightly waterworn.
fissure	A fracture or a crack in rock along which there is a distinct separation. A fissure is often filled with mineral-bearing material.
formation	A body of rock strata that consists dominantly of a certain lithologic type or combination of types.
fracture	A break in a rock with no significant displacement across the break.
fresh water	Water that contains 600 milligrams per liter or less of chlorides, 300 milligrams per liter or less of sulfates, and 1,000 milligrams per liter or less of total dissolved solids.
gaging station	A particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.
geomorphic	Relating to the form of the Earth or its surface features.
gneiss	A medium- to coarse-grained, hard, metamorphic rock composed of alternating bands of light- and dark-colored minerals.
granodiorite	A hard, crystalline, igneous rock that is massively bedded, light to dark grey, medium to coarse grained, and often foliated. This rock is excellent for all engineering purposes. If not highly fractured or weathered, it is difficult to drill through and normally yields little ground water.
graywacke	A coarse sandstone or fine-grained conglomerate that is usually dark gray and is composed of subangular to rounded fragments of quartz, feldspars, and bits of other dark-colored minerals or rocks firmly cemented.

ground water	Water beneath the Earth's surface, often between saturated soil and rock, that supplies wells and springs.
hydrocarbons	Organic compounds of hydrogen and carbon whose densities, boiling points, and freezing points increase as their molecular weights increase. Although composed only of two elements, hydrocarbons exist in a variety of compounds because of the strong affinity of the carbon atom for other atoms and for itself. The smallest molecules of hydrocarbons are gaseous; the largest are solids.
hydrogeological	Pertaining to hydrogeology which deals with subsurface waters and with related geologic aspects of surface waters.
impermeable	Bed or stratum of material through which water will not move.
infiltration	The flow or movement of water into the soil.
intake site	A pumping operation next to a surface water body from which water is withdrawn.
interfluvial	The area between adjacent streams flowing in the same general direction.
intermontane	Area between mountains.
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.
irrigation	The artificial distribution of water on land for one of the following reasons: (1) to cultivate crops in arid areas where agriculture would otherwise be difficult to impossible; or (2) to increase crop yields in areas where rainfall is adequate but not consistently dependable during the growing seasons.
lahar	A mudflow containing much volcanic debris.
low water	The flow occurring in a stream during the driest period of the year.
limestone	(1) For military purposes, the rock types which refer to all carbonate sedimentary rocks. (2) Soft to moderately hard rock composed of calcium carbonate. Compact, crystalline varieties are generally good materials for all construction needs. Limestone is often highly fractured and solutioned, and it often yields significant volumes of ground water.
lithology	The study of rocks.
lutite	A general name for rocks composed of material that was mud once, e.g., shale or mudstone.
mangrove	A group of plants that grows in a tropical or subtropical marine swamp. A marine swamp dominated by a community of these plants.

marsh	A shallow lake, usually stagnant, filled with rushes, reeds, sedges, and trees.
marshy	A saturated, poorly drained area, intermittently or permanently water covered.
meander	A tortuous or winding stream channel.
mudflow	A fluid mass of soil or volcanic material which pours down deep narrow valleys or ravines in a mountainous region.
mudstone	An indurated mud having the texture and composition of shale, but lacking its fissility; a blocky fine-grained sedimentary rock in which the proportions of clay and silt are about equal.
orographic effects	Relating to mountains, especially their location, distribution, and accompanying effects.
pathogen	Disease-causing microorganism, such as a virus or bacterium.
perennial	Pertaining to water that is available throughout the year.
permeability (rock)	The property or capacity of a porous rock for transmitting a fluid. Permeability is a measure of the relative ease of fluid flow under unequal pressure.
phyllite	A foliated rock that is intermediate in composition and fabric between slate and schist.
porphyry	An igneous rock of any composition that contains conspicuous phenocrysts in a fine-grained ground mass.
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.
quartzite	An extremely hard, fine to coarsely granular massive rock which forms from sandstone. Quartzite is one of the hardest, toughest, and most durable rocks. It makes excellent construction material, but it is often difficult to excavate and crush. Antistripping agents are usually required with bituminous mixes.
Quaternary Period	A period of geologic time from the end of the Tertiary Period to the present time during which rocks were formed.
rapids	Steep stream-channel gradient segments with high-velocity flows and generally very rough and rocky bottoms.
reach	An extended part of a stream, generally from a point of major change in slope. A stream may be divided into three reaches–an upper reach with the highest slope, a middle reach with moderate slope, and a lower reach with the lowest slope.

Recent	The most recent geologic time division, from 10,000 years ago to the present. Starting at the end of the Pleistocene. Recent is synonymous with Holocene.
recharge	Addition of water to the zone of saturation from precipitation, infiltration from surface streams, and other sources.
reservoir	A pond, lake, tank, basin, or other space that is used for storage, regulation, and control of water for recreation, power, flood control, or drinking. A reservoir can be either natural or manmade.
reverse osmosis	An advanced method used in desalination which relies upon a semipermeable membrane to separate the water from its impurities. An external force is used to reverse the normal osmotic flow, resulting in movement of the water from a solution of higher solute concentration to one of lower concentration. Reverse osmosis is also known as hyperfiltration.
runoff	That portion of the precipitation in a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, and seepage.
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion	Displacement of fresh surface or ground water by the advance of salt water due to its greater density. Saltwater intrusion usually occurs in coastal and estuarine areas where it contaminates fresh water wells.
sandstone	A soft to moderately hard sedimentary rock composed primarily of cemented quartz grains. The harder, massive rock is generally good for most construction uses. Many aquifers and oil reservoirs are sandstone.
schist	A fine- to coarse-grained, foliated, metamorphic rock composed of discontinuous thin layers of parallel minerals. Because of a tendency to split along these layers into thin slabs or flakes, schist is avoided by construction engineers.
sediments	Solid mineral and organic materials that are (1) in suspension in air or water, or (2) resting after suspension on the Earth's surface, be it on land or in water.
semiconfined aquifer	An aquifer that is not completely bounded above and below by beds of distinctly lower permeability.
shale	A soft to moderately hard sedimentary rock composed of very fine-grained quartz particles. Shale often weathers or breaks into very thin platy pieces or flakes. In most places it can be excavated

	without drilling and blasting. Due to weakness and lack of durability, it makes very poor construction material. Shale is a confining bed to many aquifers in sedimentary rock.
silt	As a soil separate, the individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of sand (0.05 millimeter).
snowmelt	Water which has formed from snow. The transformation of snow into water.
specific runoff	The ratio of the total mean annual water resources availability of a country to its land surface area.
spring	A place where ground water flows naturally from a rock or the soil onto the land surface or into a body of surface water.
sulfate	The negatively charged divalent ion SO_4^{2-} present in natural waters. Excessive concentrations are undesirable for many uses of water, due to mild to moderate corrosive properties. Sulfate may have laxative properties at levels exceeding 600 to 1,000 milligrams per liter.
swamp	An area of saturated ground dominated by trees and shrubs.
Tertiary Period	A period of geologic time, 29 to 65 million years ago, during which rocks were formed.
thermal spring	A hot or warm spring, in which the water produced has been heated by natural processes.
total dissolved solids	The sum of all dissolved solids in water or waste water.
tuff	A soft rock formed from compacted volcanic fragments. Tuff is easily excavated and has few engineering uses, but may be used as a fill or base course material.
unconfined aquifer	An aquifer where the water table is exposed to the atmosphere through openings in the overlying material.
water point	Intake site located next to water source from which water is withdrawn.
watershed	The area contained within a drainage divide above a specified point on a stream.
well	An artificial excavation that derives water from the interstices of the rocks or soil which it penetrates.
wetland	A lowland area, such as a marsh, swamp, or seasonally inundated area that is saturated with moisture.
yield	Pertains to the amount of water production from a well. Yield is usually measured in liters per minute or gallons per minute.