WATER RESOURCES ASSESSMENT OF BOLIVIA

US Army Corps of Engineers
Mobile District &
Topographic Engineering Center

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Executive Summary

Bolivia is rich in hydrologic resources, although the spatial distribution and the temporal variation in hydrologic activity complicate the efficient use and management of these resources. The country's rivers range in size from navigable year-round to seasonal and short-lived. Despite the abundance of water resources, severe droughts and floods devastate the country.

The southern mountainous part of the country has severe water problems. The high seasonal rainfall occurs in a very short time span, causing rapid runoff. There are serious shortages of water supply throughout the southwestern part of the country, and in the Chaco region. There is an enormous need for water resources projects and programs in these areas.

The major water resources issues are water quality and pollution control; a stronger national water resources management and policy structure, particularly a national water law; watershed management and deforestation control; increased access to water and sanitation services; and increased wastewater treatment. Presently, a comprehensive water law does not exist to control the use and abuse of the nation's waterways, and, as a result, the rivers are used for sewage disposal. The lack of a national water law has also stressed the aquifers in some areas, particularly Cochabamba, due to uncontrolled ground water withdrawals. This area, as well as many others in the country, rely heavily upon ground water resources for their water supply. Many wells are going dry, due to the rapidly plunging water table caused by over pumping.

Bolivia is one of the poorest countries in the Western Hemisphere. Access to water and sanitation facilities is inadequate, particularly in rural areas, which constitutes as much as 50 percent of the total population of the country (about 4 million people). This leads to poor living conditions, disease, and a high mortality rate. Rapid migration of the population from rural to urban areas increases the burden of providing adequate services. The Bolivian government regards water and sanitation as one of the key areas to improve to make a direct impact upon poverty.

Surface water and ground water are used for water supply. However, much of the surface water is contaminated due to deforestation, industrial pollution and biological contamination. La Paz discharges all of its waste into the Rio Choqueyapu. Downstream of La Paz this river is so contaminated that it is unfit for irrigation water. Some farmers, however, do use this water to irrigate their crops. The human consumption of these crops causes illness.

Many agencies share the responsibility for overseeing the water resources of the country. Coordination between the individual agencies working to provide water and sanitation would be helpful in the management of the water supply and sanitation sector. The passage of a national water law would also help preserve and protect the nation's future water resources and supplies. Long-term national construction programs of wastewater treatment plants, a national well drilling program, and many other programs and plans recommended in this assessment are long-term solutions requiring proper management, conservation and changing societal habits. Without these ingredients, the beneficial effects of water resources projects will be short-lived.

Preface

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

A team consisting of the undersigned water resources specialists from the U.S. Army Corps of Engineers Mobile District and the Topographic Engineering Center conducted the water resources investigations for this report in 2002 and 2003. An in-country trip to La Paz was made by Nancy Ferris, Amy Harlan, and Alberto Montes de Oca in June 2002, to meet with the numerous agencies, organizations, companies, academia and individuals in Appendix A having responsibility for and knowledge of the water resources of the country. The following assessment resulted. This assessment is also available on website: http://www.sam.usace.army.mil/en/wra/wra.html.

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List of Acronyms and Abbreviations

Acronyms

AAPOS	Administracion Autonoma Para Obras Sanitarias (Potosi water authority)
ANESAPA	Asociacion Nacional de Empresas e Instituciones de Servicio de Agua Potable y Alcantarillado (national association of entities and institutions for potable water and sewer services)
CARE	Cooperative for American Relief to Everywhere
CGIAB	Comision para la Gestion Integral del Agua en Bolivia (commission for the integral management of water in Bolivia)
COATRI	Cooperativa de Agua Trinidad (Trinidad water authority)
COBEE	Compania Boliviana de Energia Electrica
CONIAG	Consejo Interinstitucional del Agua
COSAALT	Cooperativa de Servicios de Agua y Alcantarillado Tarija (Tarija water authority)
COSAPCO	Water authority of Cobija
COSPAGUAS	Water authority for intermediate cities
DSA	Water authority for rural areas
EC	European Community
EDOBOL	Editorial Offset Boliviana
ELAPAS	Empresa Local de Agua Potable y Alcantarillado Sucre (Sucre water authority)
ENDE	Empresa Nacional de Electricidad (national electric company)
FNDR	Fondo Nacional de Desarrollo Regional (national agency for regional development)
GTZ	Deutsche Gesellschaft Fuer Technische Zusammenarbeit (German agency for technical co-operation)
INE	Instituto Nacional de Estadistica (national institute of statistics)
IWL	International Water Limited
JICA	Agencia de Cooperacion Internacional del Japon (Japanese agency for international co-operation)
LIDEMA	Liga de Defensa del Medio Ambiente (environmental defense league)
NGO	Non-governmental organization
PAHO	Pan American Health Organization
PRONAR	Programa Nacional de Riego (national irrigation program)
SAGUAPAC	Cooperativa de Servicios Publicos 'Santa Cruz' Ltda (Santa Cruz water agency)
SAMA	A national park
SAMAPA	Servicio Autonomo Municipal de Agua Potable y Alcantarillado (former La Paz water authority)
SEARPI	Servicio de Encauzamiento de Aguas del Rio Pirai (the Pirai River watershed authority)
SeLA	Servicio Local de Acueducto y Alcantarillado (Oruro water supply company)

SEMAPA	Servicio Municipal de Agua Potable (former Cochabamba water company)
SENAMHI	Servicio Nacional de Metereologia e Hidrologia (national service of meteorology and hydrology)
SERGEOMIN	Servicio Nacional de Geologia y Mineria (geology and mines agency)
SIDA	Swedish International Development Cooperation Agency
SISAB	Superintendencia de Saneamiento Basico (basic sanitation agency)
TAMS	An Earth Tech company
TDPS	Titicaca-Desaguadero-Poopo-Salar System
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development

Abbreviations

a.s.l.	above sea level
°C	degrees Celsius
ft^3/s	cubic feet per second
gal/min	gallons per minute
km^2	square kilometers
kW	kilowatts
L/s	liters per second
m^3/s	cubic meters per second
m^3/yr	cubic meters per year
mg/L	milligrams per liter
mm/yr	millimeters per year
MW	megawatts
%	percent
TDS	total dissolved solids
US$	United States dollar

List of Place Names

The place names listed below are some of the names mentioned in the text, except for Appendix C. The geographic coordinates for the place names in Appendix C are provided with the place name. Coordinates are from the GEOnet Names Server (GNS). GNS provides access to the National Geospatial-Intelligence Agency (NGA) and the U.S. Board on Geographic Names' (US BGN) database of foreign geographic feature names.

Place Name	Geographic Coordinates
Aguallamaya	1822S06716W
Altiplano Cordillera Occidental	1800S06800W
Altiplano (area)	1800S06800W
Amazon Basin	1500S06400W
Andes Mountains	2000S06700W
Banados del Izozog	1848S06210W
Beni (department)	1400S06530W
Beni Plain	1400S06530W
Brazilian Shield	1600S06200W
Camiri	2003S06331W
Central Basin	1800S06800W
Chacaltaya (glacier)	1620S06808W
Chaco region	1900S06000W
Chaguaya	2149S06450W
Chapare	1630S06530W
Chuquisaca (department)	2000S06420W
Cobija	1102S06844W
Cochabamba (city)	1723S06609W
Cochabamba (department)	1730S06540W
Copacabana	1609S06905W
Cordillera Central	1700S06500W
Cordillera Occidental	2000S06500W
Cordillera Oriental	1902S06517W
Cordillera Real	1700S06710W
Cuenca de Tajzara	2142S06502W
Eastern Andes	1902S06517W
El Alto	1629S06811W
Escudo Proterozoico	1600S06200W
Gran Chaco Plain	1900S06000W
Guaqui	1635S06852W
Guayaramerin	1048S06523W
Huatajata	1610S06841W
Isla del Sol	1601S06909W
Lago Poopo	1845S06707W
Lago Titicaca	1548S06924W

List of Place Names (Continued)

Place Name	Geographic Coordinates
Lago Uru Uru	1806S06708W
Laguna Caceres	1856S05748W
Laguna Colorada	2217S06747W
Laguna Concepcion	1729S06125W
Laguna de Coipasa	1912S06807W
Laguna La Gaiba	1745S05743W
Laguna Mandiore	1808S05733W
Laguna Uberaba	1731S05747W
La Paz (city)	1630S06809W
La Paz (department)	1530S06800W
Oruro (city)	1759S06709W
Oruro (department)	1840S06730W
Montero	1758S06323W
Nevado Illampu	1550S06834W
Nevado Illimani	1639S06748W
Palmar de las Islas y las Salinas de San Jose	1928S06121W
Pando (department)	1120S06740W
Pantanal Boliviano (wetlands)	1800S05830W
Pantanal-Chaco Pampeano	1900S06000W
Piso Firme	1341S06152W
La Plata basin	2000S06200W
Potosi (city)	1935S06545W
Potosi (department)	2040S06700W
Puerto Heath	1230S06840W
Puerto Rico	1105S06738W
Puerto Sucre	1048S06523W
Puerto Villarroel	1652S06447W
Rio Abuna	0941S06523W
Rio Acre	1102S06844W
Rio Alto Beni	1431S06730W
Rio Beni	1023S06524W
Rio Bermejo	2652S05823W
Rio Blanco	1430S06330W
Rio Caine	1823S06521W
Rio Camblaya	2057S06445W
Rio Chapare	1558S06442W
Rio Choqueyapu	1633S06808W
Rio Coroico	1531S06750W
Rio Curiche Grande	1653S05929W

List of Place Names (Continued)

Place Name	Geographic Coordinates
Rio Desaguadero	1824S06705W
Rio Grande	1551S06439W
Rio Grande de Lipez	2047S06714W
Rio Grande de Tarija	2254S06421W
Rio Grande o Guape	1551S06439W
Rio Guadalquivir	2124S06445W
Rio Ichilo	1557S06442W
Rio Isiboro	1550S06512W
Rio Itenez o Guapore	1154S06501W
Rio Itua	2221S06407W
Rio La Paz	1541S06715W
Rio Lauca	1911S06808W
Rio Madera	1021S06523W
Rio Madidi	1232S06652W
Rio Madre de Dios	1058S06609W
Rio Mamoré	1023S06523W
Rio Mapiri	1528S06749W
Rio Miguilla	1616S06712W
Rio Misicuni	1714S06615W
Rio Mizque	1840S06420W
Rio Orthon	1050S06604W
Rio Paragua	1334S06153W
Rio Paraguay	2008S05809W
Rio Parapeti	1928S06232W
Rio Pilaya	2055S06404W
Rio Pilcomayo	2216S06240W
Rio Pirai	1748S06310W
Rio San Juan del Oro	2144S06549W
Rio San Pablo	2121S06406W
Rio Tapado	1317S06545W
Rio Taquesi	1624S06740W
Rio Tarija	2221S06407W
Rio Unduavi	1623S06733W
Rio Yacuma	1338S06523W
Rio Yapacani	1559S06430W
Rio Yata	1029S06526W
Rio Zongo	1543S06741W
Sajama	2007S06629W
Salar de Coipasa	1926S06809W

List of Place Names (Continued)

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

Aguallamaya 1822S06716W

Geographic coordinates for Aguallamaya that are given as 1822S06716W equal 18°22'S67°16'W and can be written as a latitude of 18 degrees and 22 minutes south and a longitude of 67 degrees and 16 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. Coordinates are approximate.

Figure 1. Country Map

Water Resources Assessment of Bolivia

I. Introduction

Water, possibly the world's most indispensable resource, nourishes and sustains all living things. At least 400 million people in the world live in regions with severe water shortages. By the year 2050, it is expected to be 4 billion people. The projected short supply of usable potable water could result in a devastating natural disaster.[1] Water resources are projected to be among the principal global environmental challenges of the 21st Century.

A direct relationship exists between the abundance of water, population density, and quality of life. As the world's population grows, pressure on the limited water resources grows. Unless water resources are properly managed, scarcity can be a roadblock to economic and social progress. A plentiful supply of water is one of the most important factors in the development of modern societies. The two major issues in the development of water resources are quantity and quality. Availability of water for cleansing is directly related to the control and elimination of disease. The convenience of water improves the quality of life.[2] In developing countries, water use drops from 40 liters per day per person when water is supplied to the residence, to 15 liters per day per person if the source is 200 meters away. If the water source is more than 1,000 meters away, water use drops to less than 7 liters per day per person.[3] As well as being in abundant supply, the available water must have specific quality characteristics, such as the low concentration of total dissolved solids (TDS). The TDS concentration of water affects the domestic, industrial, commercial, and agricultural uses of water. The natural nontoxic constituents of water are not a major deterrent to domestic use until the TDS concentration exceeds 1,000 milligrams per liter. As TDS values increase over 1,000 milligrams per liter, the usefulness of water for commercial, industrial, and agricultural uses decreases. In addition to TDS concentrations, other quality factors affect water. These factors include the amount of disease-causing organisms, the presence of manufactured chemical compounds and trace metals, and certain types of natural ions that can be harmful in higher concentrations.

Clean water prevents widespread outbreaks of:

- Cholera
- Diarrhea
- Amoebic and parasitic dysentery
- Typhoid and other gastro-intestinal diseases

Clean water means:

- Health for families
- Sanitary households
- Lower mortality rates in children under 5 years of age
- Less productive work hours spent hauling water great distances and dealing with illness

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

The organization of this Water Resources Assessment consists of Chapters 1 through VII with associated tables and figures followed by appendices. The following information summarizes the contents of each chapter and appendix:

- Chapter 1 presents an introduction to the purpose and scope of this assessment.
- Chapter II presents a country profile and discusses the geography, population and social impacts, economy, flooding and flood control, legislative framework, and hydrological monitoring.
- Chapter III presents current uses of water resources including water supply and sanitation for domestic, industrial and commercial, and agricultural uses, hydropower, waterway transportation and recreation.
- Chapter IV presents information on the existing water resources including surface water resources, ground water resources, and water quality.
- Chapter V presents water resources maps and tables and summarizes the water resources information for each department.
- Chapter VI provides recommendations for water resources management and policy, watershed protection and management, troop exercise opportunities, and water quality and supply improvement.
- Chapter VII provides a summary of the water resources issues discussed in this report.
- Tables 1 through 8 and Figures 1 through 3 are provided within the document following the text reference.
- Appendices A through C provide supporting information for the report:

  Appendix A - Officials Consulted
  Appendix B - Glossary
  Appendix C - Surface Water and Ground Water Resources Tables and Figures

This information can be used to support current and potential future investments in managing the water resources of the country and to assist military planners during troop engineering exercises. The surface water and ground water graphics, complemented by the tables in Appendix C, should be useful to water planners as overviews of available water resources on a countrywide scale. The surface water graphic, figure C-1, divides the country into surface water regions, based on surface water quality and quantities available. The ground water graphic, figure C-2, divides the country into regions with similar ground water characteristics.

In 1990, the U.S. Army Corps of Engineers, Mobile District prepared an "Evaluation of Water Resources in Bolivia, South America" for the U.S. Agency for International Development (USAID). This evaluation is a professional appraisal of the drought situation that occurred in several regions of Bolivia in 1990. To address the problems, 23 projects and programs were recommended in the evaluation.

In addition to assisting the military planner, this assessment can aid the host nation by highlighting its critical need areas, which can be used to support potential water resources development, preservation, and enhancement of funding programs. Highlighted problems are: the lack of access to water supply by a significant part of the population; the lack of a national water law and coordination between different agencies; the high population density in urban areas; the lack of wastewater treatment; the devastating effects of deforestation; and the lack of hydrologic data.

Responsibility for overseeing the water resources of Bolivia is shared by several government agencies and institutions. The U.S. Army Corps of Engineers (USACE) assessment team met and consulted with the organizations most influential in deciding priorities and setting goals for the water resources (see Appendix A). Most of these agencies conduct their missions with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources.

II. Country Profile

A. Geography

Bolivia covers about 1,098,580 square kilometers, which includes land and inland water bodies. See figure 1. The country, in land area comparison, is slightly less than three times the size of Montana, and twice the size of France. The country is landlocked with no maritime claims, bounded by Argentina, Brazil, Chile, Paraguay and Peru. See figure 2.[4]

The two parallel Andean ranges, on roughly north-south axis, divide the country into three ecozones. The western range (Cordillera Occidental) runs along the Peruvian and Chilean borders. The eastern range (Cordillera Oriental) is a broad system of mountains lying from Peru to Argentina. One ecozone consists of a huge arid Altiplano plateau between the western range and the eastern range, with Lago Titicaca in the north. This plateau is 805 kilometers long and 129 kilometers wide. Another ecozone consists of the semitropical Yungas and the temperate valleys of Cordillera Oriental. The third ecozone consists of the eastern lowlands, including the semiarid Chaco region.

The Cordillera Occidental is a chain of dormant volcanoes and solfataras, volcanic vents emitting sulfurous gases. Bolivia's highest peak, the snowcapped Sajama (6,542 meters), is located here. The entire cordillera is of volcanic origin and an extension of the volcanic region found in southern Peru. Most of the northern part of this range has an elevation of about 4,000 meters; the southern part is somewhat lower. Rainfall, although scanty everywhere, is greater in the northern half, where the land is covered with scrub vegetation. The southern area receives almost no precipitation, and the landscape consists mostly of barren rocks. The entire Cordillera Occidental region is sparsely populated, and the south is virtually uninhabited.

The Altiplano, the high plateau between the two cordilleras, comprises four major basins formed by mountainous spurs that jut eastward from the Cordillera Occidental to about halfway to the Cordillera Oriental. Along the Altiplano's eastern side is a continuous flat area, which has served as Bolivia's principal north-south transportation corridor since colonial times. The entire Altiplano was originally a deep rift between the cordilleras that gradually filled with highly porous sedimentary debris washed down from the peaks.

The most prominent feature of the Altiplano is Lago Titicaca. At 3,810 meters above sea level, it is the highest navigable body of water in the world. With a surface area around 8,400 square kilometers, it is larger than Puerto Rico and is South America's largest lake.

Rainfall in the Altiplano decreases toward the south, and the scrub vegetation grows sparser, eventually giving way to barren rocks and dry red clay. The land contains several salt flats, the dried remnants of ancient lakes. The largest of these is Salar de Uyuni, which covers over 9,000 square kilometers. The salt is more than five meters deep in the center. In the dry season, heavy trucks can traverse the lake. Near the Argentine border, the floor of the Altiplano rises again, creating hills and volcanoes lying between the eastern and western cordilleras of the Andes.

The much older Cordillera Oriental begins on the north side of Lago Titicaca, extends southeastward to approximately 17 degrees south latitude, to the Argentine border. The northernmost part of the Cordillera Oriental, the Cordillera Real, is a series of granite mountains. Many of these peaks exceed 6,000 meters, and two of these peaks, Nevado Illimani and Nevado Illampu, have large glaciers on their upper slopes. South of 17 degrees south latitude, the range changes character and is called the Cordillera Central.

The northeastern flank of the Cordillera Real is known as the Yungas. The steep slopes and peaks of this semitropical valley area northeast of La Paz has created beautiful scenery. The land is among the most fertile in the country, but inaccessibility has hindered its agricultural development.

The eastern slopes of the Cordillera Central descend in a series of complex north-south ranges and hills. Rivers, draining to the northeast, have cut long narrow valleys; these valleys and the basins between the ranges are favorable for crops and settlement. Rich alluvial soils fill the low areas, but erosion has followed the removal of vegetation in some places. The valley floors range from 2,000 to 3,000 meters above sea level. Two of Bolivia's most important cities, Sucre and Cochabamba, are located in valleys in this region.

The eastern lowlands include all of Bolivia north and east of the Andes. Although comprising over two-thirds of the national territory, the region is sparsely populated and, until recently, has played a minor role in the economy. Most of Bolivia's important rivers, such as Rio Alto Beni, are found in the water-rich northern parts of the lowlands. The land in the upper part of the river basin is suitable for crops such as coffee and cacao.

Differences in topography and climate separate the lowlands into three areas. The flat northern area, made up of Beni and Pando departments and the northern part of the department of Cochabamba, consists of tropical rain forest. Because much of the topsoil is underlain by clay hardpan, drainage is poor, and rainfall is heavy, much of the area is wetlands. The central area, comprising the northern half of the department of Santa Cruz and part of Cochabamba, has gently rolling hills and a drier climate than the north. Forests alternate with savanna, and much of the land has been cleared for cultivation. Santa Cruz, the largest city in the lowlands, is located here, as are most of Bolivia's petroleum and natural gas reserves. The southeastern part of the lowlands is a continuation of the Chaco region of Paraguay. With no precipitation nine months of the year, this area becomes a swamp during heavy rains. The extreme variation in rainfall supports only thorny scrub vegetation and cattle grazing, although recent discoveries of natural gas and petroleum have attracted settlement to the region.

Although Bolivia lies entirely within tropical latitudes, climatic conditions vary from tropical in the lowlands to polar in the highest parts of the Andes. Temperatures depend primarily on elevation and seasonal variation is minimal. Northern lowland areas have a tropical wet climate with year-round high temperatures, high humidity, and heavy rainfall. Central lowland areas have a tropical wet and dry climate. The Chaco has a semitropical, semiarid climate. Temperatures and rainfall amounts in the mountains vary considerably.[5]

Inefficient uses of soil and water resources exist in Bolivia. Poor farming methods, lack of knowledge of soil conservation techniques, slash and burn agriculture, overgrazing, and deforestation have led to high runoff of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of ground water recharge, and pollution of surface and ground water resources.

Figure 2. Vicinity Map

B. Population and Social Impacts

The second poorest country in the Western Hemisphere and one of the least developed countries in South America, Bolivia has a fairly young population, whose life expectancy at birth is 61 years. There is extensive malnutrition, especially among children. Thirty-eight percent of Bolivian children under five years old suffer from some degree of malnutrition. The infant mortality rate is one of the highest in Latin America. For children five years and under, the mortality rate is very high - 116 per thousand live births, most of those deaths resulting from diarrheal disease. According to Bolivia's National Secretariat for Health, 13,000 children in that age group die every year from diarrheal disease alone.[6] Human development indicators are on a par with countries of sub-Saharan Africa.[7] About two-thirds of the population lives in poverty.

Table 1 shows the population distribution from a 2001 census report. In 1999, the population was estimated at 7.9 million, with an annual growth rate of 1.96 percent.[8] Some other sources of information indicate slightly higher growth rates of over 2 percent.[9] Other sources also indicate slightly varying population figures. The young population is growing at a rate of over 2 percent per year. Population density ranges from less than one person per square kilometer in the northeastern plains to about 10 per square kilometer in the central highlands. The high mortality rate restricts the annual population growth rate.[10] Despite the harsh conditions, the Altiplano is the population center of Bolivia. Of the total population, about 38 to 50 percent is rural.[11] Other sources indicate well over half of the total population are indigenous people, a majority of whom are excluded from the benefits of economic growth. This exclusion creates and reinforces poverty.[12] Bolivia is undergoing rapid urbanization. In the 1980's with the collapse of the tin mining industry and the increases in extreme levels of rural poverty in much of the country, migration to Cochabamba, Santa Cruz and La Paz increased the size of these cities three-fold.[13] El Alto is an example of rapid urbanization.

El Alto is adjacent to La Paz and is considered a suburb of La Paz. Much of the population works in La Paz, where most of the economic opportunities are. El Alto has grown from nothing during the past 30 years (particularly in the past 10 years) as a result of large-scale rural-urban migration. The population of El Alto is around 600,000.[14]

In 1992, 70 percent of Bolivia's 1,322,512 homes lacked adequate access to basic education, health, and housing and were classified as poor (51 percent of urban and 94 percent of rural homes). Thirty-seven percent of these families lived in conditions of extreme poverty (32 percent were considered indigent and 5 percent lived in abject poverty); 13 percent lived at the poverty threshold, with a minimum level of satisfaction of their basic needs; and only 17 percent were able to properly meet their basic needs.[15]

The microclimatic influence of Lago Titicaca draws a major population concentration around the lake, which creates an excessive division of the land property. Towards the south, the population decreases, but communities exist wherever there is adequate water along the Rio Desaguadero. There are also small settled valleys in the northern part of the Cordillera Occidental. In the south, the semiarid plateau supports only semi-nomadic shepherds.

The eastern lowlands is sparsely populated, even though it comprises more than 2/3 of the country. The economy and population of Santa Cruz has grown tremendously in recent years, since becoming a commercial and industrial hub in the eastern lowlands.[16]

Table 1. Population Distribution, Census 2001*

Department	Population	Approximate Area (km^2)	Capital
Chuquisaca	531,522	51,524	Sucre
La Paz	2,350,466	133,985	La Paz
Cochabamba	1,455,711	55,631	Cochabamba
Oruro	391,870	53,588	Oruro
Potosi	709,013	118,218	Potosi
Tarija	391,226	37,623	Tarija
Santa Cruz	2,029,471	370,621	Santa Cruz
Beni	362,521	213,564	Trinidad
Pando	52,525	63,827	Cobija
Total	**8,274,325**	**1,098,581**	

Sources: *Geografia y Recursos Naturales de Bolivia.* 3rd ed. EDOBOL, La Paz, 1997; and *Atlas de Bolivia*, Comando General del Ejercto Instituto Geografico Militar (2nd edition).
Instituto Nacional de Estadistica de Bolivia, Censo 2001 – Poblacion Por Organizaciones Comunitarias Y Localidades, Internet, http://www.ine.gov.bo/cgi-bin/PobComunitLocalidadesADAxx.exe/DESPLIEGUE1, Accessed 4 November 2004.
* Note the population information in this table may differ from the population information in other paragraphs in this assessment due to the different sources and year of reporting of the information.

C. Economy

Bolivia is one of the poorest countries in the hemisphere with a per capita gross national product of US$800 in 1995. One of the clearest manifestations of that poverty is the extensive prevalence of malnutrition. About 70 percent of all Bolivian households and approximately 94 percent of rural households live in absolute poverty. Such human problems affect the economic health of the nation. It is one of the least developed Latin American countries, but has made considerable progress toward the development of a market-oriented economy.[17] The Bolivian government regards health, education, and water and sanitation as three of the key areas to improve for making a direct impact upon poverty.[18]

Bolivia still lives by a subsistence economy. A large part of the population makes its living from growing coca, the source of cocaine. Coffee, cotton, soybeans, corn, sugarcane, rice, potatoes, cacao, and wheat are the other major crops. Timber is also important. Industry is limited to processing and small-scale manufacturing. Although Bolivia has much hydroelectric potential, it is underutilized.[19] Hydroelectric plants were planned but oil and gas deposits were found, which supplied their energy needs. Tourism is increasing, and is hoped that the growth will continue increasing, to become a primary source of the economy.[20] Traditionally, the economy was based on mining, principally of tin, silver and zinc. However, in the last three decades, productive activity has diversified to oil and gas production, large-scale agriculture and agro-processing industries, along with growth in the services sector.[21]

Despite abundant and diverse metal and mineral deposits, huge hydrocarbon reserves, vast untapped fertile plains, dense virgin forests, and numerous swift rivers with great hydroelectric potential, the country's gross domestic product in 1987 was only approximately US$4.35 billion. Its per capita income of US$640 made Bolivia the poorest nation in South America. The economy's slow development is due to the rugged and varied terrain, inadequate infrastructure, lack of direct access to international markets, corruption, political instability and under-population.

Mining dominated the economy from colonial times until the 1985 crash of the international tin market. Natural gas replaced tin and other minerals in the 1980's as the leading export. Agriculture employed nearly half the labor force, and government policies favored increased diversification toward manufactured agricultural products. In the late 1980's, an underground economy based on contraband, coca production, and other commercial trading in the informal sector also thrived. These 'unofficial' activities employed two-thirds of the work force and the international trade from it was more than the official international trade.

In the 1990's, the free trade agreement with Mexico was signed and the Southern Cone Common Market was joined. The state airline, telephone company, railroad, electric power company, and the oil company were privatized. A national anticorruption campaign in the 1990's was conducted to try to further improve the country's standing. Slower economic growth in 1999, combined with a few major civil disturbances in 2000, held overall growth to 2.5 percent.

Bolivia is no longer a net importer of agricultural and food products. Domestic production provides about 90 percent of national food supply; 7 percent comes from commercial imports and 3 percent from food aid. The country is dependent on imported wheat and wheat products. Commercial agriculture has increased over the years, but peasant agriculture supplies a substantial amount of food to rural households.

The immediate economic future lies in the development of the oil and gas industry. Within a two year period in recent years, proven gas reserves quadrupled. This made Bolivia the second largest holder of gas reserves in South America, after Venezuela. Gas exports under contract to Brazil are expected to reach US$600 million by 2005. Brazil is in need of even greater volumes of Bolivian gas to reduce its energy deficit. Prospects of gas exports to Peru, Mexico, and the West Coast of the U.S. exist. Gas production is expected to increase from the expansion of thermoelectric energy generation and the development of petrochemical industries.[22]

Bolivia appears to have a reasonably diverse economy and substantial resources. Unfortunately, many obstacles constrain development, hindering progress towards wealth and quality living. These constraints include: location of major subsistence farming in areas prone to drought or flood; shortages of raw materials for manufacturing; limited investments in local enterprises; weak domestic demand for industrial goods combined with a poor infrastructure; cumbersome institutional bureaucracies with corruption, and a viable and growing black market production and retail sector; and the human and financial costs of the drug trade.[23]

D. Flooding and Flood Control

Flooding is problematic in tropical areas during the rainy season. Most of the major rivers in the Amazon Basin experience annual flooding during the wet summer months. Approximately 100,000 to 150,000 square kilometers of land are inundated annually. The largest flooded area in this basin is near the Rio Mamoré and lower reaches of Rio San Pablo (no coordinate available), and the upper reaches of Rio Tapado and Rio Yacuma (see figure C-2). The Rio Mamoré course shifts throughout the year because of flooding. From November to May, the area surrounding the Rio Yacuma is flooded and impassable to ground traffic. In the La Plata basin in the southeast, flooding is most pronounced in the flat eastern plains known as the Chaco. This area is very dry most of the year.

Economically, floods cause damage and do not allow the development of roads over the affected places, as well as interconnections to those places. For the Rio Mamoré basin (Central Basin), flow measurement stations were installed upstream from floodplains. These work as an early alert system that allows ranchers and inhabitants to take some precautions concerning an imminent flood. Even though flooding expenses were reduced, every year some recurrent flooding expenses occur.[24]

Many floods have plagued Bolivia since the early 1980's. In March 1983, flooding of the Rio Pirai affected residential neighborhoods in the city of Santa Cruz. This river changed course near the city of Montero, resulting in 100 deaths, 900 missing and economic damage of US$37 million. In 1983, SEARPI (Servicio de Encauzamiento de Aguas del Rio Pirai, the Pirai River watershed authority) initiated flood control and channeling projects. In 1991 and 1992, damages due to water level increases in the river were limited to the ditches and protecting walls of Santa Cruz.[25] Major flooding during 1986 to 1989 prompted the Global Binational Master Plan (see below.)[26] In January 2001, the government declared the country in a state of natural disaster after two weeks of heavy rain that caused loss of life and destruction of homes. The national weather service estimated that a daily average of 6.7 gallons of water per 1.2 square yards drenched La Paz, the worst affected area. A month later, another rainstorm hit La Paz, killing 50 people, injuring 150 and forcing over 300 families from their homes. La Paz borders a main river and is located at the lowest point of a natural bowl surrounded by the Andes.[27] On February 19, 2002, the worst rain and hailstorm in the history of La Paz killed 77 people, wounded more than 200 people, destroyed several homes and buildings in the historic center and damaged asphalt roads.[28] In one hour, 39.4 millimeters of rainfall fell in some areas of town.[29] During this flood, a huge volume of hail fell, which exacerbated the flooding problems by clogging the drainage system. The areas affected included La Paz and rural communities downstream of the Rio Choqueyapu and Rio La Paz. The following day, the government of Bolivia declared a state of emergency in the capital. Estimated costs of structural repairs and mitigation measures for the damaged infrastructure have been reported by the Municipality of La Paz to be around US$10 million.

The European Community (EC) signed agreements with Bolivia, with the principal objectives to study and establish a Global Binational Master Plan of Protection-Prevention of Floods and usage of the water resources of Lago Titicaca, Rio Desaguadero, Lago Poopo and Laguna de Coipasa. That system forms a closed basin which lies in Peru and Bolivia. There is dependence between the countries to utilize the natural resources and particularly the water resources. The Special Lake Titicaca Projects were created in La Paz and Puno, Peru under the surveillance of a Binational Commission. European consulting firms, hired by the EC by the government of Peru and Bolivia, studied the basin from 1991 to 1993. Field measurements were made, and existing information was validated. Using existing maps and satellite imagery, more maps of the soil, geology, geomorphology, climate, hydrology, and water quality were developed.[30]

Flooding affects the lower parts of Lago Titicaca's tributaries, the areas around the lake, and along the Rio Desaguadero. For these reasons many regulatory and local protection measures are required. Due to the difficulty in properly regulating the water level of Lago Titicaca in the case of extreme floods (1986-87), the Master Plan includes basin management, river levees, water volume control, use restriction, and efficient water use controls. The Master Plan also defines the need to provide regulation of the Rio Desaguadero. The regulation consists of two dams, one in the outlet of the lake to the river, close to the International Bridge. Another dam 40 kilometers downstream is located in Aguallamaya. The next dam will be constructed in La Joya, which will control the flow in the two branches of the river. Other work consist of dredging the riverbed for addressing the sedimentation problem and to improve the hydraulics of the river.[31] Some dredging has taken place to date.[32] The first dam, besides its regulation role in controlling discharge, will minimize the effects of flooding along the shorelines of the lake. This dam has four gates, which will be opened when the lake level reaches 3.81 meters above sea level (a.s.l.), permitting water to flow out of the lake.[33,34]

Many rivers in the country are important for transportation during the rainy season, as many roads become inundated and impassable. These include the Rio Mamoré-Rio Madera system, Rio Madre de Dios, Rio Yacuma, and Rio Beni.[35]

To better attenuate damage from flooding, automated hydrometeorological stations with real-time data collection is necessary.[36]

E. Legislative Framework

Bolivia lacks a comprehensive water policy. Various agencies and non-governmental organizations (NGO’s) share the responsibility for overseeing the water resources and supplies. Many of these agencies conduct their missions with little or no coordination with other agencies, which creates duplication of work and inefficient use of resources. There is a need for centralizing water information. The lack of a regulatory framework has not allowed the creation of a solid administrative system for water resources. Throughout history, several public institutions have been in charge of the administration of the water resources ranging from ministries to independent institutions. Since 1997, the responsibility for water resources administration was shared between the Ministry of Housing and Basic Services (Ministerio de Vivienda y Servicios Basicos) and the Superintendencia de Saneamiento Basico (the Agency for Basic Sanitation) (SISAB). Some department capitals have their own agency handling the water and sanitation.

The Ministry of Housing and Basic Services establishes guidelines for drinking water quality. They have developed a 10 year plan for water and sanitation for the country. The plan contains guidelines and projects, but there is no funding for the recommended projects. The Ministry works with the World Bank and other financial institutions to increase and improve water services relating to supply and sanitation. The superintendent of this ministry checks that the water suppliers follow the guidelines and standards set by the Ministry. Fondo Nacional de Desarrollo Regional, the National Agency for Regional Development (FNDR) executes projects from the 10 year plan created by the Ministry of Housing and Basic Services. They build sewage systems, lay pipes, drill wells and develop the infrastructure network. FNDR works on projects that serve over 10,000 people. Their 10 year goal is to supply 90 to 100 percent of all the urban population with water and 60 to 70 percent of the urban population with sanitary services.

SISAB is the agency responsible for ensuring good drinking water quality. The water quality must meet the guidelines of Norma Boliviana 512 Agua Potable - Requisitos.

The various sectors involved in water use conduct their activities independently according to sector laws. The Law of Electricity, the Law of Hydrocarbons, the Law of Mining, the Law of Lands, and the Law of the Environment address water use, without establishing common criteria of usage and priorities.[37]

Comision para la Gestion Integral del Agua en Bolivia, Commission for the Integral Management of Water in Bolivia (CGIAB) is a consortium of different organizations. The purpose of this commission is to provide a forum for sharing water information and to build consensus for establishing a national water law and governing body.[38]

The current water law was created in 1906. Since 1906, there have been numerous new water law drafts, but none has been ratified.[39] There is a lot of political pressure from indigenous groups who feel they have a right to all of the natural resources because they were inhabitants first, and whenever a new law is proposed, they create obstacles to its passing.[40] There are various regulations on water, but they are buried in other laws such as mining and forestry. The discussion on the new Law of Water began in 1985. The approval of the Law will allow the creation of a formal system of administration based on the hydrographic watershed.[41]

Within the country, a few government agencies are involved with limited management of water resources. Servicio Nacional de Metereologia e Hidrologia (National Service of Meteorology and Hydrology) (SENAMHI) is responsible for the collection and processing of hydrological information. SENAMHI works with the Bolivian Air Force, the airport administration and the National Directory of Naval Hydrography (Servicio Nacional de Hidrografia Naval). SENAMHI maintains hydrological and meteorological monitoring stations, and along with other agencies has been given specific mandates for managing hydrographic regions. They produce thematic maps of natural resources pertaining to water. The National Directory of Naval Hydrography maintains gaging stations on navigable rivers, flood alert systems, and they publish reports with flow data and navigation charts.

Servicio Nacional de Geologia y Mineria (the National Geology and Mineral Service) (SERGEOMIN) is in charge of ground water, geology and mining. They produce hydrology, geology, economic, environmental, and geomorphic maps/studies. Sistema de Regulacion Sectorial, the Sectoral Regulation system is responsible for regulating the water, hydrocarbons, electricity, telecommunications and transportation sectors.

Instituto de Hidraulica e Hidrologia de la Universidad Mayor de San Andres is a research institution for hydraulics and hydro-engineering that was established in 1972 in conjunction with the University of Berlin.

The Bolivia Water Industry is a group of regional companies with municipally based management strategies in La Paz, Cochabamba, and Santa Cruz. Each department capital has their own water and sanitary sewer agency, which belong to Asociacion Nacional de Empresas e Instituciones de Servicio de Agua Potable y Alcantarillado; National Association of Entities and Institutions for Potable Water and Sewer Services (ANESAPA). ANESAPA, discussed in more detail in Chapter III, is a governing body of agencies and partner companies that provide water and sanitary services in the department capitals. The Water Industry is also discussed in more detail in Chapter III.

Ministerio de Agricultura, Ganaderia y Desarrollo Rural organizes small irrigation projects, not larger than about 500 hectares. Programa Nacional de Riego, the National Irrigation Program (PRONAR), is structured within the Agriculture, Cattle and Rural Development Ministry, under the interior of the Vice-Ministry of Integral Exploitation of Renewable Resources, and more specifically under the Direccion General de Suelos y Riego, the General Direction of Soils and Irrigation.

The Ministerio de Desarrollo Sostenible y Medio Ambiente (the Ministry of Sustainable Development and Environment) has a wide range of missions. Its main function is managing and protecting the environment and making sustainable development plans.

The EC has started a cooperation strategy program with Bolivia which will last until 2006. The Memorandum of Understanding signed in October 2001 commits the EC and the Bolivian Government to work on regional physical integrations, water and sanitation, alternative development, and economic cooperation. The Bolivian government regards health, education, and water and sanitation as the key areas to improve for making a direct impact upon poverty. The water and sanitation sector has been chosen as a sector for concentration because it is not well covered by other donors. Objectives of the water and sanitation program are to provide access to drinkable water and to sanitation services for disadvantaged and poor communities, with a view to the sustainability of the investments.[42]

Cooperative for American Relief to Everywhere (CARE) is an NGO in Bolivia that focuses on children and mothers' reproductive health.[43] They returned to Bolivia after a 16 year hiatus in 1976, building rural water systems. Over the years, CARE expanded its activities. Currently CARE's portfolio in Bolivia includes projects in primary health care, urban and rural water and sanitation, reproductive health, agriculture and natural resources management.[44] CARE has worked in about 1,300 communities, mainly rural, on improving or constructing small water supply systems and sanitation services.[45] CARE Bolivia implements a project portfolio of about US$8 million each year. In its long-range strategic plan, they identified seven key problems which will be addressed by CARE projects. The lack of rural water and sanitation services is one of the seven key problems that will be addressed.

Many more NGO's working to provide water and/or sanitation in Bolivia are making a direct impact. Adventist Development and Relief Agency International is a relief organization working in Bolivia on water, sanitation, and the development of water supply systems. Programas de Apoyo al Sector Agropecuario de Chuquisaca y Potosi, the Agricultural Sector Support Program in Chuquisaca is another relief organization working in Bolivia, mainly for irrigation projects and research. Liga de Defensa del Medio Ambiente (LIDEMA) is a network of NGO’s and universities founded in 1987. This organization works on environmental issues.

Agencia de Cooperacion Internacional del Japon (JICA) is a private corporation that drills wells throughout the country. They have invested US$50 million in non-refundable grants. Their goal is to provide safe, clean water to the population that does not have access to it. JICA is working toward determining a water supply source for scarce regions, such as the Chaco and mountainous areas.

Agencia Suiza para el Desarrollo y la Cooperacion is a private firm that provides international funding for water sanitation and irrigation issues.

Several regulatory agencies have oversight responsibility for energy in Bolivia.[46] In 1994, the government passed the Electricity Law which unbundled the state-owned electric company (ENDE) into its generation, distribution, and transmission components. This law established the Superintendent of Electricity as the regulatory body for the Bolivia electricity sector. Two companies own most of the hydroelectric generating capacity: Empresa Electrica Corani South America and Compania Boliviana de Energia Electrica (COBEE).[47]

F. Hydrological Monitoring

Hydrologic resources research is minimal, with most conducted by State universities, research institutes and foreign technical assistance. The dissemination of the resulting studies is very low. Several agencies and NGO's maintain gaging stations. A central clearinghouse and standard format for data management is needed for proper information sharing. SENAMHI is responsible for the collection and processing of hydrological information.[48]

The quantity and quality of rainfall data is regular; but the amount of evapotranspiration data is inadequate. The quantity and quality of hydrological data is inadequate with low values regarding seasonal density.

To improve data gathering on hydrologic resources, the following should be considered:

- Improvement of the hydrometric and meteorological network;
- Preserve the existing hydrologic research, and the information obtained from national and international organizations;
- Strengthen the institutions dedicated to collecting data, as well as university research institutes whose activities involve hydrologic resources.

Of the 855 meteorological stations existing, the larger numbers of stations are in the departments of La Paz, Cochabamba, and Santa Cruz. The watershed of Lago Titicaca has the largest density of stations, with 46 for every 10,000 square kilometers.[49]

The insufficient data hinders the calibration of forecasting models for project development. Historically, little importance has been given to SENAMHI. Strengthening and support to SENAMHI is necessary for hydrologic resources development. Currently, data centralization in SENAMHI is counterproductive. Information is sometimes stored without being processed, or in physical media that do not allow a rapid data analysis.

SENAMHI placed 10 new hydrometeorological stations in the Amazon Basin. The 10 stations are automatically read by satellites due to the inaccessibility of the stations. Theft is also a problem, so the stations were not optimally placed hydrologically, but placed in safer locations.

In the lowlands, stations are being placed on cattle farms to obtain flooding information. There are problems with obtaining this information, too. The information is transmitted via radio, but the frequency is low and it is not always possible to transmit. A great need also exists for satellite imagery through clouds, and for flooding information.

There are many meteorological stations which need upgrading. Some have real time data, some transmit information over phone lines, and some have manual readers. For optimal benefits, at least 33 percent of the information is needed in real-time data.[50]

III. Current Uses of Water Resources

A. Water Supply and Sanitation

Lack of water supply services and proper sanitation is a serious problem in Bolivia. More often than not, particularly in developing countries, proper sanitation services (including proper waste disposal) affects the quality of the water supply.[51] These issues, lack of water supply and poor drinking water quality, create a critical health threat to the population. The provision of piped water and sewerage services to low income neighborhoods is a particularly challenging problem. The costs of such services are often prohibitively high for poor families.

Data indicate high levels of water-related illnesses and deaths in both rural and urban areas.[52] As mentioned previously, the mortality rate for children under five is very high at 116 per thousand live births, according to a 1994 report. Most of those deaths were from diarrheal disease.[53] Hygiene practices, and access and use of potable water are key factors in reducing diarrheal disease, and subsequently lowering the child mortality rate.

According to a 1999 report, the annual extraction of water by economic sector shows that 10 percent is for domestic use, 5 percent for industrial use and the remainder for agricultural use.[54]

Water supply and sanitary services coverage is higher in urban areas than rural areas. Most of the financing sources for the water supply sector come from international cooperation organizations through treaties and donations.[55]

In addition to the local water companies, there are many entities, programs, and NGO's working to supply water and sanitation throughout Bolivia. Many, such as JICA, CARE, the Swedish International Development Cooperation Agency (SIDA), and the FNDR, are discussed in Chapter II, Legislative Framework.

The EC started a cooperation strategy program with Bolivia which will last until 2006. The Memorandum of Understanding commits the EC and the government to work on water and sanitation, along with other issues. The water and sanitation sector was chosen as a sector for concentration because it is not well covered by other donors, and its improvement can make a significant impact on reducing poverty. Objectives of the water and sanitation program are to provide access to drinkable water and sanitation systems for poor communities.[56]

Water supply and sanitation service coverage estimates vary, depending upon the organization reporting and the year of service reported. The Catholic Missionary Union estimated that in 1995, 82 percent of the urban population in Bolivia had access to safe water, while only 21 percent of the rural population had access.[57] According to World Health Organization figures for 1994, 55 percent of the population had access to potable water and 41 percent to sanitation. Pan American Health Organization (PAHO) estimated that about 73 percent of the population had access to drinking water services in 2001.[58] It was also estimated that between 1990 and 1995, 72 percent of the urban population had access to sanitation services, while 32 percent of the rural population had access.[59]

Run-off from glaciers in the Cordillera Real contributes to reservoirs that supply La Paz and El Alto, and also some hydroelectric plants that serve the cities. These glaciers, however, are rapidly diminishing. Data collected from tropical ice fields near La Paz show losses in the 1990's that are 10 times greater than that of previous decades. The Chacaltaya glacier, the world's highest ski-field, has lost over 40 percent of its thickness and surface area.[60] The disappearance of the glaciers could lead to water shortages. Some government officials and scientists believe that if the glaciers keep melting at this rapid pace, a serious water shortage could occur.[61]

Water supply reservoirs exist in La Paz, Cochabamba, Potosi, and Sucre. Tarija is in dire need of a new reservoir. Table 2 lists the sources of potable water by percentage surface water and ground water for some major cities.

Table 2. Surface Water Supply vs. Ground Water Supply for major cities

City	Source, Surface Water Production (m^3/yr)	%	Source, Ground Water Production (m^3/yr)	%
La Paz, El Alto	60,590,592	92	5,052,864	8
Santa Cruz		0	47,571,738	100
Cochabamba	7,920,000	34.8	14,808,629	65.2
Oruro	1,072,044	13.7	6,768,903	86.3
Potosi	8,167,824	100		0
Sucre	6,851,048	100		0
Tarija	7,153,920	65.7	3,732,480	34.3
Montero		0	2,371,714	100
Trinidad		0	1,946,021	100
Yacuiba	788,400	22.8	2,672,114	77.2

Source: ANESAPA, June 2002

1. Domestic Uses and Needs

About 93 percent of urban households have drinking water services coverage.[62] Table 3 shows the projected figures for potable water coverage by department for 1997 by Instituto Nacional de Estadistica (INE).[63]

Table 3. Projected Potable Water Coverage by Department for 1997

Department	Total Coverage %	Urban coverage %	Rural coverage %	Urban Population %
Chuquisaca	52	95	29	36
Cochabamba	66	82	46	65
La Paz	80	98	44	67
Oruro	74	96	28	67
Potosi	52	95	29	35
Tarija	73	97	39	59
Santa Cruz	83	97	36	78
Beni	57	73	17	72
Pando	31	80	10	30
Total	72	93	37	61

Source: INE, November 1997 Roger Mattos R. and Ing. Alberto Crespo, *Informe Nacional Sobre la Gestion del Agua en Bolivia,* 19 January 2000, p. 80.

The department city capitals, intermediate cities and small population areas with their respective entities providing water service are listed in table 4.

Table 4. Entities That Provide Potable Water and Sewerage System Services in the Department Capital Cities

City Size	City Name	Water Authority	Type Water Authority
Department City Capitals	La Paz and El Alto	Aguas del Illimani	Private
	Santa Cruz	SAGUAPAC	Cooperative
	Cochabamba	SEMAPA	Decentralized public
	Sucre	ELAPAS	
	Potosi	AAPOS	
	Oruro	SeLA	
	Tarija	COSAALT	Cooperative
	Trinidad	COATRI	Cooperative
	Cobija	COSAPCO	Cooperative
Intermediate Cities	Populations over 2000	COSPAGUAS	
Small and Dispersed Populations	Populations less than 2000	DSA	

Source: Roger Mattos R. and Ing. Alberto Crespo, *Informe Nacional Sobre la Gestion del Agua en Bolivia,* 19 January 2000, p 71; and Aguas del Illimani, 1er, 1997-2001.

Urban Areas. The Bolivian Water Industry is a group of regional companies with municipally-based management strategies in the three largest cities of La Paz, Santa Cruz and Cochabamba. Historically, many of the city-based companies were partly dependent on ENDE, the former electricity company, for water sources. Many of the water companies in Bolivia have been privatized, or are planned to be privatized. The privatization of the water supply company in Cochabamba was not well received by the public and caused widespread rioting. In 1997, the government of Bolivia granted a 30 year concession contract for the provision of water and sewerage services to La Paz and El Alto, adjacent cities with a combined population of 1.6 million. The concession contract was awarded to Aguas del Illimani, a consortium led by Lyonnaise des Eaux. A major objective of the contract was to improve access to water and sewerage services in El Alto. Aguas del Illimani replaced SAMAPA as the water supply agency for La Paz. Revenues from the company were not as high as expected. The company had an US$800,000 deficit in 2001, but worked with the government so rates did not have to be raised. Connection charges for water and sanitation, however, were raised to generate revenue. Each department capital has its own water and sanitary sewer agency, which belong to ANESAPA.

ANESAPA is a governing body of the agencies and partner companies that provide water and sanitary services in the department capitals. This association was created in 1982 to improve the institutions and management of the water and sanitary agencies in order to improve the quality of life by assuring water and sanitary services and sustainability of the environment. The objective is to cooperate and assist the partner and public companies of the potable water supply and sewerage systems to increase the efficiency and effectiveness. The association is organized by a board of directors, composed of the main officers of all the partner companies. The German Technical Cooperation (GTZ) provides technical support. GTZ is a private German company that provides grants to Bolivia, technical assistance and training programs to farmers with irrigation projects, and small water supply projects in communities.

Access to sanitary services in department capital cities is lower than access to drinking water services. The lack of sanitation services has a direct impact on drinking water quality.[64] The cities of Santa Cruz, Cochabamba, Tarija, Oruro, Trinidad and El Alto have sewage treatment through stabilization lagoons. Lagoons are discharged into rivers that are used for irrigation water, and if these lagoons do not reach an irrigation effluent quality, they contaminate agricultural products and most likely cause sickness. In La Paz, all sewage is discharged untreated into the Rio Choqueyapu. There is no wastewater treatment in La Paz, and no funds to build a wastewater treatment plant. The river is so polluted that it cannot be used for irrigation downstream of La Paz. Some farmers, however, do use the river water for irrigation. Their fruits and vegetables end up in city markets, which often cause illness.[65]

According to Aguas del Illimani literature, as of 2001, potable water coverage in La Paz and El Alto is 100 percent, while sanitation service coverage is 88 percent in La Paz and 54 percent in El Alto. Cochabamba, Potosi, Sucre and Cobija have water supply deficits, with service less than 24 hours each day. According to records between 1976 and 1992, the potable water coverage in urban and rural areas increased drastically. Five of the 9 department capitals have coverage 24 hours each day. The remaining 4 capitals have restricted water use during the dry season. The most severe restrictions are in Cochabamba, Cobija and Potosi. The high population growth and the rapid migration from rural to urban areas puts increased pressure on the water resources in the urban areas.[66] This increase in population in urban areas puts a tremendous strain on the over-burdened water systems.

As mentioned earlier, El Alto is an example of rapid urbanization. This suburb of La Paz is less than 35 years old, with a population of approximately 600,000. The coverage of sanitation and water supply services has not been able to keep up with the rapid population growth. In July 1997, Aguas del Illimani was granted a 30 year concession contract by the government of Bolivia to provide water and sewerage services to La Paz and El Alto. A major objective of the contract was to improve access to water and sewerage services in El Alto. The El Alto Pilot Project resulted. The project came about through a venture between the government of Bolivia, the private concessionaire, the Andean Region of the Water and Sanitation Program and SIDA (main financial contributor). The Water and Sanitation Program of the World Bank facilitated the transfer of technology about low cost water and sewerage systems from Brazil. The El Alto Pilot Project began in 1998, and aimed to find innovative ways of reducing the cost of providing water and sewerage connections to poor households, while upholding the quality of the services. The cost of both water and sewerage connections were reduced around 40 percent. The innovative 'condominial' network design achieved this goal. Groups of houses are connected to the main supply rather than each individual home. Volunteers from the community construct the system. The project has provided water connections to almost 2,000 households in El Alto, and sewerage connections to over 4,000 households.[67]

The intermediate cities have developed their own administration and management systems for potable water and sanitary sewerage systems. Most of the intermediate cities have disrupted service, with little continuous coverage. The water availability of these cities is basin dependent.[68]

The groundwater resources in La Paz and Cochabamba areas have been overexploited resulting in water supply shortages. The main sources of water lie further north, but most of the watersheds in this area drain away from the valley, so large scale engineering schemes are needed if water is to be re-directed south. Population growth and increased agriculture in the area have contributed to the higher demand for water. Ground water supplies drinking water to Santa Cruz, Oruro, part of Cochabamba, part of El Alto and much of the area in the eastern part of the country. Potable water in Tarija and Chuquisaca in the Chaco is also scarce. Ground water supplies much of the potable water needs in these two areas.[69] In Cochabamba, the charge for water use is not enough to cover the cost of providing water services. This is often the case in Latin America, and is probably the case for many, if not most, of the other areas of the country.

Glaciers near La Paz supply water to reservoirs that serve La Paz and El Alto.[70] These glaciers, as discussed earlier, are retreating rapidly, causing concerns for water shortages in the future for La Paz and El Alto, where much of the Bolivian population lives. Rainfall, however, is believed to be the main contributor of water to the reservoirs. Nonetheless, water shortages as a result of glacier loss is a concern for some government officials and scientists. Over the next decade, water use in the region is expected to increase 20 percent.[71]

Water supply wells in urban areas are generally constructed of polyvinyl chloride, with diameters between 4 and 8 inches, fitted with submersible turbine pumps of varying flow, with well depths between 40 and 150 meters.[72]

Due to the need for more water supply sources, the Misicuni Dam project was planned for Cochabamba. The Misicuni project is an integrated water supply and an Environmental Health Project that, if built, would meet the region's water supply and irrigation needs well into the next century.

Many of the city-based water companies have been partly dependent on ENDE for water sources.

a. <u>Cochabamba Water War</u>. The privatization of Servicio Municipal de Agua Potable (former Cochabamba water company) (SEMAPA), the water company of Cochabamba, was not well received by the public and caused widespread rioting in 2000. After privatization, the water rates were drastically increased.[73] As a result of the rioting, the government declared martial law. In Cochabamba, with a population of 800,000, the third largest city in Bolivia, widespread rioting by much of the population occurred. This huge uprising became known as the *Water War*. Peasants from the countryside manned barricades and blocked all roads into Cochabamba. The chief demand was the reversal of the privatization of Cochabamba's water system.[74] The public uprising forced the cancellation of the concession granted to Aguas del Tunari to run the water industry in Cochabamba.[75] Aguas del Tunari is a consortium led by International Water Limited (IWL). IWL is jointly owned by the U.S. construction company Bechtel and the Italian energy company Edison. Debates about the need to privatize largely focused on the need to improve efficiency and increase connection rates, as urban connection rates in poor areas are notoriously low in Latin America. As of 1996, the Cochabamba network covered 64 percent of the city's population. Only 320,000 out of a population of 500,000 are serviced, and even then water is often rationed and only available during limited hours. Connection to the sewerage network is also limited to only about 40 percent of all households. Both SEMAPA and the government publicly accept that it has not been possible to increase the ratio of connections per household in the city between approximately 1985 and 1995. This failure is linked to population increase and overall inefficiency in management. It is assumed by the government that privatization will avoid problems of managerial corruption and the failure to use foreign aid and investment efficiently.[76]

b. Water treatment and volume. Table 5 shows the urban (including intermediate) cities that have treatment, the type, and capacity.

Table 5. Water Treatment Type and Capacity by City

Capital and Intermediate Cities	Disinfection Only	Conventional Treatment: Surface Water (flocculation, sedimentation, filtration, disinfection)	Total Volume of Potable Water Production (m^3/yr)
La Paz, El Alto		Yes	65,643,456
Sucre		Yes	6,851,048
Cochabamba		Yes	22,728,629
Tarija		Yes	10,886,400
Potosi		Yes	8,167,824
Oruro	Yes		7,840,947
Santa Cruz	Yes		47,571,738
Trinidad		Yes*	1,946,021
Cobija	Not available	Not available	Not available
Yacuiba		Yes	3,460,514
Camiri	Yes		Not available
Montero	Yes		2,371,714
Guayaramerin	Yes	Ultraviolet radiation†	Not available

*Treatment plant under construction
† Bolivian government donated the equipment
Source: ANESAPA, June 2002

Rural Areas. There is deficient coverage of water supply services, about 37 percent overall, in rural areas. About half of the total population of Bolivia is rural, so the need for increased coverage is critical. The government launched a Ruling for Drinking Water, Sewage Systems, and Sanitation for cities under 5,000 inhabitants in November 1996. A total of 33 percent of the rural population has access to sanitation services.[77] Many NGO's work in rural areas to provide water and sanitation services.

The improvement of potable water coverage in rural areas has been important, but the coverage remains lower than urban areas. Financial limitations and the lower population density in rural areas are some of the reasons for the lower coverage of services.[78] Table 3 shows potable water coverage for rural and urban areas by department.

The water supply wells in the Chaco are very deep, requiring submersible pumps. However, in many areas of the Chaco, there is no power. Solar powered pumps are the best option for the Chaco.[79]

One of the greatest water supply and sanitation service needs of the country is increased coverage for rural areas.[80]

2. Industrial and Commercial Uses and Needs

ANESAPA reports that about 1.5 percent of the water supply is for industrial uses, and about 22 percent for commercial. Other sources indicate different percentages. The manufacturing industry has traditionally been a relatively small sector within the global economy; however, in recent years, it has increased. Eighty percent of the industries are located in La Paz, El Alto, Santa Cruz and Cochabamba. The largest industrial water consumers in La Paz are textiles, tanneries, yeast production and beer. Aguas del Illimani supplies the water for these industries.

Industrial water use is low, but the contamination of the water by industry is fairly high. The Rio Pilcomayo has been contaminated by industry. Sugar cane processing also contaminates the water.[81] Aguas del Illimani collects fees from industry that will be used to build a waste treatment facility.

3. Agricultural Uses and Needs

According to a 1999 report by Global Water Partnership, about 85 percent of the water extracted is for agricultural use. Agricultural usage of water for irrigation has limited development in Bolivia. The Andean regions, the valleys and a part of the Chaco with annual rainfall lower than 600 mm/year need irrigation. PRONAR is the national irrigation program. It falls under the Ministry of Agriculture, Cattle and Rural Development Ministry.[82]

Bolivia has the least amount of irrigated land and the least efficient irrigation systems in South America. The average efficiency of the irrigation systems is 15 to 20 percent. This means that about 80 percent of the irrigation water is lost before reaching its destination. Modest efforts are being made to install more efficient systems and to increase the efficiency of existing systems. Lining irrigation canals with concrete is one effort being made. This can increase the efficiency from the current 15 to 20 percent to 80 percent.[83]

According to the National Inventory of Irrigation Systems, 2000, there are a total of 4,724 irrigation systems, excluding Beni and Pando departments, irrigating a total of 226,564 hectares. Cochabamba has the most irrigated land, 87,534 hectares, with over 1,000 irrigation systems. The sources of water for the irrigation are from rivers (69 percent), reservoirs (19 percent), wells (6 percent), and other surface water sources (6 percent).

After treatment, urban and industrial wastewater from Cochabamba is used in irrigation systems.

There is a national regulation for irrigation water, dated July 1967. This regulation establishes that ground water is public domain; therefore permits are required for drilling wells.[84]

The San Jacinto project is the only irrigation project in Bolivia which has tariffs based on the volume of delivered water. Due to the tariff, water usage decreased significantly.

There are many traditional irrigation areas in the Altiplano. The Altiplano conditions have important irrigation potential due to the favorable soils and water resources. The Global Binational Master Plan of Protection and Prevention of Floods and usage of the water resources of the Titicaca-Desaguadero-Poopo-Salar System Studies (TDPS) have studies of four irrigation pilot projects for the area, which would irrigate 74,000 hectares.[85]

4. Water Supply Quality

SISAB is the agency responsible for regulating the quality of the water supply. Norma Boliviana (NB 512, October 1997) is the regulation for the quality requirements of potable water. This regulation was adopted in 1997. The Ministerio de Vivienda y Servicios Basicos establishes guidelines for drinking water quality. The problem areas for water contamination are from agriculture, from pesticides and chemicals, industrial contamination, and sewerage. Not all cities have water treatment, and wastewater treatment is insufficient or non-existent for some areas. See table 5 for water treatment by city.[86]

In 1992, there was a cholera outbreak with 24,000 reported cases caused by the water supply. The major percentages of child mortality are due to water quality related diseases, mainly diarrhea.[87]

Several major watersheds continue to have high pollution levels, and according to a 2001 PAHO report, only four major cities have wastewater treatment plants.[88] As a result, much of the collected sewage and waste is untreated and discharged raw into the waterways. The rivers become so polluted that they should not be used for irrigation, but often are. The Rio Choqueyapu is one example. The resulting contaminated crops are a major environmental health concern. Wastewater volume and treatment for urban areas are outlined in table 6.

Diarreal diseases, which are frequently transmitted by fecally contaminated water, continue to be a leading cause of morbidity and mortality among children in developing countries. The optimal approach to preventing waterborne diseases, which includes the construction of water treatment and/or disinfection and distribution systems and sewage treatment facilities, is very expensive and time-consuming.[89]

According to a USAID quantitative study of the environment, the critical elements in water quality responsibility is the lack of infrastructure, and the lack of environmental consciousness of the citizens, but mainly the lack of consciousness of the institutions. Water quality tends to increase with increasing population density and earning wages of the population. Also, the more rural the population, the more involved the population is in taking responsibility for the water quality. As the size of the population increases, the tendency to make the government responsible increases; i.e., the more urban the population, the less responsible the population is for the water quality.[90]

Table 6. Wastewater Information by City

City	Treatment of Wastewater	Wastewater (m^3/yr)	Unaccounted for water (%)
La Paz	None	43,850,419	33
El Alto	Yes		
Oruro	Under construction	5,488,663	41
Cochabamba	Yes, but has deficiencies	15,910,040	45
Sucre	Under construction	4,795,734	25
Potosi	None	5,717,477	40
Tarija	Yes, but has deficiencies	7,620,480	45
Santa Cruz	Yes	33,300,217	23
Trinidad	Implementing	1,362,215	49
Cobija	None	No data available	No data available
Yacuiba	Yes	2,422,360	No data available
Montero	Under construction	1,660,200	15
Camiri	In planning	No data available	No data available

Source: ANESAPA, notes, June 2002.

5. Misicuni Dam

The planned Misicuni Dam, as previously mentioned, is part of a multipurpose project, designed to alleviate the water supply shortages in Cochabamba. The Misicuni Company of Bolivia recently selected TAMS, an Earth Tech company, to design the dam. The dam will be in the Tunari mountain range. Design work on the US$40 million dam project has already begun with construction scheduled to begin in 2004. The entire multipurpose project is estimated to cost US$354 million. The completed project should provide 6.6 cubic meters per second (m^3/s) of potable water for Cochabamba for 30 years, provide irrigation water to more than 15,000 acres and support a 120 megawatts (MW) hydropower plant. The dam will be constructed as a concrete faced rockfill structure, built in two phases. The first phase will be at a height of 85 meters and the second phase at 120 meters.[91]

B. Hydropower

Bolivia's rivers have considerable untapped hydroelectric potential, and per capita electric consumption remains low. Partly in an effort to improve services, a controlling interest in ENDE was sold in the 1990's to energy companies in the United States and Spain, and the remaining shares were turned over to a national pension system.[92] Many environmental groups oppose the building and development of large hydropower projects.[93]

In the late 1980's, hydroelectric sources provided about 60 percent of the power supply. ENDE, part of the Ministry of Energy and Hydrocarbons, controlled 80 percent of the country's electricity capacity, including five hydroelectric plants. The hydroelectric capacity of approximately 300 MW represented only 2 percent of the potential. Many large hydropower plant projects are dependent upon natural gas exports prices with Brazil.[94] Most of the hydropower potential is in the Amazonian watershed, where most of the existing plants are located.[95]

In 1908, the first hydroelectric plants were installed in Chuquisaca (Duraznillo 100 kilowatts (kW)), La Paz (Achachicala 1.8 kW) and Potosi (Cayara 360 kW) departments.[96] Now there are 68 hydroelectric dams, ranging from small systems (0.006 MW of installed power) up to 75 MW.[97] Two companies own most of the hydroelectric generating capacity: Empresa Electrica Corani South America, and COBEE. A summary of existing hydroelectric power plants is shown in table 7.

By 2006, Bolivia is expected to more than double its hydroelectric generating capacity. Hydroelectrica Boliviana, a subsidiary of U.S.-based Tenaska, Inc., completed a US$100 million project consisting of two new hydroelectric plants near La Paz. The plants, completed in 2002, which are in service now, add about 84 MW in capacity (the capacity figure varies from 83.5 to 91 MW, depending on the source of the information). These two new plants supply electricity to about 100,000 households in the La Paz area. The company's financial projections indicate the project could turn a profit even if it can only sell power during the four hours of peak time a day. A summary of planned hydroelectric projects is shown in table 8.[98]

Table 7. Hydropower Plants, 2002
(5 MW and greater)*

Project	River Name	Installed Capacity (MW)
Yanacachi Norte	Rio Unduavi	84†
La Chojilla	Rio Taquesi	
Santa Isabel	Rio Malaga	75
Corani	Rio Malaga	52
Huaji	Rio Zongo	29
Cahua	Rio Zongo	29
Harca	Rio Zongo	27
Churuaqui	Rio Zongo	26
Cuticucho	Rio Zongo	21
Sainani	Rio Zongo	21
Zongo	Rio Zongo	16
Santa Rosa	Rio Zongo	13
Tiquimani	Rio Zongo	10
San Jacinto Asj	Rio Tolomosa	8
Kanata	n/a	8
Botijlaca	Rio Zongo	7
Carabuco	Rio Miguillas	6
Choquetanga	Rio Miguillas	5

Sources: Utility Data Institute, via US Department of Energy, *An Energy Overview of Bolivia,* Internet, http://www.fe.doe.gov/international/bolvover.html, Accessed May 29, 2002; and Energy and Water for Sustainable Living, *Bolivia Private Hydropwer Project,* Internet, http://www.pi.energy.gov/library/EWSLbolivia.pdf, Accessed June 2, 2003.
*represents 93% of Bolivia's installed hydroelectric capacity excluding Yanacachi Norte and La Chojilla.
†represents the combined capacity of the two plants.
n/a - not available

Table 8. Hydropower Plants Planned or Under Construction, 2002
(10 MW and greater)

Hydroelectric Facility	Owner	River	Capacity, MW	Status	Completion Date
Miguillas	COBEE	Miguillas	350	Planned	2005
Misicuni	Empresa Misicuni	Misicuni	120	Planned	n/a
Cambari	Comision Regional Rio Bermejo	Tarija	102	Planned?	n/a
San Jose Corani	Empresa Electrica Corani	Malaga	84	Planned	n/a

Sources: Utility Data Institute, via US Department of Energy, *An Energy Overview of Bolivia,* Internet, http://www.fe.doe.gov/international/bolvover.html, Accessed May 29, 2002; and
Energy and Water for Sustainable Living, *Bolivia Private Hydropower Project,* Internet, http://www.pi.energy.gov/library/EWSLbolivia.pdf, Accessed June 2, 2003.

C. Waterway Transportation

During the rainy season in the tropical zones of the country, many rivers serve as a main method of transportation, as many roads are inundated and impassable. The Rio Yacuma in the Amazon Basin is one example. The river is used as the primary means of transportation in the area. Bolivia is land-locked, and shares control of Lago Titicaca with Peru. Lago Titicaca is the world's highest navigable lake.

The largest navigable streams in the country are in the Amazon Basin (see figure C-2). The Rio Madre de Dios is navigable for about 500 kilometers from Puerto Heath to the confluence with Rio Beni. There is high boat traffic on the Rio Mamoré for over 1,000 kilometers from Puerto Villarroel to Puerto Sucre. Rio Orthon is navigable for over 200 kilometers from Puerto Rico to the confluence with Rio Beni. Rio Itenez is navigable for about 550 kilometers from Piso Firme to the confluence with Rio Mamoré.

Lago Titicaca connects the railroads of La Paz Guapi and Puno Matarani. Bolivia has three main ports in the lake: Guaqui, Chaguaya and Crillon Tours (Huatajata). Guaqui is the oldest and most important port in the lake, and is connected to La Paz by railroad and highway. The Chaguaya port was constructed to export zinc from a mine, and Crillon Tours for tourism boats. There are also several dock berths for smaller boats.[99]

Although land-locked, Bolivia has free port privileges in maritime ports in Argentina, Brazil, Chile, and Paraguay. There are 10,000 kilometers of commercially navigable waterways.

The Paraguay Parana Waterway, Tamengo Canal, is the most important in the country because it provides access to the Atlantic Ocean. The Canal is also connected to Laguna Caceres and Rio Paraguay. The commerce of grains, especially soybeans, is transported from Aguirre port via the Tamengo Canal.

D. Recreation

Conservation International - Bolivia has been working under an agreement of the Bolivian government and the international NGO Conservation International. One of the main projects was the creation of the 4.5 million acre Madidi National Park. Other projects are: Sustainable Development and Ecotourism; and Biodiversity in Regional Development.[100]

Lago Titicaca is one of the major tourist sites. Copacabana is a town on the shore of Lago Titicaca, usually visited by tourists on their way to or from Peru. As well as being a transit point, the town also serves as a departure point for trips across the lake, in particular to the famous Isla del Sol. The lake can be traversed by large ships, or by hiring a smaller boat.[101] There are also organized trips to Lago Titicaca from La Paz. Many other islands in Lago Titicaca are popular tourist sites.[102]

The damming of the Rio Desaguadero will be beneficial for international tourism and will establish recreation areas for the native population.[103]

IV. Existing Water Resources

A. Surface Water Resources

1. Precipitation and Climate

The extreme range of elevations in Bolivia creates a wide variety of climate variations.[104] Precipitation is directly related to elevation, so higher elevations receive more precipitation than lower elevations. The rainy season occurs in the summer, with 60 to 80 percent of the precipitation falling between the months of December and March. The severity of the dry season varies with location, but generally increases with altitude. Although there is more precipitation overall in higher altitudes, the dry seasons are drier and more severe in these higher climes. In general, there are four climatological regions in the country, classified as tropical, subtropical, temperate, and cold.

The northernmost part of the country is tropical, with average annual temperatures ranging from 24 to 27 degrees Celsius (^{o}C). The tropical region consists of the lowlands in the department of Pando. Annual precipitation rates are high, averaging around 1,950 millimeters (see figure 3).[105]

The north-central part of the country is subtropical, with average annual temperatures roughly ranging from 20 to 27 ^{o}C. The subtropical area consists of the plains in the departments of La Paz, Beni, and Cochabamba.[106] Average annual precipitation varies throughout the region. In general, precipitation gradually increases from 1,200 millimeters per year (mm/yr) in the south to around 2,000 mm/yr in the north. Annual precipitation varies widely throughout this area.

The southeastern part of the country is temperate, with average annual temperatures ranging from 10 to 26 ^{o}C. The temperate region consists of the plains in the departments of Santa Cruz, Chuquisaca, and Tarija. Average annual precipitation in this region ranges from around 500 millimeters in the west to 1,500 millimeters in the center. Precipitation is lower in the east but gradually increases to around 1,300 mm/yr in the northeast.

The southwestern part of the country is cold, with average annual temperatures ranging from 3 to 15 ^{o}C. The cold region consists of the mountains and Altiplano in the departments of Oruro and Potosi, and the southern part of La Paz. Average annual precipitation in this region is very low, ranging from less than 1,000 millimeters in the north to less than 200 millimeters in the south.

Figure 3. Precipitation Map

2. River Basins

The country can be divided into three hydrological basins: the Amazon, the La Plata, and the Central basin.[107] These basins are delineated in figure C-1. Topography and surface water resources vary in each basin. All surface water in streams is fresh, except in the arid southwest.

The largest of the basins is the Amazon basin in the north. This basin covers an area of approximately 724,000 square kilometers, which represents about 66 percent of the country. The largest navigable streams in the country are located in the Amazon basin. Their headwaters are located in the Andes Mountains or the surrounding uplands, and drain to the northern tip of the country. There are five major sub-basins within the larger basin. The Rio Beni, Rio Acre and Rio Abuna, Rio Mamoré, Rio Itenez o Guapore, and the Rio Madera drain these sub-basins. Precipitation ranges from 700 millimeters to 5,000 mm/yr, with the highest concentration of rainfall in the headwater area of Rio Chapare. Average annual precipitation for the basin is 1,380 millimeters. Most of the major rivers experience annual flooding during the wet summer months.[108] Approximately 100,000 to 150,000 square kilometers of land are inundated annually. Streams at high elevations have steep, deeply eroded streambeds, and rise rapidly in response to precipitation. Downstream, in the lower elevations, streams are generally meandering and have poor access due to heavy vegetation cover and lack of a developed road network. Rapids and tree snags are common in the largest streams.

The second largest basin is the La Plata basin in the southeast. This basin covers an area of approximately 229,500 square kilometers, which represents about 21 percent of the country. The southern rivers have headwaters located in the Andes Mountains and flow to the south. The eastern rivers have headwaters located in the plains and flow to the east or southeast. There are three major river sub-basins within the larger basin: the Rio Paraguay, Rio Pilcomayo, and Rio Bermejo. Precipitation ranges from 400 mm/yr in the southeast to 1,300 mm/yr in the north and northeast. Average annual precipitation for the basin is 840 millimeters. Flooding is most pronounced in the flat eastern plains known as the Chaco. Streams in higher elevations have steep, deeply eroded streambeds, and rise rapidly in response to precipitation. Downstream in the lower elevations, streams generally are meandering and have poor access due to heavy vegetation cover and lack of a developed road network.

The smallest basin is the Central basin located in the Altiplano in the southwest. This basin covers an area of approximately 145,081 square kilometers, which represents about 13 percent of the country. This is an endorrheic basin, which means that all the drainage in the area lacks an outlet. Streams either flow into lakes, or salars, which are thick, expansive deposits of salts left behind from water bodies that have evaporated. Most streams flow toward the south, and become increasingly saline as they encounter drier conditions and accumulate more total dissolved solids. Surface water TDS values range from less than 100 milligrams per liter (mg/L) to more than 100,000 mg/L. There are five major sub-basins within the larger basin, draining Lago Titicaca, Rio Desaguadero, Lago Poopo, Salar de Coipasa, and Salar de Uyuni. Precipitation ranges from less than 100 mm/yr in the southwest to 1,000 mm/yr in the north and northeast. Average annual precipitation for the basin is 220 millimeters. The few streams that flow through this basin have very low gradients and follow a meandering course. Access to streams may be hindered by rugged terrain and lack of a developed road network.

3. Lakes, Reservoirs, and Wetlands

Lago Titicaca is located in the Andes Mountains on the Peruvian border west of the capital, La Paz.[109] It is the highest navigable lake in the world.[110] The lake is situated at an elevation of 3,810 meters a.s.l.[111] Lago Titicaca has a surface area of 8,400 square kilometers, and is 176 kilometers long and 70 kilometers wide at the widest point. It is South America's largest fresh water lake. The lake has a maximum depth of 283 meters, and average volume of 930,106 million cubic meters.[112] Although irrigation and industrial activities take place near the lake, the lake and surrounding tributaries are protected by a bi-national agreement between Bolivia and Peru to prevent the resources from being overexploited.[113] While there are many tributaries feeding the lake, primarily from Peru, the only outlet from the lake is Rio Desaguadero. Lago Titicaca drains southward through the Rio Desaguadero to Lago Poopo. The river is fresh at its origin at Lago Titicaca but becomes increasingly saline as it flows south to Lago Poopo. Dredging operations have been established to combat problems with sedimentation.

Between 1998 and 2001, regulation flood gates of Lago Titicaca were installed at a cost of US$7.2 million. Dredging of Desaguadero River has been ongoing since 2000. These activities were initiated after the start of the Binational Autonomous Authority of the Titicaca – Desaguadero – Poopo – Salar Hydric System in 1996. The governments of Bolivia and Peru contributed funding to the projects.[114]

Lago Poopo is a hypersaline lake, with TDS of 100,000 mg/L. The water has such a high concentration of dissolved salts that it has crusty salt deposits on its shores. Because Lago Poopo is totally dependent on seasonal rainfall and the overflow from Lago Titicaca, the lake's surface area varies considerably throughout the year. Several times in the twentieth century the lake nearly dried up when rainfall was low, or when silt deposits accumulated in the Rio Desaguadero and blocked flows to the lake. During years of heavy rainfall, Lago Poopo has overflowed to the west, filling the Salar de Coipasa with shallow water. Lago Uru Uru is located just north of Lago Poopo. It has a surface area of 260 square kilometers and also has high salt concentrations.

The land south of these salt lakes becomes increasingly arid. Salar de Coipasa is a dry, salt encrusted area covering 2,225 square kilometers. Salar de Coipasa has a perennial body of salt water, Laguna de Coipasa, which is fed by a radial network of surrounding streams.[115] Further south is Salar de Uyuni, which has a surface area of 12,000 square kilometers, and is seasonally inundated with water. The water in the salar is saline.[116] The Rio Grande de Lipez flows south from this salt-covered region.

There are several clusters of sizeable lakes located throughout Bolivia. The Amazon basin is dotted with lakes, with a large concentration of them near Rio Yata and Rio Mamoré. There is another cluster of lakes located further to the south near Rio Chapare and Rio Grande o Guape. Several lakes are shared with Brazil in the La Plata basin along the border near Rio Curiche Grande. The 10 kilometer long Tamengo Canal is fed by one of these lakes, Laguna Caceres.[117] Each of these lakes has a surface area ranging between 10 and 300 square kilometers.

Five major cities have reservoirs that provide water to their municipal water distribution systems. Sucre has one reservoir and La Paz has several reservoirs that are well maintained. Cochabamba has a new reservoir, which is under construction. Potosi has an old reservoir in poor condition, and Tarija has an old reservoir that requires new dam construction.[118]

There are several wetlands of international importance located throughout the country.[119] Ramsar, an international convention on wetlands, has several of them on their protected list: the wetlands and marshes surrounding Lago Titicaca, Lago Poopo, Lago Uru Uru, Laguna Colorada, Laguna Concepcion, the Pantanal Boliviano wetlands, Banados del Izozog and Rio Parapeti in the Chaco region, the lake and marsh areas of Cuenca de Tajzara, and the saline and non-saline palm forests of Palmar de las Islas y las Salinas de San Jose. Many of these wetlands are protected national parks or biological reserves.

4. Deforestation and Effects

Land clearing for agricultural purposes and the international demand for tropical timber are contributing to deforestation. Deforestation began when mining activities increased between Potosi and Oruro in colonial times. Timber harvesting in the nineteenth century started the deforestation process in the Chaco valleys of Tarija. In the middle of the twentieth century, oil development reduced forest cover in Santa Cruz and Tarija. Between 1978 and 1997 the percentage of Bolivia covered by forests dropped from 51.4 to 21.9 percent. Deforestation is one the major current environmental issues of the country. According to World Bank figures for 1990 to 1995, annual deforestation was 5,814 square kilometers. The increased erosion as a result of deforestation causes many problems with the surface water. Among the problems, also discussed in C. Water Quality, are increased surface water runoff, reduced aquifer recharge, and increased salinity and sediments loads in streams.

According to a World Resources Institute Study from 1991, forest covered about 51 percent of Bolivia. However more recent figures, show a much reduced forest cover. The forestry sector is in great disequilibrium. In areas of high population density there is almost a complete lack of timber resources, while in the less populated areas these resources are abundant, but subject to large-scale exploitation. Deforestation for farming and grazing purposes has been a main cause of environmental degradation, yet forest product industries such as sawmills are scarce, and operate well below capacity.[120]

The high salinity in the Lago Titicaca watershed is due in part to the transport of sediments. These sediment loads can be attributed to mining activities and to deforestation.

Wood exploitation rights granted by the state institutions to the wood companies covers a surface area equivalent to 36 percent of the country's forested land, or 18 percent of the country's total land surface. Overall, deforestation affects 100,000 hectares per year. Tree cutting for charcoal and poles is causing deforestation in the Chaquenian forests, located in Santa Cruz, Chuquisaca and Tarija.

In the last 20 years, there has been considerable migration of farmers to the Bolivian tropics, especially toward the Amazonian and Del Plata springs. The farmers have few resources (equipment, fertilizers, pesticides, other chemicals, etc.) to clear the land, so they 'slash and burn'. The burning methods disturb the ecological balance, and cause different impacts to the soil and water.[121]

The production of cocaine in the Andean region has caused tremendous destruction to the environment. Biodiversity loss is rampant, as forests, with divergent plant species are cleared for more coca fields, in response to demand. Proper agriculture techniques are frequently not applied by the migrant laborers by cultivating raw coca on un-terraced plots. In the 1980's and 1990's, it is estimated that 2,700 square miles of Amazon rain forest were destroyed as a result of coca cultivation. This exacerbates soil fertility problems in the area, because the trees and plant life that prevent soil erosion are recklessly cleared. These unfertile lands are quickly abandoned by the farmers, and they move on to clear new areas for new fields, in a vicious cycle. Associated activities with this illegal industry causes additional environmental destruction. An example is the clearing in the forests for obscure, illegal air strips for transporting the crops and end product.[122]

USAID is a key donor working to protect forest resources. More than a million hectares have been protected or placed under improved management since 1995.[123]

B. Ground Water Resources

The use of ground water resources is very limited compared to surface water. Variations in the geological structures, geomorphology, rock types, and precipitation contribute to the widely varying ground water conditions in different parts of the country.

The most productive sources of ground water are in the Quaternary age alluvial aquifers and Quaternary to Tertiary age sedimentary and igneous aquifers. These sources are located in the Beni and Gran Chaco Plains and on the eastern slopes of the Andes Mountains. The Chaco-Beni hydrogeological unit forms the largest single ground water reservoir in the country. The Brazilian Shield area of eastern Bolivia contains no continuous aquifers, and the geologic formations have low porosity and permeability. Ground water only occurs in the fractured and weathered zones of the Precambrian age metamorphic and igneous rocks. However, alluvial aquifers are a major source of ground water, especially along the Rio Paragua. The quantity and quality of ground water in the Altiplano varies from north to south. Low precipitation and high salinity contribute to poor ground water conditions in the southern Altiplano area.[124]

The unconsolidated and semi-consolidated aquifers (map units 1, 2 and 5) make up about 55 percent of the country and contain about 55 percent of the available ground water reserves. Areas containing Mesozoic to Paleozoic age sedimentary and igneous aquifers consisting of basalt, dacite, tuff, and ignimbrites (map unit 3) make up about 25 percent of the country and contain about 40 percent of the available ground water reserves. Precambrian age igneous and metamorphic aquifers with poor porosity and permeability (map unit 4) make up about 20 percent of the country and contain about 5 percent of the available ground water reserves.

The ground water resources range from easy to difficult to develop. Extensive geophysical investigating or exploratory drilling is necessary to locate areas of maximum yield and quality. Although ground water is generally safer than untreated surface water supplies, many shallow aquifers are biologically contaminated near populated areas. Accessibility to drilling sites is difficult in many areas due to the steep slopes of hills and mountains. Wells in all areas should be cased and screened, especially where aquifers are composed of unconsolidated sediments. Hard rock drilling techniques are required in areas of dense igneous and metamorphic aquifers to locate water-bearing fractures.

1. Aquifer Definition and Characteristics

To understand how ground water hydrology works, and where the most likely sources of water may be located, a short aquifer definition of aquifer characteristics are presented here, followed by specific country attributes.

Ground water supplies are developed from aquifers, which are saturated beds or formations (individual or groups), which yield water in sufficient quantities to be economically useful. To be an aquifer, a geologic formation must contain pores or open spaces (interstices) that are filled with water, and these interstices must be large enough to transmit water toward wells at a useful rate. An aquifer may be imagined as a huge natural reservoir or system of reservoirs in rock whose capacity is the total volume of interstices that are filled with water. Ground water may be found in one continuous body or in several distinct rock or sediment layers within the borehole, at any one location. It exists in many types of geologic environments, such as intergrain pores in unconsolidated sand and gravel, cooling fractures in basalts, solutions cavities in limestone, and systematic joints and fractures in metamorphic and igneous rock. Unfortunately, rock masses are rarely homogeneous, and adjacent rock types may vary significantly in their ability to hold water. In certain rock masses, such as some types of 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 fractures or joints in the rock. Therefore, if a borehole is drilled in a particular location and the underlying rock formation (bedrock) is too compact (consolidated with little or no primary permeability) to transmit water through the pore spaces and the bedrock is not fractured, then little or no water will be produced. On the other hand, if a borehole is drilled at a location where the bedrock is compact and the rock is highly fractured and has water flowing through the fractures, then the borehole could yield sufficient water to be economically useful.

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

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

2. Hydrogeology

Variations in the geological structures, geomorphology, rock types, and precipitation contribute to the wide variety of ground water conditions in different parts of the country, as shown in figure C-2. Five distinctive hydrogeological provinces can be identified from west to east: the Altiplano and Western Andes (Altiplano Cordillera Occidental, map unit 5); the Eastern Andes and Subandean Zone (Vertiente Andina, map unit 3); the Beni Plain (Vertiente Amazonas, map unit 1); the Gran Chaco Plain (Pantanal-Chaco Pampeano, map unit 2); and the Brazilian Shield (Escudo Proterozoico, map unit 4).

The primary aquifers in these hydrogeological provinces are Quaternary age unconsolidated and semi-consolidated aquifers (map units 1 and 2); Quaternary age alluvial aquifers, Mesozoic to Paleozoic age sedimentary aquifers and Quaternary to Tertiary age igneous aquifers (map unit 3); Precambrian age metamorphic and igneous aquifers with smaller areas of Quaternary age alluvial aquifers (map unit 4); and Quaternary age alluvial aquifers and Quaternary to Tertiary age igneous aquifers (map unit 5). These aquifer systems are described in table C-2 and depicted on figure C-2. Descriptions are based upon interpretation of the most current hydrogeological information available.[125]

In the Beni Plain (map unit 1), depth to aquifer generally ranges from 30 to 90 meters, and depth to aquifer in the Gran Chaco Plain (map unit 2) ranges from 130 to 150, and greater than 180-200 meters. In the Eastern Andes and Subandean Zone (map unit 3) depth to aquifer is generally less than 100 meters. In the Brazilian Shield (map unit 4) and the Altiplano and Western Andes (map unit 5), depth the aquifer is generally less than 90 meters. In many areas, the depth to water may be too deep and yields too low for economic use. Throughout the country the water table is subject to seasonal fluctuations. In the Altiplano and along the eastern border, the water table drops and many wells go dry during the dry season. Most hand pumps cannot produce water from depths greater than 80 meters or so. Aquifers in the mountains are generally recharged by rainfall, while those in the lowlands are primarily recharged by rainfall, streams, and aquifers originating in the mountains.[126]

Access to well sites is generally easy in the Beni and Gran Chaco Plains and Altiplano. In the Western and Eastern Andes, steep slopes make ground water exploration difficult. Hard rock drilling techniques and exploratory drilling are necessary in the igneous and metamorphic aquifer areas to locate zones of maximum yield and best quality. However, the lack of an established road network and dense vegetation in some remote areas make site access difficult. Wells in all areas should be cased and screened, especially where aquifers are composed of unconsolidated sediments or volcanic deposits.

a. Unconsolidated and Semi-consolidated Aquifers (map units 1 and 2)

Small to very large, and small to enormous quantities of fresh water are generally plentiful from productive Quaternary unconsolidated and semi-consolidated aquifers composed of unconsolidated and semi-consolidated gravel and sand interbedded with clay, and silt. These aquifers are found in the Beni Plain (Vertiente Amazonas, map unit 1) and the Gran Chaco Plain (Pantanal-Chaco Pampeano, map unit 2) hydrogeological provinces. Ground water in these aquifers is generally found at depths ranging from 70 to 90 meters in the Beni Plain, and from 180 to over 200 meters in the Gran Chaco Plain.

b. Sedimentary Aquifers and Volcanic Pyroclastic and Lava Aquifers (map unit 3)

Very small to very large quantities of fresh water are locally plentiful from productive Quaternary alluvial aquifers consisting of sandstone and shale with some conglomerate; Mesozoic to Paleozoic sedimentary aquifers consisting of sandstone, siltstone, shale and conglomerate; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff, and ignimbrites. Mineral and thermal springs are common from Silurian and Devonian age rocks. These aquifers are part of the Eastern Andes and Subandean Zone (Vertiente Andina, map unit 3) hydrogeological province. Depths to aquifers are generally less than 100 meters.

c. Metamorphic and Igneous Aquifers and Local Alluvial Aquifers (map unit 4)

Fresh water is locally plentiful from Precambrian age metamorphic and igneous aquifers consisting primarily of fractured and jointed basalt and granite. These aquifers are found in the Brazilian Shield (Escudo Proterozoico, map unit 4) hydrogeological province of eastern Bolivia. Partially metamorphosed sandstone, siltstone and limestone aquifers are present near the border with Brazil. Very small to very large quantities of ground water are available from these aquifers. Ground water is primarily from weathered zones and fractures and joints that have enhanced porosity and permeability. Quaternary alluvial aquifers are the major source of ground water in the Brazilian Shield, especially along the Rio Paragua. Depth to aquifers is variable but generally less than 90 meters.

d. Other Aquifers (map unit 5)

Fresh water is scarce or lacking in the Altiplano hydrogeological province. Ground water availability and quality vary from north to south. The region with the best quality ground water is between Lago Titicaca and La Paz. However, some aquifers near La Paz have been over pumped. The southern part of the Altiplano, which includes the substructures of Lago Poopo, Coipasa and the Salar de Uyuni, has low precipitation and high salinity, which contributes to poor quality ground water. Brackish to saline water is available in meager to very large quantities from Quaternary age unconfined to semi-confined aquifers, consisting of unconsolidated to semi-consolidated gravel, sand, silt and clay interbedded with salt layers. The Western Andes, along the border with Chile, are volcanic mountains and are also included in this category. These Quaternary to Tertiary age aquifers are mainly igneous rocks consisting of basalt and tuff along with some sandstone and shale. Springs are common. Meager to small amounts of fresh water are available from the igneous and metamorphic aquifers and aquifers composed of tuff and sandstone. Locally, larger quantities may be available where weathering and fracturing has enhanced the porosity and permeability. Depth to aquifer is variable but is generally less than 90 meters. These aquifers are found in the Altiplano and Western Andes (Altiplano Cordillera Occidental, map unit 5) hydrogeological province.[127] In this area the water table drops, and many wells go dry during the dry season.

C. Water Quality

Problem areas include contamination coming from agriculture, from pesticides and chemicals, and industries. This is a major problem in every city and community, and in the rural areas of the country. Water contamination has serious implications for the health of the entire nation. In the Altiplano, industrial contamination is a problem. In the valleys and plains, industrial and agricultural (pesticides, chemicals) contamination is a problem.

Mining was a very important industrial activity in the country. However, mining wastes and processes cause a lot of water contamination. Cyanide, used for gold extraction, is dumped in the rivers after processing.[128]

Lago Poopo is highly contaminated with natural salinity, and by heavy metals, produced by mining activity. Water quality is good in the tributary rivers of Lago Titicaca, while the increasing salinization south limits its use for irrigation purposes.[129]

Not all effluent water is treated before being discharged into rivers and coastal waters. Table 6 in Chapter III contains information on discharged wastewater by city, obtained from ANESAPA. Note that all sewage from La Paz is discharged into the river without treatment. This severely contaminates the river downstream of La Paz, rendering it unfit for irrigation. The lack of wastewater treatment causes severe degradation of the water quality in the nation's surface water resources.

1. Surface Water Quality

The predominant threats to the surface water resources are desertification from deforestation, and contamination from development activities.[19] There is a direct correlation between decreased forest cover and increased erosion. Rapid deforestation has created problems with increased surface water runoff, reduced aquifer recharge, increased salinity and sediment loads in streams, and increased soil moisture loss. This in turn has created changes in rainfall patterns, loss of biodiversity, changes in soil composition, and increased incidence of forest fires, all of which encourage further desertification. Deforestation has had such a devastating effect on vegetation cover that sand dunes have been forming in the Chaco region, and in arid valleys and basins of the Andes region.

Currently, one of the most common reasons for clearing forest cover is to create agricultural space. In 1997, 52.2 percent of land in the country was used for agriculture or livestock grazing. The resulting increase in agricultural land has elevated levels of chemical contamination from pesticides and herbicides, and from processing harvested crops. The highest growth rate in agricultural activity is around Santa Cruz. There has also been a lot of agricultural development in the Chaco region, in Chapare, in the areas north of La Paz, and in the departments of Beni and Pando.

Industrial contamination is the greatest problem in the Altiplano.[130] In the valleys and plains, surface water is threatened by contamination from industrial sources as well as from agricultural activities, pesticide and herbicide use, and other sources of chemical contamination. All navigable rivers are subject to pollution from biological contamination and hydrocarbons from watercrafts.

Mercury contamination and increased sediment loads are common problems downstream from silver and gold mining operations.[131] Large mining companies often provide some sort of treatment before dumping their mining tailings downstream. However, there are countless numbers of small mines operated by individual landowners throughout the country who do not treat their mining tailings before discharging them into the streams, even when the water they use for their personal use is located downstream from the mines. Mercury contamination is an especially urgent problem in Rio Pilcomayo, where fish are considered too toxic to safely eat, and long-term studies are proving that local residents are suffering ill health effects from mercury poisoning. The Rio Madera also has problems with mercury contamination.[132] Exacerbating the problem is the fact that in many areas of the country, there are naturally high concentrations of arsenic and mercury in the soil, which creates relatively high contaminant concentrations in the streams even without mining pollution.

The production of cocaine in the Andean region has also had a destructive impact on the surface water quality. During the growth process, to maximize profits, large quantities of pesticides, weed killers, and fertilizers are used. Peruvian environmentalists estimate that coca growers use 1.5 million liters of paraquat, a herbicide, each year in one valley alone. These chemicals affect the soil, and contaminate the waterways, which in turn has serious effects on other life in the area. Coca processing plants use huge amounts of toxic chemicals to produce the final product. After the chemicals are used, the waste is simply dumped onto the ground, or directly into rivers. Chemical wastes include kerosene, sulfuric acid, lime, calcium carbide, acetone, toluene, and ethyl ether. Another waste product is hydrochloric acid, which can increase water pH, reduce oxygen availability, and lead to acute and chronic fish poisoning. Some coca eradication methods use herbicides that are highly toxic, eventually finding their way into the surface and ground water.[133]

2. Ground Water Quality

Except for brackish or saline ground water in the Altiplano hydrogeological province in the southwest, generally, ground water is suitable for most uses. However, some areas may have natural and manmade contamination. Natural factors include hardness, phosphates, sodium, bacteria, chlorides, dissolved solids, organic material, and dissolved oxygen content. Manmade pollutants include nitrates, phosphates, sodium, potassium, chlorides, bacteria, ammonia, nitrogen, oil and grease, heavy metals, dissolved solids, chlorine, pesticides, and fertilizer. These pollutants result from agricultural runoff, livestock production, industrial effluent, urban runoff, soil leaching, marine water inflow, erosion, road construction, mining, forestry, slash and burn agriculture, and domestic wastewater. Biological and chemical contamination occurs in shallow aquifers near population centers. Chemical contamination of shallow aquifers by pesticides occurs in the agricultural areas. Mining activities near the Cordillera Oriental cause local contamination. Ground water from the igneous and metamorphic aquifers may be distasteful and discolored due to high iron and manganese content.[134]

V. Water Resources Departmental Summary

A. Introduction

This chapter summarizes the water resources information of Bolivia, which can be useful to water planners as a countrywide overview of the available water resources. Figure C-1, Surface Water Resources, divides the country into surface water categories identified as map units 1 through 5. Table C-1, which complements figure C-1, details the quantity, quality, and seasonality of the significant water features within each map unit and describes accessibility to these water sources. Figure C-2, Ground Water Resources, divides the country into ground water categories identified as map units 1 through 5. Table C-2, which complements figure C-2, details predominant ground water characteristics of each map unit including aquifer materials, aquifer thickness, yields, quality, and depth to water. A summary based on these figures and tables is provided for each of the nine departments.

B. Water Conditions by Map Unit

Figure C-1, Surface Water Resources, divides the country into five map unit categories based on water quantity, water quality, and seasonality. Map units 1 through 4 depict areas where fresh surface water is perennially available in small to enormous quantities. Map unit 5 depicts where unsuitable to moderate quantities of fresh to brackish water are seasonally available, and large quantities of saline water are available from intermittent and perennial streams. Figure C-1 also divides the country into three hydrographic basins, the Amazon drainage region, the Central drainage region, and the La Plata drainage region, labeled I through III. The locations of selected river gaging stations are also depicted in figure C-1.

Figure C-2, Ground Water Resources, divides the country into five map unit categories based on water quantity, water quality, and aquifer characteristics. Map units 1 and 2 depict areas where ground water development appears to be most favorable and fresh water is generally available in small to enormous quantities. Map units 3 and 4 depict areas where fresh ground water is locally plentiful in very small to very large quantities. Map unit 5 depicts areas where perennial sources of fresh ground water are scarce or lacking or areas where the ground water is brackish to saline.

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

Surface Water Quantitative Terms:

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

Ground Water Quantitative Terms:

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

Qualitative Terms:

Fresh water	= maximum total dissolved solids (TDS) ≤1,000 milligrams per liter [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

C. Water Conditions By Department

The following information is compiled for each department from figures C-1 and C-2 and tables C-1 and C-2. The write-up for each department consists of a general and regional summary of the surface water and ground water resources, derived from a country-scale overview. The conditions described may differ locally. The department summaries should be used in conjunction with figures C-1 and C-2 and tables C-1 and C-2. Additional information is necessary to adequately describe the water resources of a particular department. Specific well information is limited and for many areas unavailable. For all areas that appear to be suitable for tactical and hand pump wells, local conditions should be investigated before beginning a well-drilling program.

Beni

Area and Relative Size:	213,564 square kilometers (19.5 percent of the country)
Estimated Population (2001):	362,521 (4.4 percent of the population)
Population Density:	1.7 people per square kilometer
Department Capital:	Trinidad
Location:	This department is in the northern part of the country and borders Brazil on its northeastern side. Bordering departments are Pando and La Paz to the north and northwest, Cochabamba to the south, and Santa Cruz to the southeast.

Surface Water:

Fresh water is perennially available from streams and lakes throughout the department. The primary sources of surface water are Rio Itenez o Guapore, Rio Mamoré, and Rio Beni, located in map unit 1. Enormous quantities of water are available from Rio Itenez o Guapore. Very large quantities of water are available from Rio Mamoré and Rio Beni. Each of these streams has major tributaries that provide moderate to large quantities of water. A cluster of lakes is located in the north-central part of the department from map unit 2, which also provides large quantities of water. Small to large quantities of water are available from streams in map unit 4 in the Andes Mountains in the southeastern part of the department.

Water quality is generally fresh. A narrow band of petroleum reserves is located in the southwestern portion of the department. Mineral reserves are located in the northern, eastern, and southwestern parts of the department. Extraction activities could potentially contaminate ground and surface water resources. All surface water should be considered biologically contaminated, especially near and downstream from populated places.

Geography throughout most of the department consists of alluvial plains, with the exception of the piedmont region on the southwestern border, where the foothills of the Andes Mountains interrupt the flat topography. Elevations in the plains range from 115 to 250 meters above sea level, rising up to 500 to 1,000 meters above sea level in the piedmont. Average annual precipitation varies from 1,300 to around 3,000 millimeters. Precipitation is highest December to March, and lowest June to August.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map unit 1. About 75 percent of the department lies in map unit 1. Small to very large quantities of fresh water are available from the Quaternary aquifers. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 30 to 90 meters. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Wells should be cased and screened. The departmental capital of Trinidad lies in this unit, and ground water production provides 100 percent of the water supply.

Map unit 4 covers about 25 percent of the department. Very small to very large quantities of fresh water are available from fractures and joints in Precambrian age metamorphic and igneous aquifers consisting of granite and gneiss. These aquifers are located in the northeastern and eastern parts of the department. Locally along streams, ground water is available from alluvial aquifers. Depth to water is generally less than 90 meters. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Shallow ground water is often biologically contaminated near settlements. Reconnaissance and exploratory drilling is necessary to locate water-bearing fracture zones. Wells should be cased and screened.

Chuquisaca

Area and Relative Size: 51,524 square kilometers (4.7 percent of the country)
Estimated Population (2001): 531,522 (6.4 percent of the population)
Population Density: 10.3 people per square kilometer
Department Capital: Sucre
Location: This department is located in the southeastern part of the country, and borders Paraguay on its eastern side. Bordering departments are Santa Cruz and Cochabamba to the north, Potosi to the west, and Tarija to the south.

Surface Water:

Fresh water is perennially available from streams throughout the department. The primary sources of surface water are Rio Grande and its tributary Rio Caine, Rio Pilcomayo, Rio Parapeti, and Rio San Juan del Oro, all located in map unit 4. Moderate to large quantities are available from Rio Grande and Rio Pilcomayo. Moderate quantities are available from Rio Caine and Rio Parapeti. Small quantities are available from Rio San Juan del Oro. Moderate to large quantities of water are available from streams in the eastern part of the department in map unit 3. In general, stream flows fluctuate greatly throughout the year, and most streams carry high sediment loads.

Water quality is generally fresh, although salt and heavy metal contamination has been reported in Rio Pilcomayo. Petroleum reserves are located in the eastern part of the department, and mineral reserves are located in the western part of the department. Extraction activities could potentially contaminate ground and surface water resources. Problems with desertification have been identified throughout the department. All surface water should be considered biologically contaminated, especially near and downstream from populated places.

In the western and central part of the department the geography consists of Andean and sub-Andean mountainous terrain with parallel lines of mountains and valleys, transitioning into plains in the eastern Chaco region. Altitude ranges from 600 to 2,200 meters above sea level. Average annual precipitation varies from 200 millimeters in the west up to 1,100 millimeters in the northeast, and down to 600 millimeters on the eastern edge. Most precipitation occurs between December and March. The driest months are June to August. A reservoir supplies water to Sucre, the capital of the department. 100 percent of the city’s water supply is provided by the reservoir. The reservoir and dam are approximately twenty years old and in good condition.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map unit 2. About 25 percent of the department lies in map unit 2. Small to enormous quantities of fresh water are available from the Quaternary aquifers of the Gran Chaco Plain area. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 180 to greater than 200 meters. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Wells should be cased and screened. Aquifers are also suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps.

Map unit 3 covers about 75 percent of the department and is found in the west and north. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains. The departmental capital of Sucre lies in this unit, and ground water is not used as a source for water supply.

Cochabamba

Area and Relative Size: 55,631 square kilometers (5 percent of the country)
Estimated Population (2001): 1,455,711 (17.6 percent of the population)
Population Density: 26.2 people per square kilometer
Department Capital: Cochabamba
Location: This department is located in the central part of the country. Bordering departments are Beni to the north, Santa Cruz to the east, Chuquisaca and Potosi to the south, and Oruro and La Paz to the west.

Surface Water:

Fresh water is perennially available from streams throughout the department. The primary sources of surface water are Rio Alto Beni, Rio Isiboro, Rio Mamoré, Rio Chapare, Rio Ichilo, Rio Mizque, Rio Grande, and Rio Caine. Very large quantities of water are available from map units 1 and 2 from Rio Alto Beni, Rio Mamoré, Rio Ichilo, and Rio Chapare. Moderate to large quantities of water are available from Rio Mizque, Rio Grande, and Rio Caine, located in map unit 4. High flows generally occur in January. The largest streams in the northern part of the department flood annually. Low flows generally occur July to October. The dry season is more pronounced in the southern part of the department.

Water quality is generally fresh. Petroleum reserves are located in the northeastern part of the department, and mineral reserves are located in the central and southern parts of the department. Extraction activities contaminate ground and surface water resources. Problems with desertification have been identified throughout the southern part of the department. Further study is required in the northern part of the department. All surface water should be considered biologically contaminated, especially near and downstream from populated places.

Geography consists of mountainous elevations in the Andes up to 4,000 meters, sub-Andean elevations between 900 and 2,500 meters with steep valleys and subtropical microclimates, and flat topography between 500 and 900 meters above sea level. The largest streams flow through deeply entrenched V-shaped valleys. Average annual precipitation varies from 5,000 millimeters in the center of the department to 500 millimeters in the southwest. Most precipitation occurs December to March. The driest months are May to August. A reservoir supplies much of the water for the city of Cochabamba, the capital of the department.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map unit 1. About 45 percent of the department lies in map unit 1. Small to very large quantities of fresh water are available from the Quaternary aquifers. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 30 to 90 meters. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Wells should be cased and screened.

Map unit 3 covers about 55 percent of the department. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains. The departmental capital of Cochabamba lies in this unit and ground water supplies about 65 percent of the water for the city. However, over pumping has stressed aquifers near Cochabamba.

La Paz

Area and Relative Size:	133,985 square kilometers (12.2 percent of the country)
Estimated Population (2001):	2,350,466 (28.4 percent of the population)
Population Density:	17.5 people per square kilometer (not including the surface area of Lago Titicaca. 3,690 square kilometers)
Department Capital:	La Paz
Location:	This department is located in the northwestern part of the country and borders Peru and Chile on its western side. Bordering departments are Pando to the north, Beni and Cochabamba to the east, and Oruro to the south.

Surface Water:

Fresh water is perennially available from Lago Titicaca, Rio Alto Beni, Rio Desaguadero, Rio Madre de Dios, Rio Madidi, Rio Mapiri, Rio Coroico, and Rio La Paz. Fresh to saline water is seasonally available from perennial and intermittent streams throughout the department. Enormous quantities are available from Lago Titicaca, located in map unit 1. Lago Titicaca is flanked by marshes. The Ramsar Convention on Wetlands has listed this site as site number 959, which is a “Wetland of International Importance”. Very large to enormous quantities are available from Rio Alto Beni, Rio Madre de Dios, and Rio Madidi, located in map units 1 and 2. Small to large quantities are available from the Rio Mapiri, Rio Coroico, and Rio La Paz, located in map unit 4. Moderate quantities of fresh to brackish water are available from Rio Desaguadero in map unit 5. Water in the Rio Desaguadero starts out as fresh when it flows from Lago Titicaca, but becomes increasingly brackish as it flows south. High flows generally occur January to April; low flows generally occur July to October. Drought conditions are severe during the dry season, especially in the southern portion of the department.

On a yearly average 442 m^3/s of water is contributed to Lago Titicaca from superficial waters from its tributary rivers, direct rainfall, and ground water from subsurface drains from the area around the lake. Evaporation flow from Lago Titicaca averages 200 m^3/s yearly. The mean annual evaporation from the lake is 1,500 mm/year (400 m^3/s).[135]

Lago Titicaca has a useful volume of 21,000 million cubic meters of water. However, 42,000 million cubic meters can be provided if a 5 meter water brace above the flood gates is achieved. The effluent for Titicaca Lake is Desaguadero River. Lagoons have formed along Desaguadero River during the last 60 years in part due to a lack of dredging.[136]

Melting glaciers contribute surface water to reservoirs that supply water for cities, particularly La Paz and El Alto. Most of the water supply for La Paz and El Alto comes from these reservoirs. The reservoirs and dams are between thirty and fifty years old, and in good condition.

Water quality is generally fresh, although salinity generally increases in the dry, southern portion of the department. A narrow band of petroleum reserves is located in the central part of the department, and mineral reserves are located in the central and southern parts of the department. Extraction activities contaminate ground and surface water resources. Problems with desertification have been identified throughout the southwestern part of the department, covering about 42 thousand square kilometers. All surface water should be considered biologically contaminated, especially near and downstream of populated places. La Paz discharges all its wastes into the Rio Choqueyapu. Downstream of La Paz this river is so contaminated that it is unfit for irrigation water. Farmers often use it anyway, with human consumption of these crops causing illnesses.

Geography varies throughout the department. The central area consists of steep mountainous terrain in the Andes with elevations up to 6,400 meters above sea level. The flat Altiplano lies to the south at elevations around 3,900 meters above sea level. The north consists of low plains at around 200 meters above sea level. Average annual precipitation ranges from 400 millimeters in the south to 2,000 millimeters in some northern and eastern parts of the department.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map unit 1. About 25 percent of the department lies in map unit 1. Small to very large quantities of fresh water are available from the Quaternary aquifers. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 30 to 90 meters. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed are suitable for municipal and irrigation wells. Wells should be cased and screened.

Map unit 3 covers about 50 percent of the department. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for hand -pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains. The departmental capital of La Paz lies in this unit and ground water production provides a small percent of the water supply. However, aquifers near La Paz are stressed due to over pumping. Ground water is heavily relied upon for water supply for La Paz. About three percent of the treated water supply for La Paz and El Alto is provided by ground water.

Fresh water is scarce or lacking in the remaining 25 percent of the department that lies in the Altiplano. Ground water exploration for military operations is not recommended in this area. Meager to very large quantities of brackish to saline water are available from Quaternary age aquifers in map unit 5. Ground water salinity increases to the south. The best quality ground water is between Lago Titicaca and the national capital, La Paz. These aquifers consist of unconsolidated gravel, sand, silt, and clay. The Quaternary to Tertiary age igneous aquifers and pyroclastic deposits of the western Andes also lie in this department. Depth to water is generally less than 90 meters. Springs are abundant in the Western Andes with high mineralization and gas content. Water temperatures vary between 60 and 80 degrees Fahrenheit. Shallow ground water may be biologically contaminated near settlements.

Oruro

Area and Relative Size:	53,588 square kilometers (4.9 percent of the country)
Estimated Population (2001):	391,870 (4.7 percent of the population)
Population Density:	7.3 people per square kilometer
Department Capital:	Oruro
Location:	This department is located in the southwestern part of the country, and borders Chile on its western side. Bordering departments are La Paz to the north, Cochabamba to the northeast, and Potosi to the east and south.

Surface Water:

Fresh water is generally scarce or lacking throughout the department. The primary sources of surface water are Rio Desaguadero, Rio Lauca, Lago Uru Uru, Laguna de Coipasa, and Lago Poopo, located in map unit 5. Moderate quantities of fresh to brackish water are perennially available from Rio Desaguadero. Small quantities of fresh to brackish water are available from Rio Lauca. Large quantities of saline water are available from Lago Poopo and Lago Uru Uru. Small to large quantities of fresh water are available from streams in the mountainous northeastern part of the department in map unit 4. Surface water provides about 15 percent of the water supply for the department capital city, Oruro.

Water quality ranges from fresh to saline. Water quality is best in the highest elevations in the north, and becomes progressively worse to the south and with decreasing elevation. Mineral reserves are located in the central and eastern parts of the department. Extraction activities contaminate ground and surface water resources. Problems with desertification have been identified throughout the department. All surface water should be considered biologically contaminated, especially near and downstream of populated areas.

Geography mainly consists of closed basins, also known as endorrheic basins, which do not have a drainage outlet. Elevation ranges from around 3,600 to 3,900 meters above sea level. Average annual precipitation ranges from 200 to 500 millimeters. Droughts occur annually between June and October, and there is a 50 percent chance of drought during the months of January and February.

Ground Water:

The best areas for ground water exploration are found in the northeastern and eastern parts of the department as depicted by map unit 3. Map unit 3 covers about 20 percent of the department. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains.

Most of the department lies in map unit 5 where fresh water is scarce or lacking. Ground water exploration during military operations is not recommended. Meager to very large quantities of brackish to saline water are available from Quaternary age aquifers. Ground water salinity increases to the south. The areas of Lago Poopo and Laguna de Coipasa have low precipitation and high salinity which contributes to poor quality ground water. These aquifers consist of unconsolidated gravel, sand, silt, and clay. The Quaternary to Tertiary age igneous aquifers and pyroclastic deposits of the western Andes also lie in this department. Depth to water is generally less than 90 meters. Springs are abundant in the Western Andes with high mineralization and gas content. Water temperatures vary between 60 and 80 degrees. The departmental capital of Oruro lies in this unit and ground water production provides about 85 percent of the water supply.

Pando

Area and Relative Size: 63,827 square kilometers (5.8 percent of the country)
Estimated Population (2001): 52,525 (less than 1 percent of the population)
Population Density: Less than one person per square kilometer
Department Capital: Cobija
Location: This department is located in the northwestern part of the country, and borders Brazil to the north and east and Peru to the west. Bordering departments are Beni and La Paz to the south.

Surface Water:

Fresh water is perennially available from streams throughout the department. The primary sources of surface water are Rio Madera, Rio Madre de Dios, Rio Beni, and Rio Orthon. Enormous quantities of water are available from Rio Madera and Rio Madre de Dios, located in map unit 1. Very large quantities of water are available from Rio Beni in map unit 1. Large quantities of water are available from Rio Orthon, located in map unit 2. High flows generally occur February to March; low flows generally occur July to August. Most major streams in this department flood annually.

Water quality is generally fresh. Mineral reserves are located along the southern border, and in the center of the department. Extraction activities contaminate ground and surface water resources. All surface water should be considered biologically contaminated, especially near and downstream from populated places.

Geography consists of alluvial plains, with elevations ranging from 115 to 500 meters above sea level. Average annual precipitation ranges from 1,700 to1,900 millimeters. Precipitation is highest December to March. The driest months are June and July.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map unit 1. About 80 percent of the department lies in map unit 1. Small to very large quantities of fresh water are available from the Quaternary aquifers. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 30 to 90 meters. Greater quantities are available as the percentage of clay and silt in the aquifer decreases. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Wells should be cased and screened. The departmental capital of Cobija lies in this unit.

Map unit 4 covers about 20 percent of the department and is located in the northeast. Very small to very large quantities of fresh water are available from fractures and joints in Precambrian age metamorphic and igneous aquifers consisting of granite and gneiss. Locally along streams, ground water is available from alluvial aquifers. Depth to water is generally less than 90 meters. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Shallow ground water is often biologically contaminated near settlements. Reconnaissance and exploratory drilling is necessary to locate water-bearing fracture zones. Wells should be cased and screened.

Potosi

Area and Relative Size:	118,218 square kilometers (10.8 percent of the country)
Estimated Population (2001):	709,013 (8.6 percent of the population)
Population Density:	6 people per square kilometer
Department Capital:	Potosi
Location:	This department is located in the southwestern part of the country, Chile borders to the west and Argentina borders to the south. Bordering departments are Oruro and Cochabamba to the north, and Chuquisaca and Tarija to the east.

Surface Water:

Fresh water is scarce or lacking throughout most of the western and central part of the department. Fresh water is perennially available from streams in the Andes Mountains along the eastern edge of the department. The primary sources of surface water are Rio Pilcomayo, Rio Caine, Rio San Juan del Oro, and Rio Grande de Lipez. Moderate to large quantities of fresh water are available from Rio Pilcomayo, in map unit 4. Moderate quantities of fresh water are available from Rio Caine, located in map unit 4. Small quantities of fresh water are available from Rio San Juan del Oro, also located in map unit 4. Unsuitable to moderate quantities of brackish to saline water are available from Rio Grande de Lipez in map unit 5. Laguna Colorada is a hypersaline lagoon fed by streams and springs in map unit 5. The Ramsar Convention on Wetlands has listed this site as site number 489, which is a “Wetland of International Importance”. A reservoir supplies 100 percent of the water for Potosi, the capital of the department. The reservoir and dam are approximately 500 years old and in need of repair.

Water quality throughout the majority of the department is brackish to saline; however, water quality in the eastern mountainous region is generally fresh. Mineral reserves are located in the eastern part of the department. Extraction activities contaminate ground and surface water resources. Problems with desertification have been identified throughout the department.

Geography varies considerably throughout the department. The northwestern and central part of the department consists of the desert Altiplano region, which includes extensive salt flats known as salars. Elevations in this region range between 3,680 and 3,800 meters above sea level. To the south, elevations rise to 4,500 meters above sea level in an area covered with volcanoes and elevated plateaus. The eastern part of the department consists of mountains with elevations ranging from 2,000 to greater than 4,500 meters above sea level. Average annual precipitation ranges from less than 200 millimeters in the southwest to 1,000 millimeters in the northeast.

Ground Water:

The best areas for ground water exploration are found in the northeastern and eastern parts of the department, as depicted by map unit 3. Map unit 3 covers about half of the department. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains. The departmental capital of Potosi lies in this unit and ground water is not used as a source for water supply.

Fresh water is scarce or lacking in the rest of the department, depicted by map unit 5. Ground water exploration for military operations is not recommended in this area. Meager to very large quantities of brackish to saline water are available from Quaternary age aquifers. Ground water salinity increases to the south. These aquifers consist of unconsolidated gravel, sand, silt, and clay. The Quaternary to Tertiary age igneous aquifers and pyroclastic deposits of the Western Andes also lie in this department. Depth to water is generally less than 90 meters. Springs are abundant in the Western Andes with high mineralization and gas content. Many salt flats are in this department, in the northern half. Shallow ground water may be biologically contaminated near settlements.

Santa Cruz

Area and Relative Size: 370,621 square kilometers (33.7 percent of the country)
Estimated Population (2001): 2,029,471 (24.5 percent of the population)
Population Density: 5.5 people per square kilometer
Department Capital: Santa Cruz
Location: This department is located in the eastern part of the country, and borders Brazil to the northeast and east and Paraguay to the south. Bordering departments are Beni to the northwest, Cochabamba to the west, and Chuquisaca to the southwest and south.

Surface Water:

Fresh water is perennially available from streams and lakes throughout the department. The primary sources of surface water are Rio Mamoré, Rio Grande o Guape, Rio Paraguay, Rio Paragua, Rio Blanco, Rio Yapacani, Rio Ichilo, and Rio Curiche Grande. Moderate to very large quantities are available from these rivers, located in map units 1, 2 and 3. Small to large quantities of water are available from streams in the southeastern part of the department in map unit 4. Large quantities of water are available from several lakes along the eastern border shared by Bolivia and Brazil, including Laguna Mandiore, Laguna La Gaiba, and Laguna Uberaba, located in map units 2 and 3.

Santa Cruz has several wetlands of international importance. Pantanal Boliviano is part of the world's largest wetland, the Pantanal. This area consists of rivers, lakes, lagoons, marshes, and inundated forests associated with the Rio Paraguay located just outside of Bolivia. The Ramsar Convention on Wetlands has listed this site as site number 1089. The Banados del Izozog and the Rio Parapeti is a riverine wetland area in the Chaco region, which provides the only source of water during the dry season for a dry forested region. It is listed as Ramsar site number 1087. Laguna Concepcion is an area in the eastern part of the department consisting of a lake and surrounding wetlands in the middle of the dry Gran Chaco Plain. Laguna Concepcion is listed as Ramsar site number 1175. Palmar de las Islas and las Salinas de San Jose is a wetland area consisting of small lakes, lagoons, and open channels, with water quality ranging from fresh to saline. These lakes provide the only water source during the dry season for a dry forested area. This wetland area is listed as Ramsar site number 1088.

Water quality is generally fresh. Petroleum and natural gas reserves are located in the western part of the department. Petroleum pipelines connect resources from the west to the eastern border with Brazil. Mineral reserves are scattered throughout the department. Extraction activities and leaking gas lines could contaminate ground and surface water resources. Problems with desertification have been identified in several places along the southern edge of the department, covering about 122 thousand square kilometers. Further study is required in the northern part of the department. Geography mainly consists of plains with an average elevation of 470 meters above sea level, with the exception of the mountain and piedmont region in the southwest that has elevations greater than 2,000 meters above sea level. Average annual precipitation varies from 600 to 2,500 millimeters.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, as depicted by map units 1 and 2. About 10 percent of the department lies in map unit 1, and 40 percent in map unit 2. Small to very large quantities of fresh water are available from the Quaternary aquifers of map unit 1. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 30 to 90 meters. Small to enormous quantities of fresh water are available from the Quaternary aquifers of the Gran Chaco Plain area, as depicted by map unit 2. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges can be greater than 200 meters. Greater quantities are available as the percentage of clay and silt in the aquifer decreases. Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Aquifers are also suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Wells should be cased and screened. The departmental capital of Santa Cruz lies in map unit 2. Average static water levels at the city of Santa Cruz are 10 meters below the surface elevation with average well depths ranging from 70 to 250 meters. The aquifers of map unit 2 provide all of the water supply for the cities of Santa Cruz and Montero.

Map unit 3 covers about 10 percent of the department, and is found in the west. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains.

Map unit 4 covers about 40 percent of the department. Very small to very large quantities of fresh water are available from fractures and joints in Precambrian age metamorphic and igneous aquifers consisting of granite and gneiss. These aquifers are located in the northeastern and eastern parts of the department. Locally along streams, ground water is available from alluvial aquifers. Depth to water is generally less than 90 meters. Aquifers are suitable for hand pump wells and most are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Shallow ground water is often biologically contaminated near settlements. Reconnaissance and exploratory drilling is necessary to locate water-bearing fracture zones. Wells should be cased and screened.

Tarija

Area and Relative Size:	37,623 square kilometers (3.4 percent of the country)
Estimated Population (2001):	391,226 (4.7 percent of the population)
Population Density:	10.4 people per square kilometer
Department Capital:	Tarija
Location:	This department is located in the southeastern part of the country, and borders Paraguay to the east and Argentina to the south. Bordering departments are Chuquisaca to the north and Potosi to the west.

Surface Water:

Fresh water is perennially available from streams throughout the department. The primary sources of surface water are Rio Grande de Tarija, Rio Bermejo, Rio Pilcomayo, and Rio San Juan del Oro. Moderate to large quantities of water are available from Rio Grande de Tarija in map unit 4. Small to large quantities of water are available from Rio Bermejo in map unit 4. Moderate to large quantities of water are available from Rio Pilcomayo in map units 3 and 4. Small quantities of water are available from Rio San Juan del Oro in map unit 4. High flows generally occur January to February; low flows generally occur May to August. Drought conditions are a problem during the dry season, and access to water is hindered during the wet season. In general, stream flows fluctuate greatly throughout the year, and most streams carry high sediment loads. The Cuenca de Tajzara is a wetland area in map unit 4 in the western part of the department consisting of seasonal and permanent streams and lakes listed by the Ramsar Convention on Wetlands as site number 1030, which is a “Wetland of International Importance.” Surface water supplies 65.7 percent of the water to the capital city of Tarija, and 22.8 percent of the water for Yacuiba. The reservoir in Tarija is in poor condition, and there is an urgent need to construct a new dam.

Water quality is generally fresh, although salt and heavy metal contamination has been reported in Rio Pilcomayo. Lead and other types of contamination from mining activities in the department of Potosi affect Rio San Juan del Oro, Rio Camblaya, Rio Pilaya, and Rio Pilcomayo. Petroleum reserves are located in the eastern part of the department, and mineral reserves are located in the central and western parts of the department. Extraction activities could potentially contaminate ground and surface water resources. Problems with desertification have been identified in several places throughout the department. All surface water should be considered biologically contaminated, especially near and downstream from populated places. Biological contamination is especially high in Rio Guadalquivir.

Geography consists of mountainous terrain in the Andes with elevations up to 4,000 meters, sub-Andean terrain with steep valleys, and flat terrain in the plains as low as 300 meters above sea level. Average annual precipitation varies from 600 millimeters on the western edge and 300 millimeters on the eastern edge to 1,100 millimeters in the south-central part of the department. Most precipitation occurs between December and March. The driest months are June to October.

Ground Water:

The best areas for ground water exploration are the Quaternary age aquifers, found in the Gran Chaco Plain of the eastern part of the department, as depicted by map unit 2. About half of the department lies in map unit 2. Small to enormous quantities of fresh water are available from the Quaternary aquifers of the Gran Chaco Plain area. These aquifers are composed of unconsolidated and locally semi-consolidated gravel, sand, silt and clay deposits. Depth to water ranges from 130 to 150 meters in the Quaternary cone area of the Rio Pilcomayo.

Shallow aquifers may be biologically contaminated near settlements. These aquifers, when properly developed, are suitable for municipal and irrigation wells. Wells should be cased and screened. Aquifers are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps.

Map unit 3 covers the other half of the department and is found in the west. Very small to very large quantities of fresh water are locally plentiful from a variety of aquifers. These aquifers include: Quaternary age alluvial aquifers consisting of sand, silt, shale and some gravel; Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, and shale; and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff and ignimbrites. Depth to water is generally less than 100 meters. Shallow aquifers may be biologically contaminated near settlements. Wells should be cased and screened. Aquifers are suitable for 3.3 liters per second (50 gallons per minute) tactical wells and wells equipped with small submersible pumps. Accessibility may be difficult along the slopes of the Andes Mountains. The departmental capital of Tarija lies in this unit, as does the city of Yacuiba. Ground water production provides about 35 percent of the water supply for Tarija, and about 75 percent of the water supply for Yacuiba.

VI. Recommendations

A. General

During the June 2002 visit with the numerous water resources and supply agencies, organizations, and key individuals, it became overwhelmingly clear that the most critical problem affecting Bolivia's water is the lack of a comprehensive water law. The existing water law was created in 1906 and is actually a revision of an even older water law. A few minor insignificant amendments to the law have been made since its inception. Also, the new water law must be enforceable to be beneficial.

In conjunction with a water law, Bolivia also needs a governmental body in charge of coordinating all water planning, policy, and development activities. CGIAB is a national water commission for providing a forum for sharing water information and building a concensus for establishing a national water law and governing body. This should be continued. Water management is addressed by various agencies and on many levels. For water supply, each major city has its own private company providing water service. In the past, these companies were public, and many are now private. One government ministry is involved in creating formal contracts with these firms, another one creates the water quality standards and supply standards they must abide by, and another group monitors the implementation of the systems. There is no agency that has all the water data: well info, surface water data, water quality, gaging station info, etc. In spite of the isolated efforts for water resources planning, the sectors involved still conduct their activities independently, according to the different sector laws. This leads to duplication of effort and inefficient use of resources.

The inadequate water and sanitation services coverage has serious consequences on the health of the population. A great proportion of child mortality is due to water quality related diseases, mainly diarrhea. Water quality and pollution is a major problem throughout the country. It has serious implications for the health of the entire nation. The lack of wastewater treatment and uncontrolled abuse of the nation's waterways by industries are large contributors to the contamination of the water.

There is a general inefficiency in uses of soil and water resources. Irrigation systems are extremely inefficient in Bolivia, losing as much as 80 percent of the water during distribution. Some sources indicate that about 85 percent of the total extracted water is used for irrigation. Therefore, tremendous increases in water supply could be realized if the efficiency of irrigation systems is improved. Deforestation and mining wastes are seriously impacting the quality of the surface water. Other major environmental concerns for the country include pollution of water bodies and rivers due to mining activities, inappropriate exploitation of the forests, poor farming methods, slash and burn, overgrazing, and lack of knowledge of soil conservation techniques. These practices cause soil erosion, high run-off of rainfall, degradation of vegetative cover, loss of soil productivity, increased salinity, sedimentation in surface water bodies, and loss of ground water recharge.

In 1990, the U.S. Army Corps of Engineers prepared an 'Evaluation of Water Resources in Bolivia, South America' for USAID. The evaluation was a professional appraisal of the 1990 drought situation in the southwestern part of the country. Twenty-three water projects and programs were recommended to address the problems. These projects are excellent recommendations and would be worthwhile investments.[137] One recommendation was the Tarija Valley Erosion Control Project. Through the USAID parks and protected areas program, USAID is supporting the work of the organization 'Protection of the Tarija Environment' in Tarija in the protection of SAMA National Park. A large part of the effort is erosion control, including reforestation and small works. Another recommendation was the construction of water systems in La Paz. USAID, through the Title II and NGO's, has been constructing community water and sanitation systems in the Altiplano for the past several years.[138]

B. National Water Resources Management and Policy

Water resources development and management programs are decentralized. There are several national ministries or organizations but their jurisdiction and authority are somewhat limited. The bulk of water resources activities seem to be directed at the department level, especially in the regional development corporations of each department. Thus, international organizations deal with individual departments as well as national offices. Considering there are over 100 international entities assisting in Bolivia's development, the complexity of the overall effort becomes apparent. Data related to wells and the various agencies and users responsible for water resources maintain surface water systems separately. As a result, lack of coordination exists between agencies and users, as well as within the different sectors. This creates duplication of effort and a lack of exchange of technical knowledge and data.

In 2002, Consejo Interinstitucional del Agua (CONIAG) was established by Presidential decree. The purpose of this group is to develop a consensus-derived water resources law that could have a chance of being enacted. CONIAG members include the Government of Bolivia (five ministries) and representatives from municipal and civil society organizations.[139]

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

Water resources management and policy are the core of efficient and equitable development. Recommended approaches for gradual improvement of the current management system are as follows:

- Form a national commission for potable water and sanitation.
- Establish a national water law.
- Form a water resources council.
- Conduct comprehensive water resources evaluations.
- Establish a national clearinghouse.
- Sponsor national and international meetings.
- Form task forces to address water resources issues.

These approaches are explained in the following paragraphs.

1. National Water Commission

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

2. National Water Law

For many years, a new water law has been proposed, but not passed. The lack of a national water law is a critical problem for the country. Meetings and discussions with managers have indicated a good, practical water law is essential to proper water management. A good water law is essential for controlling the use and abuse of the nation's waterways. Specifically, limits can be set on discharge, quality for industry and sanitation facilities, water treatment limits in major cities to prevent diseases, set requirements for cities to have goals for inclusion of all users for treated water and connection to sewer system. The law should require protection of water supply by deforestation limits, waterway transportation setbacks, mining discharge, etc.

3. Water Resources Council

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

4. Comprehensive Water Resources Evaluations

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

5. National Clearinghouse

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

6. National and International Meetings

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

7. Formulation of Task Forces

This idea is somewhat similar to others previously discussed. The difference is that one major national agency would have to take the initiative to lead the program. The first step would be to identify the national needs that would be of widespread interest to entities operating in Bolivia. Such needs might include a national water law, a national education program, a national database for technical data, national surveys and mapping, and a national program for soil and water conservation. The lead agency would then need to correspond with the various national and international entities to co-sponsor the project by assigning members of their organization to the task force.

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

8. Suggested Strategy

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

C. Watershed Protection and Management

A common concern of most government officials and technical experts is the impact of deforestation on the environment and on water resources. Integrated watershed management is needed to control deforestation and the resulting erosion and sedimentation. Agricultural activity, mining, and industrial activities should also be included in the management and protection. Development of comprehensive watershed and basin management plans is needed to curb these impacts. The intent of a watershed management plan is to achieve a comprehensive view of water and land resource problems within a watershed and to identify opportunities and authorities to address such problems. Watershed planning is a systematic approach to (1) evaluating alternative uses of water and land resources; (2) identifying conflicts and trade-offs among competing uses; and (3) making contemplated changes through informed decisions.

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

D. Troop Exercise Opportunities

Installing water wells and creating surface water impoundments for water supply in rural areas during troop exercises can provide a valuable and much-needed product for the host nation. In rural areas, adequate supplies of potable water are essential to improving the health of the population. This in turn helps to reduce poverty. Much of the rural population lives in poverty, and lacks access to potable water services.

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

1. Well Exercises

Particularly because many of the rivers are contaminated and surface water availability is declining, more of the water supply needs of Bolivia will be dependent upon ground water resources. Overall, the quality of ground water is good throughout the country. Small hand pump wells are in great demand, particularly in rural areas. Installing small hand pump wells, especially in rural areas as part of U.S. troop engineering exercises, could be of great benefit. New wells installed should be designed to protect against surface water contamination. The wells should have a minimum 30-meter-thick (100-foot) grout seal to protect the aquifer from becoming contaminated from surface water runoff, or from shallow aquifer. These wells could be a source of safe potable water to replace contaminated surface water supplies in some locations.

2. Small Surface Impoundments

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

E. Water Quality and Supply Improvement

Much of the population lacks access to water supply and sanitation services, which directly affects the quality of life. Wastewater treatment is also lacking throughout the country, with much effluent discharged into the waterways without treatment. Wastewater treatment is needed to improve the quality of the surface water resources of the country, because much of the population uses surface water for water supply needs. As the quantity of available surface water decreases and the population continues to grow, the need for ground water resources increases. Improper and inadequate wastewater treatment also negatively impacts ground water resources.

In many areas of the country, more water wells could alleviate the water supply shortage. Most small villages, however, cannot afford the cost to drill and install a water well with pumping and storage. Past attempts by many different agencies to assist in ground water resources development in Bolivia have been largely unsuccessful due to lack of future planning. Prior to 1990, most of the aid in ground water development was to purchase drilling equipment and provide it to a government agency without regard to future maintenance or the cost of supplies that the agency could not afford. These same agencies would drill blindly in some areas where no information was available with poor results, this often being dictated by local politics. The establishment of a national well-drilling program would be beneficial. Such a program should be designed to bring the numerous agencies (local and foreign) working in Bolivia together and pool many of the existing resources and supply training, equipment and expertise to conduct geophysical surveys, construct water wells, dams, and infiltration galleries.

The establishment of an Environmental Water Monitoring System is recommended. Water is critical as a main source of life and to the socio-economic development of a country. Water and its intended use should be protected and managed responsibly and in a sustainable way. The following is a list of recommended actions:

- Obtain a general perspective of the quality of surface and ground water.
- Prepare elaborate maps with different water quality problems (metals, sulfates, nitrates, etc.).
- Estimate the nutrient transport in rivers.
- Characterize the potential water contamination risks.
- Modernize the activities of the evaluation of the water resources with respect to quantity and quality in order to know their availability and use.
- Measure the volumes of extraction and releases for all uses and for all users, to increase the efficiency in using water.
- Establish a permit system for wastewater discharge, and support the institutional capacity for the exercise of monitoring.
- Establish a permit system for water extraction and treatment.

- Increase wastewater treatment to obtain better treatment for all communities.
- Create a national well-drilling program.

Even as serious as the water contamination problems are, realistic opportunities to improve the quality may be limited to education of the populous and relatively small-scale, problem-by-problem progress. The enormity of needed environmental and societal change would take billions of dollars to correct.[140]

VII. Summary

The water resources situation of the country is critical and of great concern. Many reasons for this include:

- Lack of a national water law to protect and preserve the resources.
- Uneven rainfall distribution.
- Degradation of the watersheds caused by an extremely high deforestation rate.
- Pollution of the water bodies by industry, pesticides, and mining.
- Lack of wastewater treatment and the direct discharge of untreated wastewater by most of the population.
- No single agency responsible for management of water resources.
- Lack of water and sanitation services coverage, resulting in poor health.
- Poor water resources management.
- Rapid growth in urban areas increasing demand further beyond system capacity.
- Overexploited aquifers in Cochabamba and Santa Cruz.

Critical issues are the lack of access to water and sanitation, the extensive environmental damage caused by rampant deforestation and mining, the lack of a national water law and water sector, and the lack of wastewater treatment. Solutions to these issues present significant challenges to water resources managers in Bolivia.

The lack of policy and the lack of a water law constitute one of the largest weaknesses in managing the water resources. This results in uncontrolled exploitation and use of the water.

The long-term solution to water resources needs in Bolivia must incorporate a combination of proper management, conservation and changing societal habits in the use of water and land resources. Without this, the beneficial effects of water resources projects (dams, lakes, ground water, diversions, etc.) will be short-lived. The 23 projects and programs recommended in the 1990 'Evaluation of Water Resources of Bolivia, South America' by USACE for USAID to alleviate drought and various water problems in the southwest are excellent programs to consider for future water projects.

The recommendations offered in this report present some of the opportunities to improve the water resources situation. If adopted, these actions could have positive long-term impacts. Many of the other issues discussed in this report will require long-term institutional commitments to effect change. Proper management of the abundant water resources of Bolivia can provide adequately for the needs of the country, perhaps starting with education of the populous, and relatively small-scale, problem-by-problem programs.

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Appendix A

List of Officials and Agencies Consulted

List of Officials and Agencies Consulted

Name, Title	Agency/Firm	Address	Tel/Fax/Email
Col. Paul B. Kappelman, U.S. Military Group Commander	U.S. Military Group	U.S. Embassy Arce Av. 2780 La Paz	Tel: (591-2) 243-3251 Fax: (591-2) 243-0421 Email: kappelmp@lapaz.mg.southcom.mil
Alberto Montes de Oca, Project Engineer	U.S. Army Corps of Engineers, Mobile District, Bolivia Project Office	U.S. Embassy Arce Av. 2780 La Paz	Tel: (591-2) 243-0251 Ext. 2675/7 Fax: (591-2) 243-3619 Email: amontesdeoca@compuserve.com
Victor H. Bullen, Regional Environmental Advisor	U.S. Agency for International Development (USAID)	Calle 9 N° 104, Obrajes Casilla 4530 La Paz	Tel: (591-2) 278-5548 Fax: (591-2) 278-6654 Email: vbullen@usaid.gov
Jorge Calvo Carmona, Chief Office of Economic Opportunities	U.S. Agency for International Development (USAID)	Calle 9 N° 104, Obrajes Casilla 4530 La Paz	Tel: (591-2) 278-6456 Fax: (591-2) 278-6654 Email: jcalvo@usaid.gov
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Dr. Jorge Velasco W., Coordinator of Health Activities	U.S. Agency for International Development (USAID)	Calle 9 N° 104, Obrajes Casilla 4530 La Paz	Tel: (591-2) 278-6583 Fax: (591-2) 278-6654 Email: jvelasco@usaid.gov
Joseph Narkevic, National Coordinator of Clean Water	World Bank	Fernando Guachalla 342, Edificio Victor, Piso 9, Casilla 8692, La Paz	Tel: (591-2) 244-3166 Fax: (591-2) 244-3163 Email: jnarkevic@worldbank.org
Evelyn Taucer M., Environmental Management Specialist	Conservation International, Bolivia	M. Pinilla N° 291 Esq. 6 de Agoslo, La Paz	Tel: (591-2) 243-4058 Fax: (591-2) 243-5225 Email: etaucer@conservation.org.bo
Freddy Miranda	Conservation International, Bolivia	M. Pinilla N° 291 Esq. 6 de Agosto, La Paz	Tel: (591-2) 243-4058 Fax: (591-2) 243-5225 Email: fmiranda@conservation.org.bo
Pablo Solón, Executive Director	Comisión para la Gestión Integral del Aqua en Bolivia, (CGIAB)	Ave. Ecuador No. 2519, entre Belizario Salinas y pedro Salazar La Paz	Tel: (591-2) 241-7057
Maria Esther Udaeta Velasquez, Political Action Unit	Centro de Investigación y Promoción del Campesinado (CIPCA)	Pasaje Fabiani N° 2578, Av. 20 de Octubre/Campos y Pinilla, Casilla 5854, La Paz	Tel: (591-2) 243-2272 Ext. 76 Fax: (591-2) 243-2269 Email: cipcauap@caoba.enterlnet.bo
Juan Carlos Alurralde, General Coordinator	Comisión para la Gestión Integral del Aqua en Bolivia, (CGIAB)	Ave. Ecuador No. 2519, entre Belizario Salinas y pedro Salazar La Paz	Tel: (591-2) 279-5440 Fax: (591-2) 241-7057
Mateo Ilijic Gomez, Hydrogeologist	Superintendencia General de Regulacion de Recursos Naturales Renovables (SIRENARE)	Edif. Alameda Casilla: 1955 La Paz	Tel: (591-2) 233-4660 Email: oilijic@netscape.com
Dr. Hernán Zeballos, General Superintendent	Superintendencia General de Regulación de Recursos Naturales Renovables (SIRENARE)	Calle Batallón Colorados No. 24, Edificio El Cóndor, Piso 12 La Paz	Tel: (591-2) 244-4897 Fax: (591-2) 244-4896 Email: sirenare@caoba.entelnet.bo
Ronny Vega M., General Manager	Asociación Nacional de Empresas d'Instituciones de Servicio de Agua Potable y Alcantarillado, (ANESAPA)	Calle Jacinto Benavente No. 2190 P.B., La Paz	Tel: (591-2) 241-1671/1674 Fax : (591-2) 241-2328 Email: anesapagg@unete.com

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Appendix B

Glossary

Glossary

agricultural runoff	That portion of precipitation that flows over the ground surface draining farmlands and feedlots. Usually is polluted by agricultural wastes. Wastes include pesticides and fertilizers, animal manure and carcasses, crop residues, sediment from erosion, and dust from plowing.
alluvial	Pertaining to processes or materials associated with transportation or deposition by running water.
Altiplano	Physiographic region of Bolivia characterized by cold, dry climate and high elevations, generally between 3,700 and 6,000 m.
aquifer	A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
arsenic	A naturally occurring semi-metallic element in the earth's crust. Arsenic is poisonous and a known carcinogen.
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.
banados	Shallow swamps.
basalt	A very fine-grained, hard, dense, dark-colored, extrusive igneous rock, which occurs widely in lava flows. Usually has poor hydrogeological properties and is difficult to drill through.
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.
bedrock	The solid rock underlying the loose surface material or soil.
bicarbonate (HCO_3)	A negatively charged ion which is the dominant carbonate system species present in most waters having a hydrogen-ion concentration (pH) value between 6.4 and 10.3. Excessive concentrations typically result in the formation of scale.
biological contamination	The presence in water of significant quantities of disease-producing organisms.
brackish water	Water that contains more than 1,000 milligrams per liter but not more than 15,000 milligrams per liter of total dissolved solids.
channel	A perceptible natural or artificial conveyance which periodically or continuously contains moving water or which forms a connecting link between two water bodies.
chemical contamination	The presence in water of a significant quantity of chemicals that may be a health risk.

chloride (Cl^-)	A negatively charged ion present in all natural waters. Excessive concentrations are undesirable for many uses of water. Chloride may be used as an indicator of domestic and industrial contamination. Fresh water contains a maximum chloride concentration of 600 mg/L.
clay	As a soil separate, the individual particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that contains 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.
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 or more streams join together to form one stream.
conglomerate	Gravel-size or larger, consolidated, rounded to semi-rounded rock fragments in a finer-grained material. Depending upon the degree of cementation, the drillability and ground water potential can vary significantly.
consolidated	Once loosely aggregated, soft, or liquid earth materials that have become firm and coherent rock.
contaminant	As applied to water, any dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical waste, biological material, radioactive material, heat, wrecked or discarded equipment, rock, sand, dirt or industrial, municipal, and agricultural wastes discharged into water. Also known as a pollutant.
dacite	Light colored volcanic rock containing high amounts of silica, and moderate amounts of potassium and sodium.
deforestation	The process by which large tracts of land are cleared of trees and forest. One consequence of deforestation is soil erosion, which results in the loss of protective soil cover and the water holding capacity of the soil.
desalination	A water purification process that removes dissolved salts from brackish or saline water to improve water quality.
desertification	The process of converting a geographic area into a desert climate.
Devonian	The period of the Paleozoic era between the Silurian and the Mississippian, and the corresponding system of rocks.
discharge	The release of a quantity of flow.
drainage basin	The land area from which water drains into a stream, lake, or other body of water.
drawdown	The lowering of the water level in a well as a result of withdrawal.
drought	An extended period of dry weather or a period of deficient rainfall that may extend over an indefinite period of time.
dry season	The period of the year when there is little to no rainfall or when rainfall is at a minimum.
ecozone	A biogeographical realm with unifying features of geography, fauna and flora.

effluent	An outflow of waste, as from a sewer (domestic, municipal, or industrial).
evapotranspiration	Loss of water from a land area through transpiration of plants and evaporation.
fault	A fracture or fracture zone of the Earth along which there has been displacement of one side with respect to the other.
flood plain	Nearly level land on either side of a channel which is subject to overflow flooding.
fluvial	Of or pertaining to rivers or produced by river actions.
fracture	A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress.
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 height or discharge are obtained.
gneiss	A medium- to coarse-grained, banded to weakly foliated, hard, metamorphic rock composed of alternating bands of light- and dark-colored minerals. Associated with mountains and rugged terrain.
granite	A coarsely crystalline, hard, massive, light-colored igneous rock. If not highly fractured or weathered, granite is difficult to drill through and normally yields little ground water.
gravel	Individual rock or mineral particles that range in diameter from the upper limit of sands (4.76 millimeters) to a diameter of 76 millimeters according to the Unified Soil Classification.
ground water	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
hand pump well	A well, designed to supply water for domestic use, that is powered by a hand-drawn piston pump.
hardness	A property of water due to the presence of ions of calcium and magnesium.
headwaters	The upper reaches of a stream near its source. Streams in headwater areas are typically very small and may only flow in response to rain or melting snow.
herbicide	A class of substances used to destroy plants. In small amounts, it may be harmful to human health.
high flow	The period of time when a stream's discharge is greater than average.
hydroelectric	Electrical energy produced by means of a generator coupled to a turbine through which water passes. Synonymous with hydropower.
hydrographic	Areas of physical facts, occurrences, and conditions related to precipitation, stream flow, ground water, quality of water, and water use that are similar for grouping.

hypersaline	Having high salinity, with a total dissolved solids concentration of greater than 40,000 milligrams per liter.
igneous	A class of rock formed by the solidification of molten material. If the material is erupted onto the Earth's surface, the rock is called an extrusive or volcanic rock; if the material solidifies within the Earth, the rock is called an intrusive or plutonic rock. If not fractured or weathered, it will normally yield only small amounts of ground water.
ignimbrite	A silicic volcanic rock forming thick, massive, compact, lava-like sheets. Ignimbrite consists mainly of a fine-grained rhyolitic tuff, and it often displays well-developed prismatic jointing.
interbedded	Occurring between beds or lying in a bed parallel to other beds of a different material.
intermittent stream	A stream or reach of a stream that flows only at certain times of the year, as when it receives water from springs or from some surface source such as rain.
iron and manganese	Metallic elements dissolved in natural ground water from rocks. Concentrations in excess of 0.3 milligrams per liter cause reddish-brown stains on fixtures and fabrics washed in the water, as well as an unpleasant taste in drinking water.
joint	A fracture or parting in a rock, without displacement.
lava	Fluid rock such as that which issues from a volcano or a fissure in the Earth's surface. Lava is also the same material solidified by cooling.
limestone	(1) For military purposes, the rock types which refer to all carbonate sedimentary rocks. (2) Soft to moderately hard rock primarily composed of calcium carbonate mainly in the form of shells, crystals, grains, or cementing material. Colors range from white through shades of gray to black. Commonly thick bedded, jointed, and containing fossils. Limestone is often highly fractured and soluble.
low flow	The period of time when a stream's discharge is less than average.
lowland	A general term for extensive plains that are not far above sea level.
marsh	An area of saturated ground dominated by grasslike aquatic plants.
meander	One of a series of somewhat regular and loop-like bends in the course of a stream.
Mesozoic period	A division of geologic time from 66 to 240 million years ago, during which certain rocks were formed. This era falls chronologically after the Paleozoic and before the Cenozoic eras. It includes the Triassic, Jurassic, and Cretaceous periods.
metamorphic	Rocks formed in the solid state from previously existing rocks in response to pronounced changes in temperature, pressure, and chemical environment.
nitrate (NO_3)	A mineral compound characterized by a fundamental anionic structure of NO_3. Nitrate may be an indicator of ground water pollution.
organic material	Includes plant and animal residues in various stages of decomposition.

Paleozoic era	A division of geologic time from 570 to 240 million years ago during which certain rocks were formed. The Paleozoic era falls chronologically after the Proterozoic and before the Mesozoic eras. It includes the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian periods.
paraquat	A toxic chemical that is widely used as a herbicide.
perennial	Pertaining to water that is available throughout the year.
permeability	The property or capability of a porous rock for transmitting a fluid. Permeability is a measure of the relative ease of fluid flow under unequal pressure. The customary unit of measure is a millidarcy.
pesticide	A class of substances used to destroy insects, weeds, and other pests like rodents. Includes insecticides and herbicides. In even small amounts, pesticides may be harmful to human health.
pH (potential of hydrogen)	A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale ranges from 0 to 14.
pollution (water)	The addition of contaminants to a natural body of water, which diminishes the optimal economic use of the water body and has an adverse effect on the surrounding environment.
porosity	The ratio of the volume of the openings (voids, pores) in a rock or soil to its total volume. Porosity is usually stated as a percentage.
potable water	Describes water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
Precambrian	An informal geologic time term referring to all rocks older than 570 million years. Generally includes the pre-Archean, Archean, and Proterozoic.
pyroclastic	A type of rock formed by the accumulation of fragments of volcanic rock scattered by volcanic explosions.
Quaternary period	A geologic system that represents a period of time from the present to 1.6 million years ago, during which certain rocks were formed or sediments deposited. The Quaternary period falls chronologically after the Tertiary period. It is generally broken down into the Pleistocene and Recent (Holocene), and is the youngest of the Cenozoic Era.
reach	An extended part of a stream, generally from points where there are major changes in the stream's overall slope. A stream may be divided into three reaches, an upper with the highest slope, a middle with moderate slopes, and a lower with the lowest slope.
recharge	Addition of water to the zone of saturation from precipitation, infiltration from surface streams, and other sources.
reservoir	A pond, lake, basin or other space either natural or created that is used for storage, regulation, and control of water for a variety of uses.

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. Sometimes called 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.
salar	An area covered by salt deposits left behind by a water body that has evaporated.
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
salinity	A measure of the concentration of dissolved mineral substances in water.
sand	As a soil separate, individual rock or mineral fragments with 0.05- to 2-millimeter diameters. The soil textural classification that determines a soil to be sand requires that 85 percent or more of the soil be sand and that it not consist of more than 10 percent clay. Most sand consists of quartz.
sandstone	A soft to moderately hard sedimentary rock composed primarily of cemented quartz grains. Many aquifers and oil reservoirs are sandstone.
sediment	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.
sedimentary	A class of rocks formed from the accumulation and solidification of a variety of sediments.
sedimentation	The process of deposition of sedimentary material, especially by mechanical means from a state of air or water over time.
sediment load	The solid material that is transported by a stream.
semi-confined aquifer	An aquifer that has a "leaky" confining unit and displays characteristics of both confined and unconfined aquifers, typically evidencing low permeability through which recharge and discharge can still occur.
sewage	The spent or used water of a community or industry which contains dissolved and suspended matter.
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. Shale is a confining bed to many aquifers in sedimentary rock.
silica (SiO_2)	The chemically resistant dioxide of silicon. It occurs naturally in several forms including quartz and chert.

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).
siltstone	A fine-grained, moderately hard, sedimentary rock that is thin bedded to massive. Siltstone is distinguished from shale because it has a slightly larger grain size.
Silurian	A period of the Paleozoic era between the Ordovician and Devonian, and the corresponding rock systems.
slash and burn agriculture	A farming practice where the vegetation is cut down and burned to make room for new fields.
solfatara	A vent in a volcano through which sulfur-rich gases and steam escape, leaving bright yellow sulfur deposits.
soya	The soya bean is the seed of the leguminous soya bean plant.
specific capacity	The yield of a well per unit of drawdown.
spring	A place where ground water flows from a rock or the soil onto the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, especially permeable and impermeable strata; on the position of the water table; and on the topography.
sub-Andean	The region surrounding the Andes Mountains having lower elevations and more gradually sloping terrain.
sulfate (SO_4)	A salt of sulfuric acid containing the divalent, negative radical SO_4. Fresh water contains a maximum sulfate concentration of 300 mg/L.
swamp	An area of moist or wet land with water standing on or just below the surface of the ground. A swamp is usually covered with a heavy, dense growth of vegetation.
tactical well	A well designed to support military operations and typically used for short periods of time.
Tertiary	A division of geologic time from 1.6 to 66 million years ago, during which certain rocks were formed. The Tertiary period falls chronologically after the Cretaceous and before the Quaternary periods. It includes the Paleocene, Eocene, Oligocene, Miocene, and Pliocene. Tertiary is the oldest division of the Cenozoic. Outside the United States, the Tertiary period is sometimes divided into the Paleogene and Neogene.
total dissolved solids (TDS)	The sum of all dissolved solids in water or wastewater.
tributary	Stream or other body of water, surface or underground, which contributes its water to another and larger stream or body of water.
tuff	A soft, light-colored, extrusive igneous rock formed from the compaction of pyroclastic (ash and dust) material.
unconsolidated	Loose, soft, or liquid earth materials that are not firm or compacted.

valley	Any hollow or low-lying land bounded by higher ground, usually traversed by a stream or river which receives the drainage of the surrounding heights.
volcanic	Pertaining to the activities, structures, or rock types of a volcano.
wastewater	A community or industry's spent or used water which contains dissolved and suspended matter.
watershed	The area contained within a drainage divide above a specified point on a stream.
water table	The depth or level below which the ground is saturated with water in an unconfined aquifer.
weathering	Physical and chemical changes that atmospheric agents produce in rocks or other deposits at or near the Earth's surface. These changes result in disintegration or decomposition of material into soil.
well	Artificial excavation that derives water from the interstices of the rocks or soil which it penetrates.
wetland	A lowland area, such as a marsh, swamp, or seasonally inundated area, that is saturated with moisture.
wet season	The period of the year when there is an abundance of rainfall or when rainfall is at a maximum.
yield	The volume in liters per second of water produced from a well.

Appendix C

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Surface Water and Ground Water Resources

Tables and Figures

Table C-1. Surface Water Resources

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water perennially available	Major perennial streams and lakes throughout the region. **Amazon Basin (I):** Rio Alto Beni (1431S06730W)[3], Rio Beni (1023S06524W), Rio Itenez o Guapore (1154S06501W), Rio Madera (1021S06523W), Rio Madidi lower reaches (1232S06652W), Rio Madre de Dios lower reaches (1058S06609W), Rio Mamoré (1023S06523W), Lago Titicaca, western and southern portions (1548S06924W).	Very large to enormous quantities of fresh water are perennially available from primary streams and lakes. High water occurs December to March, peaking in January. Low water occurs June to August, lowest in August. Selected stream gaging stations and stream characteristics are listed below. **Amazon Basin (I):** Rio Beni: average discharge is 4,446 m^3/s; average width is 380 m; average depth is 9 m; average velocity is 1.3 m/s. High flow in January is 5,300 m^3/s; low flow in August is 760 m^3/s. Low flows occur May to November; high flows December to March. Rio Alto Beni: average discharge is 852 m^3/s. Rio Itenez o Guapore: average width is 500 m; maximum width is 570 m; minimum width is 110 m; maximum depth is 19.5 m. Low flows occur May to December; high flows January to March. Rio Madera: average discharge is 3,372 m^3/s; average width is 200 m; average depth is 6 m; average velocity is 2.81 m/s; **1**[4] average annual discharge at Villabella (1023S06524W) is 18,000 m^3/s. Rio Madre de Dios: average discharge is 5,040 m^3/s; average width is 350 m; average depth is 8 m; average velocity is 1.8 m/s. Low flows occur May to December; high flows January to March. Rio Mamoré: Average discharge is 3,280 m^3/s; average width is	TDS in most streams is less than 200 mg/L. Agricultural activities contribute pesticide, herbicide, and bacterial contamination. Biological contamination, such as fecal coliform, is most severe around and downstream of populated places. Sediment loads are very high in each river listed below. High levels of mercury contamination from natural sources in the soil and gold mining activities are common in streams throughout the region. Contamination is highest in the plains several hundred km downstream from gold mines. Streams are used for navigation. Pollution from vessels includes hydrocarbons, and human and animal waste. Water quality data from points along selected streams are listed below. Confluence of Rio Madidi and Rio Beni (1232S06652W): TDS 63 mg/L; HCO_3 32.9 mg/L; Cl^- 1.0 mg/L; pH 6.5; temperature 28.5 ^{o}C. Rio Alto Beni at Rio Kaka (1600S6846W): TDS 120 mg/L; HCO_3 53.7 mg/L; SO_4 29.3 mg/L; Cl^- 5.8 mg/L; temperature 22.2 ^{o}C. Rio Beni measured at 1431S06729W on 12 Dec 1998 and 13 Oct 1999: TDS 36.7 to 68.7 mg/L; pH 7.4 to 7.8; Hg 34.13 to 114.3 ng/L; temperature 23.9 to 25 ^{o}C. Rio Madera: pH ranges from 6.2 to 7.2, high mercury levels.	Topography, transportation network, and vegetation may limit access and development of water points. Seasonal flooding may hinder access. Descriptions of the courses of selected rivers are listed below. Rio Mamoré: river course shifts throughout year because of flooding. Soft sediment banks collapse during floods. Rapids, tree snags, and large rocks are in the river. Rio Madera: lots of rapids. Rio Beni: the river has seasonal flooding, meandering course, tree snags, rapids, and shallow bottom areas. Rio Itenez o Guapore: rapids are at Principe de Beira, Piedras Negras, and other locations (exact location unknown). Rio Madre de Dios: the river has seasonal flooding, meandering course, tree snags, rapids, and shallow bottom areas. Seasonal floods may hinder access around Lago Titicaca and tributaries during rainy season from January to March.	Rio Madre de Dios is navigable for 505 km from Puerto Heath (1230S06840W) to the confluence with Rio Beni (1055S06607W). On Rio Mamoré there is high boat traffic for 1,481 km from Puerto Villarroel (1652S06447W) to Puerto Sucre (1048S06523W). There are many reported cases of typhoid and malaria near the Rio Itenez o Guapore.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 Fresh water perennially available (continued)		400 m; average depth is 10 m. Low flows occur May to October; high flows January to March. Lago Titicaca: surface area is 8,400 km^2; volume is 930,106 Mm^3; maximum depth is 283 m; maximum length is 70 km; altitude 3,812 m.	Rio Madre de Dios: TDS 77 mg/L; HCO_3 42.2 mg/L; SO_4 5.8 mg/L; Cl^- 3.0 mg/L; pH 6.4; temperature 26.7 °C. Rio Mamoré at Guayaramerin (1048S6523W): TDS 72 mg/L; HCO_3 35.0 mg/L; SO_4 9.0 mg/L; Cl^- 2.6 mg/L; pH 5.6; temperature 27.7 °C. Lago Titicaca: TDS <100 mg/L.		
2 Fresh water perennially available	Fresh water is perennially available from streams and lakes throughout the region. **Amazon Basin (I):** Rio Abuna (1021S06523W), Rio Acre (1102S06844W), Rio Apere (1344S06518W), Rio Blanco (1230S06418W), Rio Chapare (1558S06442W), Rio Grande o Guape (1559S06430W), Rio Ichilo (1557S06442W), Rio Isiboro (1525S06506W), Rio Madidi (upper reaches) (1304S06757W), Rio Madre de Dios (upper reaches) (1202S06808W), Rio Orthon (1050S06604W), Rio Paragua (1334S06153W),	Moderate to very large quantities of fresh water are available from primary streams and lakes. High flows occur January to March; low flows May to December. Selected stream gaging stations and stream characteristics are listed below. **Amazon Basin (I):** **2** Rio Grande o Guape measured at Abapo (1850S06328W): average discharge is 300 m^3/s. Rio Ichilo: average annual discharge is 593 m^3/s. Rio Orthon: average annual discharge is 460 m^3/s. Rio Pilcomayo: average annual discharge is 207 m^3/s. Rio Yacuma: average width ≤ 100 m; average depth is 2.5 m.	TDS in most streams is less than 200 mg/L. Agricultural activities contribute pesticide, herbicide, and bacterial contamination. Biological contamination, such as fecal coliform, is most severe around and downstream of populated places. High levels of mercury contamination from gold mining activities are common in streams throughout the region. Contamination is highest in the plains several hundred kilometers downstream from gold mines. Acid mine drainage from abandoned mines, and chemicals used in agriculture are also contaminants. Water quality data from points along selected streams are listed below. Confluence of Rio Grande and Rio Ichilo (1557S06442W): TDS 285 mg/L; HCO_3 135.9 mg/L; SO_4 58.5 mg/L; Cl^- 9.5 mg/L; temperature 26.8 °C. Confluence of Rio Ichilo and Rio Chapare (1558S06442W): TDS 54 mg/L; HCO_3 11.3 mg/L; SO_4 16.6 mg/L; Cl^- 3.6 mg/L;	Topography, transportation network, and vegetation may limit access and development of water points. Seasonal flooding may hinder access. Descriptions of the courses of selected rivers are listed below. Rio Yacuma: from November to May the surrounding area is flooded and impassible to ground traffic, during which time the river is used as the primary means of transportation. Tree snags are common.	Rio Orthon is navigable for 233 km from Puerto Rico (1105S06738W) to the confluence with Rio Beni. Rio Itenez is navigable for 550 km from Piso Firme (1341S06152W) to the confluence with Rio Mamoré.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water perennially available (continued)	Rio Secure (1513S06456W), Rio Tapado (1317S06545W), Rio Yacuma (1338S06523W), Rio Yapacani (1559S06430W), Rio Yata (1059S06906W), Laguna Huatunas (1305S06555W), Laguna Rojo Aguados (1252S06543W). **La Plata Basin (III):** Rio Curiche Grande (1653S05929W).		temperature 25.1 °C. Confluence of Rio Secure and Rio Isiboro (1525S06506W): TDS 51 mg/L; HCO_3 25.6 mg/L; SO_4 5.6 mg/L; Cl^- 1.4 mg/L; temperature 27.1 °C. Rio Apere: TDS 76 mg/L; HCO_3 41.5 mg/L; SO_4 6.0 mg/L; Cl^- 1.8 mg/L; temperature 22.5 °C. Rio Chapare: TDS 136 mg/L; HCO_3 56.2 mg/L; SO_4 14.4 mg/L; Cl^- 18.4 mg/L; pH 7.6; temperature 23.5 °C. Rio Ichilo: TDS 75 mg/L; HCO_3 25.8 mg/L; SO_4 20.3 mg/L; Cl^- 1.2 mg/L; pH 6.4; temperature 25.5 °C. Rio Isiboro: TDS 105 mg/L; HCO_3 48.9 mg/L; SO_4 5.8 mg/L; Cl^- 12.0 mg/L; pH 7.2; temperature 27.2 °C. Rio Orthon at Caracoles (1045S06614W): TDS 64 mg/L; HCO_3 29.0 mg/L; SO_4 4.8 mg/L; Cl^- 2.0 mg/L; pH 7.0; temperature 27.5 °C. Quiquibey River measured at 1438S06732W on 12 Dec 1998: pH 7.55; TDS 44.2 mg/L; Hg 68.57 ng/L; temperature 26.6 °C. Rio Yapacani at Yapacani (1700S06403W): TDS 286 mg/L; HCO_3 197.6 mg/L; SO_4 12.0 mg/L; Cl^- 2.9 mg/L; pH 7.9; temperature 27.8 °C.		

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
2 Fresh water perennially available (continued)			Rio Yata: TDS 42 mg/L; HCO_3 18.0 mg/L; SO_4 2.3 mg/L; Cl^- 6.4 mg/L; pH 4.4; temperature 28.3 °C.		
3 Fresh water perennially available	Fresh water is perennially available from streams and lakes throughout the region. **Amazon Basin (I):** Rio Parapeti (lower reaches) (1928S06232W), Banados del Izozog (wetland) (1848S06210W). **La Plata Basin (III):** Rio Paraguay (2008S05809W) Rio Pilcomayo (lower reaches) (2216S06240W) Laguna Caceres (1856S05748W) Laguna la Gaiba (1745S05743W) Laguna Mandiore (1808S05733W) Laguna Uberaba (1731S05747W).	Moderate to large quantities of fresh water are perennially available primarily from streams, lakes, and marshes. High flows occur March to May; low flows November to January. Selected stream gaging stations and stream characteristics are listed below. **Amazon Basin (I):** Banados del Izozog: surface area is 7,600 km^2. **La Plata Basin (III):** Rio Pilcomayo: average discharge is 222 m^3/s. Tamengo Canal (1856S05748W): average discharge is 96.5 m^3/s; length is 10 km. Laguna Caceres: surface area is 200 km^2. Laguna la Gaiba: surface area is 40 km^2 within Bolivia. Laguna Mandiore: surface area is 40 km^2 within Bolivia. Laguna Uberaba: surface area is 55 km^2 within Bolivia.	Agricultural activities contribute pesticide, herbicide, and bacterial contamination. Biological contamination, such as fecal coliform, is most severe around and downstream of populated places. Salt and heavy metals contaminate Rio Pilcomayo, especially mercury.	Topography, transportation network, and vegetation may limit access and development of water points. Seasonal flooding may hinder access.	Seasonal flooding, swampy conditions during wet season. The Tamengo Canal is connected to Laguna Caceres and Rio Paraguay. Banados del Izozog is a wetland that feeds the Rio Parapeti.
4 Fresh water perennially available	Fresh water is perennially available from streams throughout the region. **Amazon Basin (I):** Rio Caine (1823S06521W), Rio Grande (1856S06334W), Rio Parapeti (upper	Small to large quantities of fresh water are perennially available from streams and lakes. High flows occur March to May; low flows May to December. Selected stream gaging stations and stream characteristics are listed below. **Amazon Basin (I):**	TDS is less than 200 mg/L in most mountain streams. Agricultural activities contribute pesticide, herbicide, and bacterial contamination. Biological contamination, such as fecal coliform, is most severe around and downstream of populated places. Heavy metals are reported	Topography, transportation network, and vegetation may limit access and development of water points. Streams generally flow through steep, V-shaped valleys.	

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water perennially available (continued)	reaches) (2002S06330W), Rio Mizque (1840S6420W). **La Plata Basin (III):** Rio Bermejo (2254S06421W), Rio Itua (2221S06407W), Rio Pilcomayo (upper reaches) (2114S06338W), Rio San Juan del Oro (2144S06549W), Rio Grande de Tarija (2254S06421W).	**3** Rio Mapiri measured at Angosto Quercano (1529S06753W): average discharge is 425 m^3/s. Rio Caine: average discharge is 59 m^3/s. **4** Rio Coroico measured at Rita Buenos Aires (1531S06750W): average discharge is 243 m^3/s. **5** Rio Grande measured at Puente Arce (1837S06510W): average discharge is 130 m^3/s. Rio Grande measured at Puente Santa Rosa (location unknown): average discharge is 22.3 m^3/s. **6** Rio La Paz measured at Cajetillas (1636S06727W): average discharge is 81 m^3/s. **7** Rio Parapeti measured at San Antonio (2019S06424W): average discharge is 79 m^3/s. **La Plata Basin (III):** Rio Bermejo: Average monthly discharge ranges from 4 to 249.7 m^3/s. Low flows September to October. High flows January to March. Rio Grande de Tarija: average monthly discharge ranges from 18.8 to 381.8 m^3/s; average discharge is 145 m^3/s. Low flows September to October. High flows January to March. Rio Pilcomayo: average discharge is 46.1 to 216 m^3/s. Rio San Juan del Oro: average discharge is 7.4 m^3/s.	in Rio Pilcomayo. Water quality data from points along selected streams are listed below. Mapiri River measured at Guanay (1529S06753W) on 17 Dec 1998 and 17 Oct 1999: TDS 33 to 55.2 mg/L; Hg 88.03 to 144.66 ng/L; pH 6.99 to 7.25; temperature 26 °C. Rio Caine at La Vina (1758S06550W): TDS 773 mg/L; HCO_3 252.7 mg/L; Cl^- 21.8 mg/L; SO_4 281.1 mg/L; temperature 16.6 °C. Rio Coroico measured at 1530S06750W 17 Nov 1997 and 16 Oct 1999: TDS 16.8 to 17.8 mg/L; Hg 12.14 to 21.19 ng/L; pH 6.89 to 8.06; temperature 24.8 to 6.3 °C. Rio Grande measured at Abapo (1850S06328W): TDS 395 mg/L; HCO_3 143.1 mg/L; Cl^- 24.9 mg/L; SO_4 110.4 mg/L; temperature 24.3 °C. Rio La Paz measured at 1636S06727W on 13 Dec 1999 and 22 May 2000: TDS 408 to 490 mg/L; Hg 979.58 to 3544.26 ng/L pH 8.43 to 8.5; temperature 19.6 to 25.9 °C. Rio La Paz at Tamampaya (1616S6713W): TDS 193 mg/L; HCO_3 51.9 mg/L; Cl^- 4.0 mg/L; SO_4 79.0 mg/L; pH 6.2; temperature 18.6 °C. Rio Parapeti at Camiri (2003S06331W): TDS 241 mg/L; HCO_3 125.4 mg/L; Cl^- 16.1 mg/L; SO_4 27.0 mg/L; pH 8.3; temperature 21.3 °C. Rio Tipuani measured at 1530S06753W on 18 Dec		

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
4 Fresh water perennially available (continued)			1998 and 17 Oct 1999: TDS 9.14 to 11.2 mg/L; Hg 21.65 to 66.34 ng/L; pH 5.98 to 6.24; temperature 21.7 to 23.7 °C. Tuichi River measured at 1435S06732W on 12 Dec 1998 and 13 Oct 1999: TDS 33.5 to 38 mg/L; Hg 15.91 to 62.74 ng/L; pH 7.4 to 7.7; temperature 23.9 to 28.5 °C.		
5 Fresh water scarce or lacking	Fresh to saline water seasonally available from perennial and intermittent streams and lakes. Salt water available from streams and salt lakes in the desert altiplano. **Central Basin (II):** Rio Desaguadero (1824S06705W), Rio Grande de Lipez (2047S06714W), Rio Lauca (1911S06808W), Lakes: Lago Poopo (1845S06707W), Lago Uru Uru (1806S06708W), Laguna Colorada (2217S06747W), Laguna de Coipasa (1912S06807W).	Unsuitable to moderate quantities of fresh to brackish water are seasonally available from primary streams and lakes, especially in the northern part of the region. Large quantities of saline water are available from lakes. High water generally occurs in February. Droughts occur annually between April and October. Selected stream gaging stations and stream characteristics are listed below. **Central Basin (II):** Rio Desaguadero: average discharge in the upper reaches is 52 m^3/s. Average discharge in the lower reaches is 89 m^3/s. **8** Rio Huayllani (1630S06807W): discharge in January 1993 was <10 m^3/s. Rio Lauca: average discharge is 4.7 m^3/s. Lago Poopo: surface area is 3,191 km^2. Lago Uru Uru: surface area is 260 km^2. Laguna Colorada: surface area is 50 km^2. Laguna de Coipasa: surface area is 2,225 km^2.	Water quality ranges from fresh to saline in streams and lakes. Water is always saline in salars. Fresh water sources generally become brackish to saline during the dry months of April to October. Water quality generally decreases from north to south. Agricultural activities contribute pesticide, herbicide, and bacterial contamination. Biological contamination, such as fecal coliform, is most severe around and downstream of populated places. There are high sediment loads in the Rio Desaguadero due to deforestation and agricultural activity. Biological contamination is extremely high. TDS in urban streams in La Paz ranges from 100 to 300 mg/L. Water quality data from points along selected streams are listed below. Rio Apacheta measured at 1637S06748W and 1631S06743W on 13 Dec 1999 and 22 May 2000: TDS 48.1 to 67.2 mg/L; Hg 134.39 to 407.35 ng/L; pH 7.59 to 8.09; temperature 7.2 to 10.1°C. Rio Challiri measured at 1637S06745W on 13 Dec 1999: TDS 32.6 mg/L; Hg 2604.14 ng/L; pH 7.42;	Access may be hindered by rugged terrain and lack of developed road networks. Flooding may hinder access to lakes for brief periods during the wet season. However, due to the dry climate access to lakes is generally good.	There are two dams being built on Rio Desaguadero to regulate the river and lake levels, and provide flood control. One is located at the outlet of Lago Titicaca, the other dam is 40 km downstream. Dredging began recently to combat high sedimentation rates. Salar de Uyuni (2027S06651W) is seasonally inundated with water.

Table C-1. Surface Water Resources (Continued)

Map Unit (See Fig. C-2)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
5 Fresh water scarce or lacking (continued)			temperature 9.8 °C. Rio Desaguadero: $CaCO_3$ 18 mg/L; NaCl 465 to 16,800 mg/L; SO_4 558 to 5,544 mg/L; SiO_2 30 to 70 mg/L. Lago Poopo: TDS 100,000 mg/L. High concentration of heavy metals. Laguna Colorada: TDS 1,000 mg/L; pH 8.5; high concentrations of Na, K, Mg, Ba, SO_4, Pb, As, and phosphates. Salar de Uyuni: high K, B, Mg, and Li.		

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

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

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

Conversion Chart:

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

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

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

Rio Alto Beni…….1431S06730W

Geographic coordinates for the Rio Alto Beni that are given as 1431S06730W equal 14°31' S 67°30' W and can be written as a latitude of 14 degrees and 31 minutes south and a longitude of 67 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. Coordinates are approximate.

[4]Bold numbers correspond to stream gaging stations shown on figure C-1.

Note:

°C	degrees Celsius	m/s	meters per second
As	arsenic	m^3	cubic meters
B	boron	m^3/s	cubic meters per second
Ba	barium	Mg	magnesium
$CaCO_3$	calcium carbonate	mg/L	milligrams per liter
Cl^-	chloride	Mm^3	million cubic meters
ft^3/s	cubic feet per second	Na	sodium
HCO^-_3	bicarbonate	NaCl	sodium chloride
Hg	mercury	ng/L	nanograms per liter
K	potassium	Pb	lead
km	kilometer	pH	hydrogen ion concentration
km^2	square kilometers	SiO_2	silica
m	meters	SO_4^{2-}	sulfate
max	maximum	TDS	total dissolved solids

Table C-2. Ground Water Resources

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful	Quaternary age unconsolidated and semi-consolidated deposits consisting of gravel, sand, silt, and clay. These aquifers are located in the Beni Plain (Vertiente Amazonas) hydrogeological province (1400S06530W).[3] The Chaco-Beni hydrological unit forms the largest single ground water reservoir in the country. The departments of Pando (1120S06740W) and Beni (1400S06530W) are contained in this hydrogeological province along with portions of the departments of Cochabamba (1730S06540W), La Paz (1530S06800W), and Santa Cruz (1730S06130W).	Small to very large quantities of ground water are available. These aquifers are characterized as being semi-permeable. Average yields per well in the Trinidad (1447S06447W) area are 20 L/s. Transmissivity values are 875 m^2/d. Specific capacity is 1.9 m^3/h/m.	Water quality is fresh. In the Trinidad area the average TDS concentration is approximately 150 mg/L and is of the Na-Cl type. Fe concentrations are about 0.7 mg/L. Biological contamination of the shallow ground water is common.	Depth to water ranges from 30 to 90 m. Depth information at specific locations is listed below. Trinidad: average well depths reported to exceed 90 m; average static water level of 5 m. Well siting is easy. Reconnaissance and exploratory drilling is recommended to locate zones of maximum yield. Many existing wells are hand dug. Wells should be cased and screened due to the unconsolidated nature of the materials and to seal off biologically contaminated zones. Access and maintenance hindered by seasonal inundations.	Alluvial aquifers are suitable for municipal or irrigation wells. Aquifers are also suitable for hand pump wells and most are suitable for 3.3 L/s (50 gal/min) tactical wells and small submersible pumps.
2 Fresh water generally plentiful	Quaternary age unconsolidated and locally semi-consolidated deposits consisting of gravel, sand, silt, and clay. These aquifers are located in the Gran Chaco Plain (Pantanal-Chaco Pampeano) hydrogeological province (1900S06000W). The Chaco-Beni hydrogeological unit forms the largest single ground water reservoir in the country. Portions of the departments of Chuquisaca (2000S06420W), Santa Cruz (1730S06130W) and Tarija (2130S06400W) are contained in this hydrogeological province. The ground water is mainly recharged by infiltration from the Rio Pilcomayo (2216S06240W).	Small to enormous quantities of water are available locally. City of Santa Cruz (1748S06310W) wells have a per-well average yield ranging from 20 to 120 L/s. A well northwest of Puerto Suarez (1857S05751W) has a yield of 13.5 L/s. Average yield per well in the Abapo-Izozog (1924S06245W) area ranges from 100 to 200 L/s. Yield of well at Montero (1758S06323W) 10 L/s.	Water quality is generally fresh. Locally hard to moderately hard. Water quality may vary on a seasonal basis and become locally alkaline and/or brackish to saline.	Depth to water ranges from 70 to >200 m. The aquifers in the area of the Rio Pilcomayo (2216S06240W) alluvial cone in the Department of Tarija are at depths ranging from 130 to 150 m. Depths to aquifer in the Gran Chaco plain (2300S06000W) area and Tertiary outcroppings are >180 to 200 m. Depth to water in the Abapo-Izozog area ranges from 70 to 235 m. Average well depth is 160 m, static water level is 10 m. Average static water levels at the City of Santa Cruz are 10 m with average well depths ranging from 70 to 250 m. Depth to water ranges from 70 to 200 m.	Alluvial aquifers are suitable for municipal or irrigation wells. Aquifers are also suitable for 3.3 L/s (50 gal/min) tactical wells and small submersible pumps.

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
2 Fresh water generally plentiful (continued)	Ground water flow on the left bank is toward Paraguay and flow on the right bank is toward Argentina.			The well northwest of Puerto Suarez has a depth of 103 m. Wide seasonal fluctuations of the water table occur. Well siting is easy. Extensive reconnaissance and exploratory drilling necessary to locate zones of maximum yield and best water quality. Wells should be cased and screened.	
3 Fresh water locally plentiful	Quaternary age alluvial aquifers, Mesozoic to Paleozoic age sedimentary aquifers consisting of sandstone, siltstone, shale, and conglomerate, and Quaternary to Tertiary age igneous aquifers consisting of basalt, dacite, tuff, and ignimbrites. Aquifers are unconfined to confined. Mineral and thermal springs are common, especially from Silurian and Devonian age rocks. These aquifers are part of the Eastern Andes and Subandean Zone (Vertiente Andina) hydrogeological province (1800S06400W). Portions of the departments of La Paz (1530S06800W), Potosi (2040S06700W), Cochabamba (1730S06540W), Chuquisaca (2000S06420W) and Tarija (2130S06400W) are contained in this hydrogeological province along with portions of the departments of Oruro (1840S06730W), and Santa Cruz (1730S06130W).	Very small to very large quantities of ground water are available locally. Ground water is primarily from fractures and joints that have enhanced porosity and permeability. Well yields for Sub-Andine Vorland are 2 to 4 L/s; Chaco yields are 1 to 2 L/s; Southern Cinti yields are 9 L/s; H. Siles yields are 4 L/s. Average well yields at specific locations are listed below. When coordinates are not given, the exact location for the well is unknown. **Department of Chuquisaca**: Sub-Andine Vorland: 2 to 4 L/s; Chaco: 1 to 2 L/s; Southern Cinti: 9 L/s; H. Siles 4 L/s. Well 10-RP at Redencion Pampa: 1.8 L/s; Huass Nucchu at Cerca de Nuccho: 7 L/s; Wells J-11 and J-12 at Tarabuco: 1.5 L/s each; La Palca at Cerca de Yotala: 1.5 L/s; Villa Carmen at Yotala: 0.8-1 L/s; Totacoa at Totacoa: 0.7 L/s; Puente Villa Victoria at	Water quality is generally fresh. Biological contamination is common near populated places. Near the Cordillera Oriental (1902S06517W), mining activities cause local contamination of the ground water.	Depth to water is generally <100 m. Sub-Andine Vorland static water level 23 m, average well depth 50 m; Southern Cinti static water level 3.5 to 15 m, average well depth ranges from 50 to 70 m; H. Siles, static water level 20 m; average well depth 80 m. Depth information at specific locations is listed below. **Department of Tarija**: Tarija-San Lorenzo: static water level >2 m, average well depth 40 to 60 m; Bermejo: static water level 15 m, average well depth 70 m. **Department of Cochabamba**: Cbba-Quillacollo: static water level >10 m, average well depth 50 to 80 m; Punata-Ciza: static water level >5 to 22 m, average well depth 30 to 60 m; Sacaba: static water level 5 to 10 m, average well depth 40 to 60 m;	

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful (continued)		Camino Sucre Yotala 2 L/s; Malteria at Alto Tucsupaya: 0.8 L/s; Granja Chuquisaca at Yotala: 1 L/s; El Tejar at Cuartel el Tejar: 2 L/s; Limoquije at Mosojillajta: 4 L/s; Lajastambo at Area de Sucre: 4 L/s; Pil at Area de Sucre: 3 L/s; Barrio San Juanillo at Ciudad de Sucre: 3 L/s; Padilla at Serctor Aeropuerto: 1.3 L/s; El Centro at SE Cuenca Culpina 8: L/s; Cantu Pampa at SE Cuenca de Culpina: 20 L/s; Agua Buena at Oeste Cuenca de Culpina: 14 L/s; G-2-1 at Montegudo Cabana: 4 L/s; G2-2 at Comunidad Pampa Heredia: 0.15 L/s; VGR-PA-1 at Vuelta Grande: 4.13 L/s; VGR-PA-2 at Vuelta Grande: 4 L/s; Nancorainza #1 at El Porvenir (1115S06841W) 1.04 L/s; Nancorainza # 2 at El Porvenir (1115S06841W): 5.09 L/s; El Porvenir 4, 5 and 6 at El Porvenir (1115S06841W): 2.5, 2.3 and 6.26 L/s; Pozo Redondo at Area Carandayti: 5.2 L/s; P-0-3 at Santa Rosa de Cuevo: 2.5 L/s; P-11 at Comunida Ivo 3 L/s; P-12 at Mess Verde Muyupampa: 2.8 L/s; P-15 at Muyupampa: 3.7 L/s, El Salvador at Centro Zootecnico 2.2 L/s, and Hito Villazon: 0.6 L/s. **Department of Cochabamba**: Cbba-Quillacollo: 15 to 20 L/s; Punata-Ciza: 10 to 30 L/s;Sacaba: 5 L/s. **Department of Tarija**: Tarji-San Lorenzo: 2 to 20 L/s.		Santivanez: static water level 7.5 m, average well depth 50 m. Siting is difficult. Reconnaissance and exploratory drilling are necessary to locate zones of maximum yield and best water quality. Drilling in the basalt requires hard-rock drilling techniques. Successful ground water exploration will depend upon encountering water bearing fractures and faults. Artesian wells are common. Access may be hindered by steep slopes. Wells should be cased and screened.	

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
3 Fresh water locally plentiful (continued)		**Department of La Paz**: La Paz: 66 L/s; Sucre: 1 L/s; Potosi: 7 L/s; Montegudo 4 L/s.			
4 Fresh water locally plentiful	Precambrian age metamorphic and igneous aquifers consisting primarily of gneiss and granite. These aquifers are found in the Brazilian Shield (Escudo Proterozoico hydrogeological province (1600S06200W) of eastern Bolivia in the departments of Pando (1120S06740W), Beni (1400S06530W) and Santa Cruz (1730S06130W). Quaternary age alluvial aquifers are a major source of ground water in the Brazilian Shield especially along the Rio Paragua (1334S06153W). Sandstone, siltstone, conglomerate and limestone that are partly metamorphosed are present in the eastern part of the Brazilian hydrological province near the border with Brazil.	Very small to very large quantities of fresh water available. Ground water is primarily from weathered zones and fractures and joints that have enhanced porosity and permeability. A well southwest of San Ignacio (1625S06058W) has a yield of 1.7 L/s with a specific capacity of 0.3 m^3/h/m.	Water quality is generally fresh. Shallow ground water may be biologically contaminated near settlements.	Depth to water is variable but generally <90 m. A well southwest of San Ignacio has a depth of 69 m and a static water level of 22 m. Reconnaissance and exploratory drilling are necessary to locate zones of maximum yield and best water quality. Drilling in the metamorphic and igneous rocks requires hard-rock drilling techniques. Successful ground water exploration will depend upon encountering water bearing fractures and faults. Wells should be cased and screened.	Aquifers are suitable for hand pump wells and most are suitable for 3.3 L/s (50 gal/min) tactical wells and small submersible pumps.
5 Fresh water scarce or lacking	Quaternary age unconfined to semi-confined aquifers consisting of unconsolidated and locally semi-consolidated gravel, sand, silt, and clay deposits. These aquifers are located in the Altiplano (1800S06800W) and Western Andes (Altiplano Cordillera Occidental hydrogeological province) (1800S06800W). The glacial, fluvial and lacustrine deposits have an average thickness of 200 m. Portions of the departments of Oruro (1840S06730W), Potosi (2040S06700W) and La	Meager to very large quantities of ground water are available from the unconsolidated and semi-consolidated aquifers. Meager to small quantities of ground water are available from fractures and joints that have enhanced porosity and permeability in igneous and metamorphic rocks. Meager to small amounts of ground water are available from aquifers comprised of basalt and tuff. Quantities are meager during the dry	Water quality is saline in much of the Altiplano. Locally, wells at the borders of the salt flats yield brackish water at depths of <30 m. Biological contamination is common near populated places. Ground water quality varies from north to south in the Altiplano. The region with the largest reservoir of fresh quality ground water is between Lago Titicaca (1548S06924W) and La Paz (1630S06809W). The Southern Altiplano (2020S06742W), which includes Lago Poopo (1845S06707W), Laguna de Coipasa	Depth to water is variable but is generally <90 m. Wide seasonal fluctuations of the water table occur, with many shallow wells going dry during the dry season. Depth information at specific locations is listed below. **Northern Altiplano, Department of Paz**: Achachicali: static water level 5 m, average well depth 40 to 100 m; Penas: static water level 7.5 to >1.31 m, average	The Altiplano, between the eastern and western flanks of the Andes, forms an extensive and closed hydrogeological unit. Infiltration takes place on the interior flanks of the Andes (2000S06700W) and the Altiplano itself. The Altiplano can be subdivided based on structural, geological and hydrogeological criteria. Artesian conditions occur in the Quaternary deposits of the

Table C-2. Ground Water Resources (Continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
5 Fresh water scarce or lacking (continued)	Paz (1530S06800W) are contained in this hydrogeological province. The Western Andes (2145S06830W), along the border with Chile, are volcanic mountains, which are included in this category. Quaternary to Tertiary age aquifers are pyroclastic, igneous, and metamorphic rocks consisting of tuff, basalt and with some gneiss and quartzites.	season and many shallow wells go dry. Average well yields at specific locations are listed below. When coordinates are not given, the exact location for the well is unknown. **Northern Altiplano (1700S06830W), Department of La Paz**: Achacachi (1628S06809W) 15 to 40 L/s; Penas: 15 L/s; Pucarani A (Batallas-Laja): 15 to 25 L/s; Pucarani B (Viacha-Coiquencha): 20 to 30 L/s; Catari: 15 to 30 L/s; Tiwanacu: 20 L/s. **Central Altiplano (1840S06730W), Department of Oruro**: Oruro-Caracollo: 20 to 60 L/s; Antequera-Challapata: 15 L/s; Huachacalla-Toledo: 3 L/s.	(1912S06807W) and Salar de Uyuni (2020S06742W), does not have favorable ground water quality conditions due to little precipitation and high salinity. Springs are abundant in the Western Andes, with high mineralization and gas content. Ground water temperatures vary between 60 and 80 degrees Farenheit.	well depth 40 to 60 m; Pucarani A (Batallas-Laja): static water level 17.5 to >1.56 m, average well depth 50 to 80 m; Pucarani B (Viacha-Colquencha): static water level 0.5 to 16 m, average well depth 40 to 90 m; Catari: static water level 0.2 to >1.3 m, average well depth 30 to 90 m; Tiwanacu: static water level 2.5 m, average well depth 30 to 60 m. **Central Altiplano (1840S06730W), Department of Oruro**: Oruro-Caracollo: static water level >1.7 m, average well depth 40 to 80 m; Antequera-Challapata: static water level 1.0 m, average well depth 40 to 60 m; Huachacalla-Toledo: static water level 9 m, average well depth 30 to 60 m. Well siting may be difficult to locate the best quality water. Extensive reconnaissance and exploratory drilling necessary to locate zones of maximum yield and best water quality.	Central Altiplano. Tactical wells are not recommended for these aquifers.

[1]Quantitative Terms:

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

Table C-2. Ground Water Resources (Continued)

[2]Qualitative Terms:

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

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 Western (W) Hemisphere. For example:

Beni Plain (Vertiente Amazonas) hydrogeological province………………………………….. 1400S06530W

Geographic coordinates for the Beni Plain (Vertiente Amazonas) hydrogeological province that are given as 1400S06530W equal 14° 00' S 65° 30' W and can be written as a latitude of 14 degrees and 00 minutes south and a longitude of 65 degrees and 30 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Coordinates are approximate.

Note:

$CaCO_3$	= calcium carbonate	m	= meters
Fe	= iron	m^2/d	= square meters per day
gal/min	= gallons per minute	mg/L	= milligrams per liter
L/s	= liters per second	NaCl	= sodium chloride
m^3/h/m	= cubic meters per hour per meter	TDS	= total dissolved solids

Conversion Chart:

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