社会開発調査部報告書

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

INSTITUTO DE FOMENTO MUNICIPAL
REPUBLIC OF GUATEMALA

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE CENTRAL PLATEAU AREA IN GUATEMALA

MAIN REPORT

JULY 1995

KOKUSAI KOGYO CO., LTD., TOKYO

Preface

In response to a request from the Government of the Republic of Guatemala, the Government of Japan decided to conduct a master plan and feasibility study on Groundwater Development in the Central Plateau Area and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent to Guatemala a study team headed by Mr. Kunio Fujiwara three times between February 1994 and May 1995.

The team held discussions with the officials concerned of the Government of Guatemala, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Guatemala for their close cooperation extended to the team.

July 1995

Kimio Fujita
President
Japan International Cooperation Agency

July 1995

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

Dear Mr. Fujita:

We are pleased to submit to you the study report on the Groundwater Development in the Central Plateau Area in Guatemala.

The report presents the study results on the categorization of the ninety-six candidate municipalities lacated in the study area, on the evaluation of the present water supply conditions as well as the groundwater development potential of the visited fifty-four municipalities. Also addressed in the report is the feasibility of a water supply project using groundwater as an additional supply source in the selected ten municipalities.

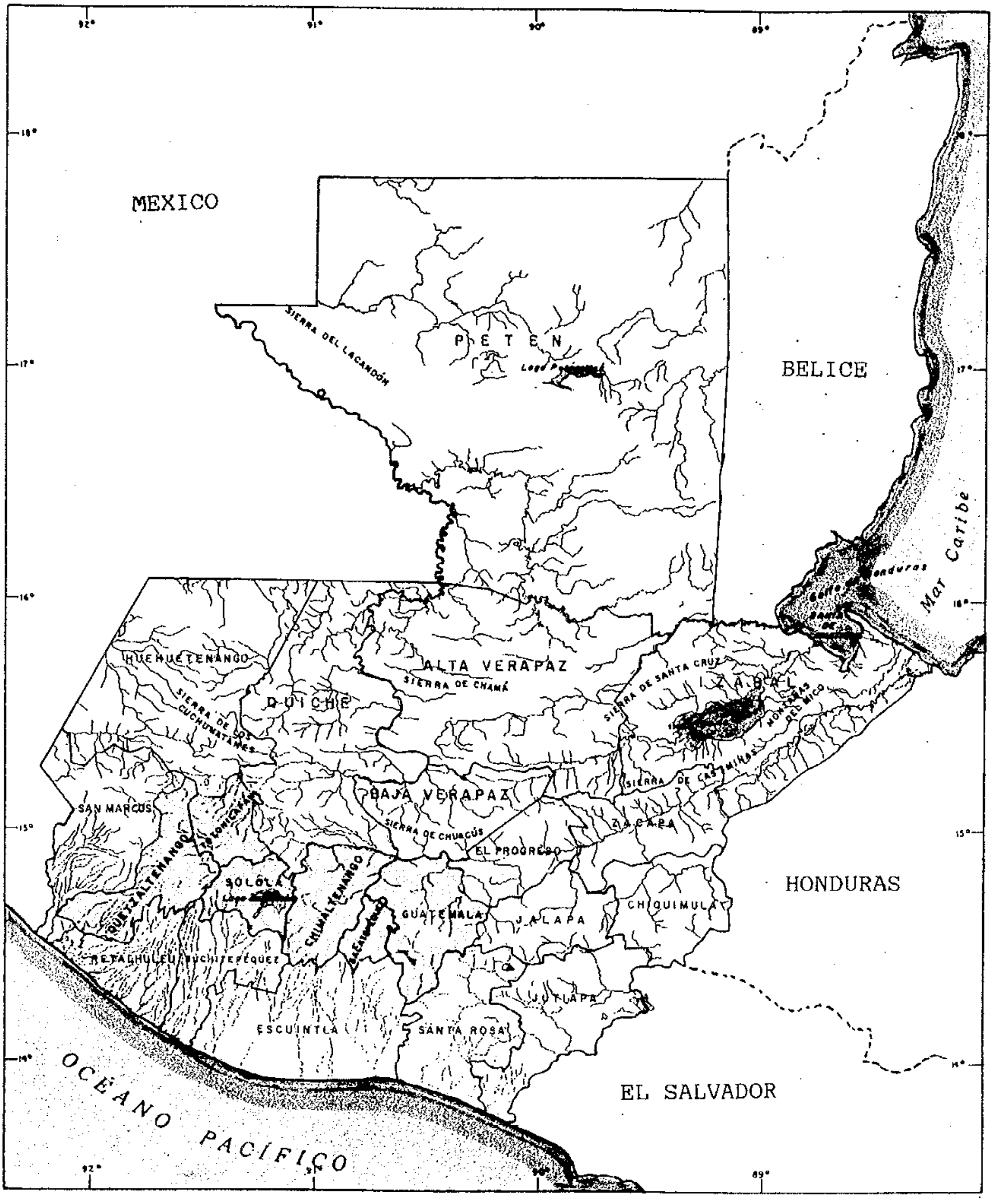
This report consists of the hydrogeological map and four separate volumes, including the Summary, Main and Supporting reports, and Data Book. The Summary states concisely the whole study results. The Main Report describes the results of the study and analysis including the groundwater development plan and the project evaluation for ten minicipalities. The Supporting Report contains the methods and specifications used in the field surveys, and the plan of the designed supply system. Data book contains the results of the field survey, well inventory and the rainfall records.

We are confident that implementation of the proposed groundwater development scheme would greatly contribute to improve the water supply conditions in the Central Plateau Area of the Republic of Guatemala.

We wish to take this opportunity to express our sincere gratitude to your agency and the Japanese Embassy in Guatemala. We also wish to express our deep appreciation to the Instituto de Fomento Municipal and other authorities concerned of the Government of the Republic of Guatemala for the close cooperation and assistance extended to us during our investigations and study.

Very truly yours,

Kunio Fujiwara
Team Leader
The Study on Groundwater
Development in the Central
Plateau Area in Guatemala



MEXICO
BELICE
HONDURAS
EL SALVADOR
OCEANO PACIFICO
Mar Caribe
PETEN
SIERRA DEL LACANDON
ALTA VERAPAZ
SIERRA DE CHAMA
HUEHUETENANGO
QUICHE
SIERRA DE LOS CUCHUMATANES
BAJA VERAPAZ
SIERRA DE CHUACUS
SAN MARCUS
QUEZALTENANGO
SOLOLA
CHIMALTENANGO
GUATEMALA
EL PROGRESO
ZACAPA
JALAPA
CHIQUIMULA
JUTIAPA
SANTA ROSA
ESCUINTLA
RETALHULEU
SUCHITEPEQUEZ
SIERRA DE SANTA CRUZ
SIERRA DE LAS MINAS
MONTAÑAS DEL MICO
92°
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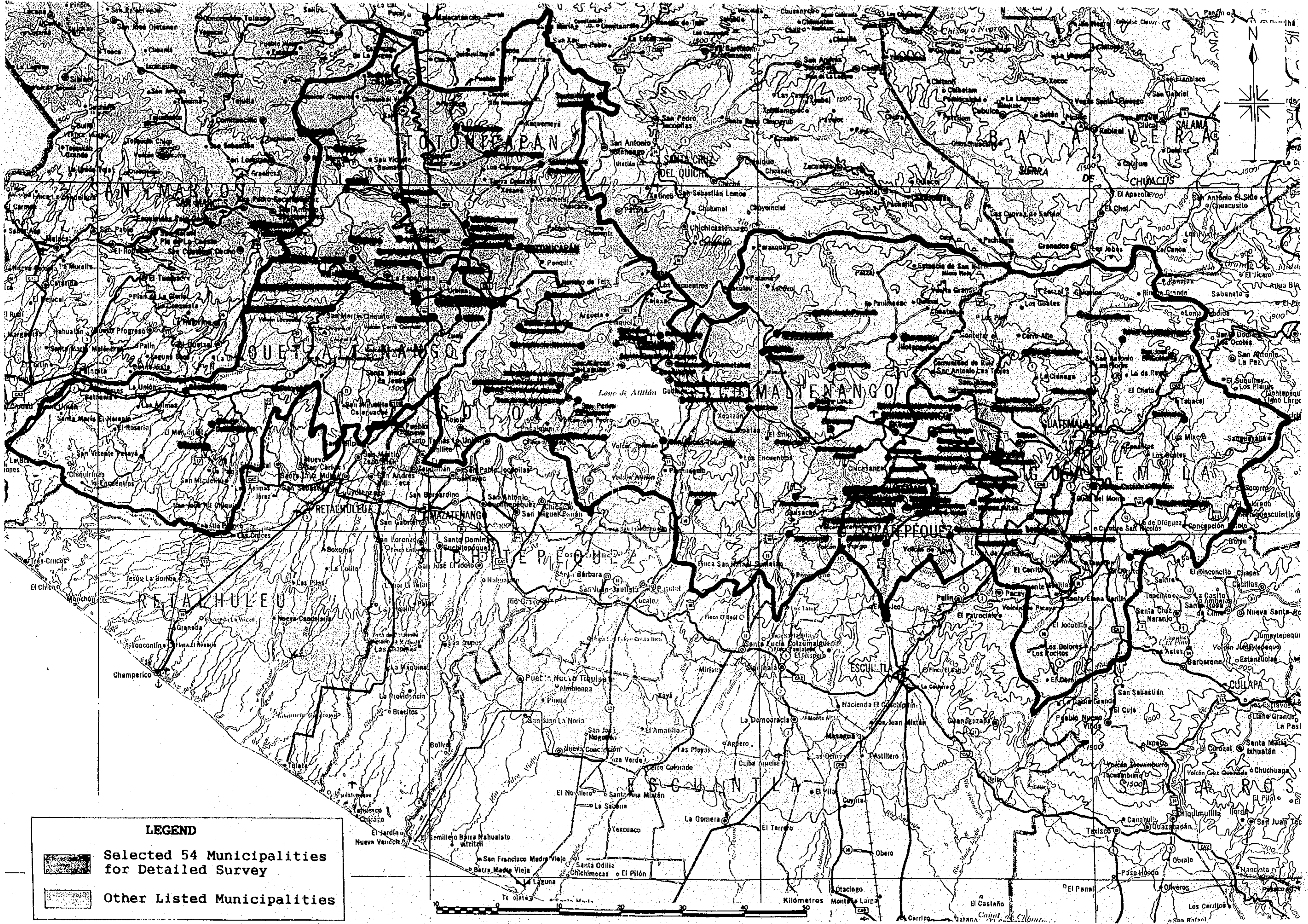
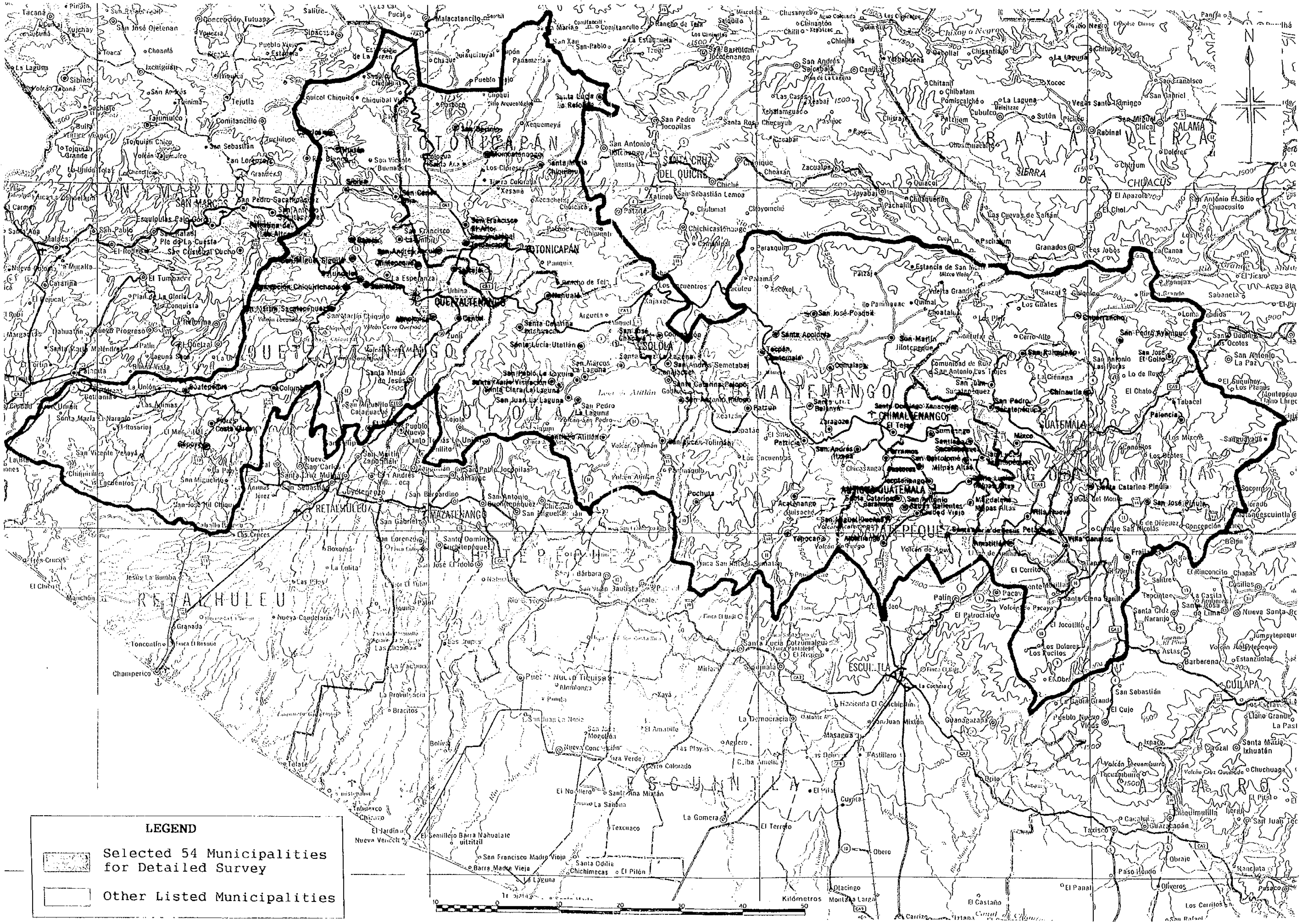
Study Area



LOCATION MAP OF STUDY AREA



LOCATION MAP OF STUDY AREA

CONTENTS

4. WATER DEMAND PROJECTION IN THE YEAR 2010

5. CATEGORIZATION OF THE CANDIDATE MUNICIPALITIES

6. WATER SOURCE DEVELOPMENT STRATEGY BY CATEGORIZATION

7. SURVEY FOR GROUNDWATER DEVELOPMENT

List of Tables

List of Figures

LISTA DE SIGLAS
(LIST OF ACRONYMS)

ANAM Asociación Nacional de Municipalidades
(National Association of Municipalities)

BID Banco Intermericano de Desarrollo
(Inter American Development Bank)

CACIF Comite Coordinador de Asociaciones Agricolas, Incustrials y Financieras
(Coordinator Committee for Agricultural, Industrial and Financial Associations)

CGC Cámara Guatemalteca de la Construcción
(Guatemalan Chamber of Construction)

CONAMA Comisión Nacional del Medio Ambiente
(National Environment Cmmission)

CONAP Consejo Nacional del Areas Protegidas
(National Council of Protected Areas)

COPECAS Comité Permanente de Coordinación de Agua Potable y Saneamiento
(Permanent Committee for the Coordination of Potable Water and Sewerage)

DGC Dirección General de Caminos
(General Road Directorate)

DSM División de Saneamiento del Medio
(Environmental Sanitation Division)

EEGSA Empresa Electrica de Guatemala S.A.
(Guatemala Electric Corporation)

EMPAGUA Empresa Municipal de Agua de la Ciudad de Guatemala
(Municipal Water Supply Corporation of Guatemala City)

IGM Instituto Geográfico Militar
(National Geographical Institute)

INDE Instituto Nacíonal de Electrificacíon
(National Institute of Electrification)

INE Instituto Nacional de Estadística
(National Institute of Statistics)

INFOM Instituto de Fomento Municipal
(Municipal Development Institute)

INSIVUMEH	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología *(National Institute of Seismology, Vulcanology, Meteorology and Hidrology)*
MAGA	Ministerio de Agricultura, Ganadería y Alimentación *(Ministry of Agriculture, Livestock and Food)*
MCTOP	Ministerio de Comunicaciones, Transporte y Obras Publicas *(Ministry of Comunications, Transport and Public Works)*
MINEDUC	Ministerio de Educación Pública *(Ministry of Public Education)*
MOF	Ministry of Finance
MSPAS	Ministerio de Salud Pública y Asistencia Social *(Ministry of Public Health and Welfare)*
ONAM	Oficina Nacional de la Mujer *(Woman's National Office)*
PAYSA	Proyectos de Agua Potable y Saneamient del Altiplano *(Projects of Potable Water and Sewerage in the Plateau Area)*
PRAS-CA	Red Regional de Agua y Saneamiento para Centro América *(Regional System of Water and Sewerage for Central America)*
SEGEPLAN	Secretaría General del Consejo Nacional de Planificación Económica *(General Secretariat of the National Council of Economic Planning)*
SRH	Secretaría de Recursos Hidraúlicos *(Secretariat of Hydraulic Resources)*
UNEPAR	Unidad Ejecutora del Programa de Acueductos Rurales *(Executing Body for Rural Agueduct Programme)*

CHAPTER 1

1 INTRODUCTION

1.1 General

This is the Final Report on the Groundwater Development Study in the Central Plateau Area in Guatemala ("The Study"), which was carried out in accordance with the "Scope of Work" agreed upon by the Instituto de Fomento Municipal (INFOM) and the Japan International Cooperation Agency (JICA) in September 1993.

The Study Area covered six Departments in the Central Plateau Area of Guatemala, where the 96 municipalities proposed as Study sites are situated.

The Study commenced in February 1994, and terminated upon submission of the Final Report in June 1995. The Study period was divided into two phases:

Phase I (from February 1994 to July 1994):

- Categorization of the 96 municipalities based on water supply shortage condition, socioeconomic features and new water sources

- Preliminary planning of water source development by categorization

Phase II (from July 1994 to June 1995):

- Feasibility study on the 10 prioritized municipalities mainly pertaining to groundwater development.

1.2 Outline of the Project

1.2.1 Background of the Project

Guatemala is situated to the south of the Yucatán Peninsula in Central America and covers a total area of about 108,900 km^2. The estimated total population in 1992 was 9.9 million, of which more than 40% is concentrated in the "Central Plateau Area" where the capital city, Guatemala City, is situated.

The Central Plateau Area, occupying about one-tenth of Guatemala, is composed of groups of mountainous basins with elevations ranging from 800 to 2,400 meters above sea level. Annual precipitation of 1,000 to 1,500 mm offers favorable conditions for agricultural production and living. The area has major potential for social, economic, and cultural development.

In spite of these attributes, many municipalities, even in the major cities of the Central Plateau Area have poor water supply services. The average coverage of water supply services in the plateau area, outside Guatemala

City, was estimated at 69% in 1988; the average service period being less than 12 hours/day. The main water source is spring water, and the capacity of the springs in many municipalities has become insufficient as the population increases. In 1993, it was found that of the 96 major municipalities, services in 29 were unable to supply the desired 150 liters per capita per day, and this is projected to increase to 42 municipalities by the year 2010 if new supply sources are not developed. Further, it is expected that the existing water source will be replaced with groundwater pumping in the future. However, groundwater development faces several technical and economic problems due to the topographic and hydrogeologic features of the Central Plateau Area.

With this background, the Government of the Republic of Guatemala requested the Japanese Government, in January of 1990, to cooperate in formulating a water supply source development plan focusing on groundwater development.

On the basis of this request, JICA dispatched a preliminary study team to Guatemala in May and again in September 1993, and formulated the Scope of Work (S/W) related to the execution of the groundwater development study.

1.2.2 Objectives of the Study

The objectives of the Study are:

1) To formulate a water supply source development plan for the candidate municipalities by categorization of the 96 municipalities with respect to water source development potential, water demand, and socioeconomic situation.

2) To formulate a supply plan for the 10 prioritized municipalities and study its feasibility.

3) To undertake technology transfer to the counterpart personnel during the course of the Study.

1.2.3 Study Area

The Study Area covers the 6 departments of Quetzaltenango, Totonicapan, Sololá, Chimaltenango, Sacatepequez and Guatemala in the Central Plateau Area, with the exclusion of Guatemala City.

Phase I of the Study covered the 96 municipalities and their surroundings, as shown on the location map. In Phase II, the Study focused on the 10 prioritized municipalities and a feasibility study was carried out.

1.2.4 Study Team

For the smooth conduct of the Study and effective transfer of technology, INFOM organized a steering and coordinating group and a counterpart group to form the INFOM/JICA joint "Study team" which consisted of the following members:

Guatemalan side:

a) Steering and coordinating group members:

Lic. Gustavo Leal, INFOM Manager
Ing. Tofic Abularach, Management Adviser
Ing. Carlos Salvatierra, Head of Operation and Maintenance Dept.
Ing. Ulrich Seifert, Head of Operation Section
Ing. Adán Pocasangre, Technical Adviser

b) Counterpart members:

Ing. Rafael Girón, INFOM Coordinator
Ing. Nelson Díaz, Civil Engineer
Licda. María del Rosario Alcantara, Biochemist

JICA members:

Eng. Kunio Fujiwara, Leader (Groundwater development)
Eng. Atsuo Kanda, Co-Leader (Hydrogeology, Natural environment)
Eng. Masatoshi Tanaka (Geophysics, Hydrology A, Test drilling A)
Eng. Masahiro Yamaguchi (Hydrology B)
Eng. Akiko Mukade (Water quality, Sanitary environment)
Eng. Shuji Arakawa (Water supply facility)
Eng. Masaharu Kina (Socio-economy A)
Eng. Masaru Obara (Socio-economy B)
Eng. Masayuki Ogata (Test drilling B)
Ms. Xiomara Yamaguchi (Administrative support)
Eng. Valerio Gutierrez (Administrative support)

1.3 Study Description

1.3.1 Study Components and Sequence

The major purpose of the Study is to devise a water source development plan to meet the increasing water demand in the concerned municipalities. Most of the existing water supply services rely on spring water, in particular, springs situated at elevations higher than the residential areas they serve, allowing distribution by natural flow which in turn reduces markedly the cost of operation and maintenance. However, such springs seem to have been fully exploited, leaving little probability for future development. Possible alternative sources are:

- Spring development at lower elevations

- Collection of shallow groundwater by construction of shallow wells or infiltration gallery

However there are problems involved in the introduction of new water sources, such as:

- Insufficient new water source development potential
- Poor water quality, especially surface water
- Higher operation and maintenance costs, in particular, water supply systems which involve motorized pumping

Consequently, Phase I comprised the following:

1) Water source development study with emphasis on groundwater development, including:

    - Hydrogeology
    - Meteorology, hydrology and water quality

2) Socioeconomic study:

    - Water demand
    - Existing water supply system and service level
    - Social environment
    - Willingness to improve water supply service and ability to pay for the operation and maintenance

3) Categorization and priority assignment of the municipalities for the establishment of a water source development strategy, based on the results of the above two study components.

In Phase II, a feasibility study for the water supply project in the 10 selected municipalities was carried out with the following 3 study components:

1) Confirmation of the hydrogeological condition by conducting detailed hydrological/hydrogeological surveys including test drilling and pumping tests.

2) Facility design of water intake (well), transmission and distribution systems for the 10 municipalities; and a trial improvement plan (distribution system) in one municipality.

3) Project evaluation including project cost estimation.

    The Study flow chart and the work items are presented in Fig. 1.3.1, and the work schedule is shown in Fig. 1.3.2.

The progress of the Study is briefly described below:

Phase I: Six and a half months, January to July 1994

The first four months were spent in Guatemala for data collection and arrangement, and detailed surveys of 49 municipalities. The 96 municipalities were categorized in terms of socioeconomic and hydrogeological conditions. Progress Report (1) was prepared and a series of discussions were held at the beginning of June in Guatemala.

The collected data and information were brought back to Japan and analysed for the establishment of a water source development strategy. The Interim Report was prepared containing results obtained up to then, along with the tentative plan for the Feasibility Study for the 10 municipalities in Phase II.

Phase II: Nine and a half months, July 1994 to May 1995

The five months from July to December were used for a detailed hydrological and hydrogeological survey for the preparation of the hydrogeological map and for the collection of additional data for the feasibility study. Progress Report (2) was prepared before the end of these five months.

After three months of analytical work in Japan, from January 1995, the Draft Final Report was prepared covering all areas of the Study. The conclusions and results were discussed with the Guatemalan officials concerned in May 1995.

Submission of the Final Report:

The Final Report was prepared based on the comments of the Guatemalan government officials on the Draft Final Report, and sent to the Government of Guatemala from JICA through diplomatic channels. This marked the end of the Study.

1.3.2 Technology

The following technologies were applied during the course of the Study.

a. For the study of water source development potential (in particular, groundwater)

a-1 Hydrogeology

(Phase I)

- Review of existing geological studies, report/ information
- Interpretation of aerial photographs (topography and geology)
- Geological field reconnaissance

- Review of existing drilling records (lithology and pumping rates)
- Geophysical prospecting (electric resistivity sounding) for classification of geological formations and for depth sounding
- Interviews on water usage and source (spring, groundwater)

(Phase II)

- Detailed hydrogeological field reconnaissance
- Aerial photograph interpretation
- Electric resistivity sounding
- Test drilling and geophysical logging
- Pumping tests to determine the hydraulic parameters of aquifers

a-2 Hydrology

(Phase I)

- Collection and review of meteorological data
- Collection and arrangement of discharge data
- Preliminary analysis of water balance in basins
- River flow observations to determine where to set up the flow measurement stations
- Spring discharge measurement
- Analysis of water quality (pH, Electric Conductivity)

(Phase II)

- Installation of automatic water level gauge in the drilled wells and the monitoring of water levels
- Measurement of spring and river discharge
- Analysis of water quality

b. Social environment and socioeconomy in Phase I

b-1 Social environment and existing water supply systems

- Collection and review of information in each municipality
- Distribution and collection of questionnaires
- Interviews on existing service level, willingness to upgrade service level and ability to pay operation and maintenance costs
- Inspection of existing intake, transmission, storage, and distribution facilities
- Interviews on water allocation (domestic use, agricultural use and industrial use)
- Sanitary environment survey by interviews and water quality analysis

b-2 Socioeconomy

- Collection and review of financial statistics
- Interviews with heads of municipalities on municipal financial affairs
- Interviews on industries and income levels in the municipalities, and the ability to pay water rates

c. Water supply system design survey in Phase II

- Survey on domestic water consumption
- Measurement of water production for domestic use
- Topographic and land use survey along the proposed transmission line
- Capacity of distribution tank
- Cost estimation of material for facility construction
- Cost estimation for facility construction and facility operation and maintenance

Fig. 1.3.1 OPERATION PLAN FLOW CHART

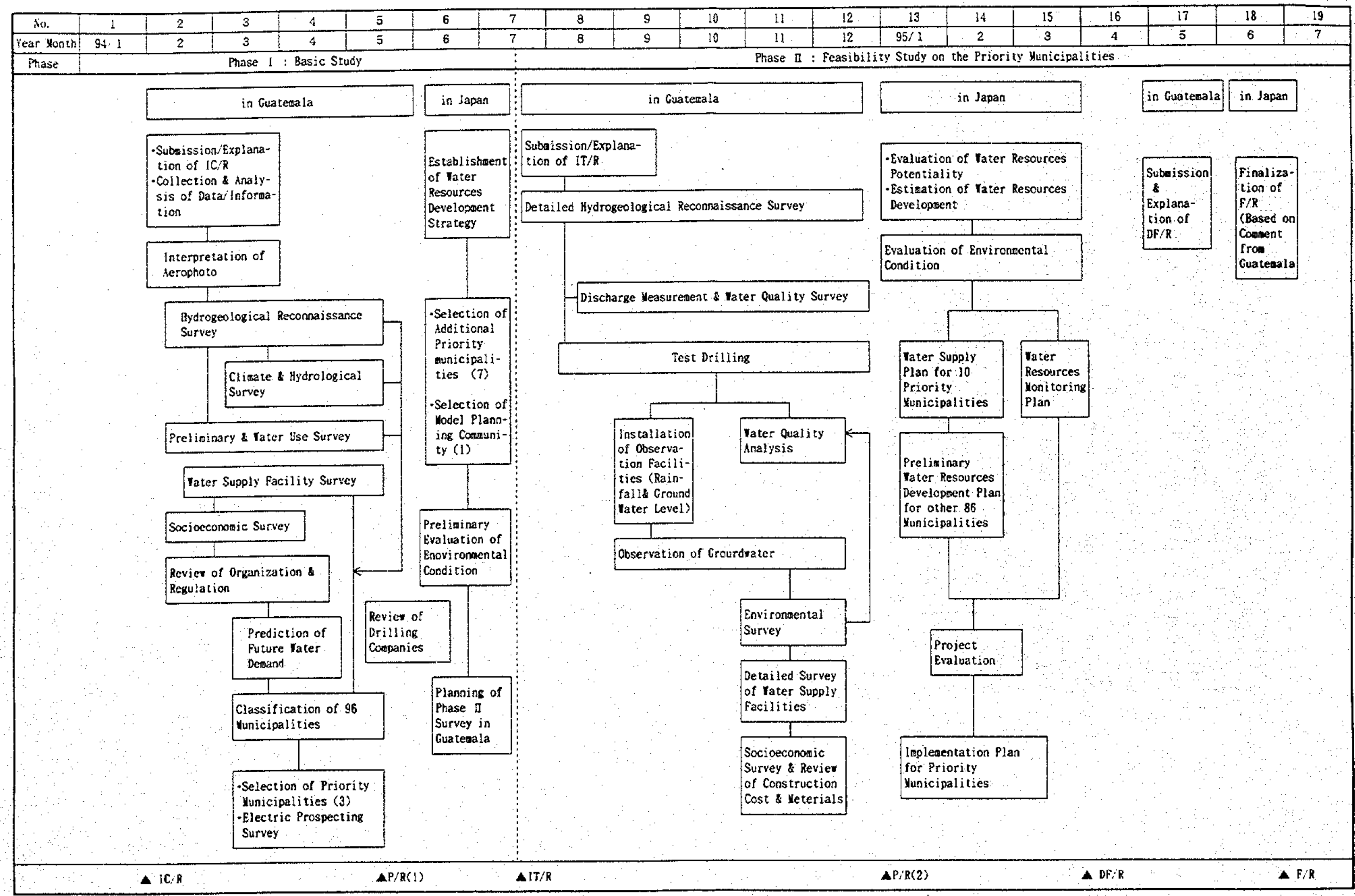
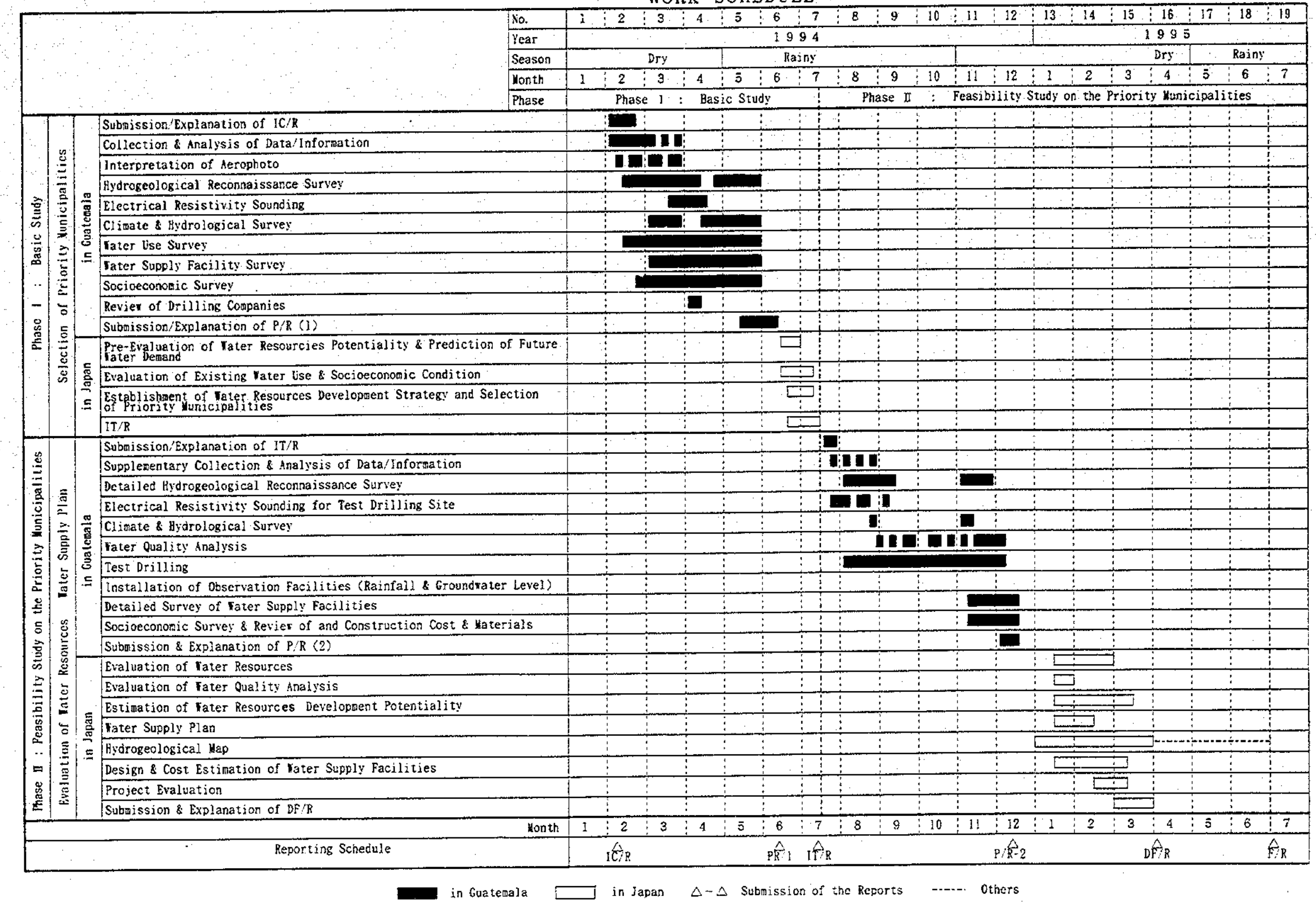


Fig. 1.3.2 WORK SCHEDULE



CHAPTER 2

2. GENERAL CONDITION OF THE STUDY AREA

2.1 Natural Conditions

2.1.1 Topography

Guatemala is located approximately between north latitudes 14° and 18°, and west longitudes 88° and 92°. Situated south of Mexico and northwest of Honduras and El Salvador on the Central American isthmus, Guatemala encompasses a land area of 108,900 km^2, extending between the Atlantic and Pacific oceans.

The land area is naturally divided into 3 regions: the coastal plains of the south, the "Central Plateau", and the forestal plains of the north. The "Study Area" is situated in the Central Plateau.

The Central Plateau region, occupying about one-tenth of the land area of the country, is composed of the mountains of the Sierra Madre and the Cuchumatanes ranges, with elevations ranging from 600 m in the southeast to over 3,000 m in the northwest. These mountainous highlands comprise numerous intramountain basins and a chain of young volcanoes extending in the NW-SE direction along the southwestern margin of the Central Plateau. The major peaks are Tajumulco (4,220 m, the highest peak in Central America), Acatenango (3,960 m) and Fuego (3,835 m).

The Study Area, located southeast of the Central Plateau region, consists mainly of Neogene and Quaternary volcanic rocks and covers an area of 8,643 km^2.

The area was divided, for this study, into 9 main intramountain basins corresponding roughly with the groundwater basins shown below and in Fig.2.1.1.

a) Río Samalá basin (Quetzaltenango-Totonicapán)
b) Río Chixoy o Negro basin (Totonicapán)
c) Lago Atitlán basin (Sololá)
d) Río Coyolate basin (Chimaltenango)
e) Río Pixcayá basin (Chimaltenango-Guatemala)
f) Río Guacalate basin (Sacatepéquez)
g) Río Las Vacas/Lago Amatitlán basin (Guatemala)
h) Río Plátanos basin (Guatemala)
i) Río Aguacapa basin (Guatemala)

Rivers flowing from the central mountain belt to the Caribbean Sea (Río Chixoy o Negro, Río Pixcayá, Río Las Vacas, and Río Los Plátanos) have relatively gentle currents while those emptying into the Pacific Ocean (Río Samalá, Río Coyolate, Río Guacalate, and Río Acuacapa) are generally rapid flowing.

Lakes Atitlán and Amatitlán, noted for their scenic beauty, are caldera lakes formed as a result of volcanic activities during the Pleistocene period. Lake Atitlán forms a semiclosed water basin.

2.1.2 Geology

The principal rock units of the Study Area are divided hydrogeologically into 3 groups. They are the basement group, the Tertiary volcanic group, and the Quaternary volcanic group, in ascending order.

The basement group, which consists of metamorphic rocks, Cretaceous series, and intrusive rocks, is hydrogeologically categorized as the impermeable basement of groundwater basins.

Metamorphic rocks composed of phyllite and schists are probably of the upper Paleozoic era. They are largely exposed in the northeastern region of the Study Area.

The Cretaceous series is lithologically divided into 3 subgroups: lower calcareous subgroup, middle volcanic subgroup (basaltic rocks), and upper clastic subgroup. The lower calcareous subgroup, consisting of limestone and dolomitic limestone of the early Cretaceous period, occurs in a massive form with weak stratification. This subgroup is partially faulted and fractured and forms partial water-bearing zones with a thickness estimated at about as much as 500 m. The middle volcanic subgroup consists mainly of fractured basaltic lava with pyroclastic materials with a thickness estimated at about 350 m. The upper clastic subgroup consists of conglomerate, greywacke, and calcareous radiolarite, with an estimated thickness of about 450 m. This subgroup is regarded as of the late Cretaceous Period.

Intrusive rocks composed of granodiorite, quartz diorite and quartz monzonite are generally found as massive rock bodies. The geological age of their intrusion in the Study Area is presumably of late Cretaceous or Paleocene.

The Tertiary volcanic group is composed entirely of volcanic materials from the Miocene and Pliocene epochs and is generally divided into lower and upper subgroups.

The lower subgroup is composed mainly of latitic (trachyandesitic) to dacitic welded tuffs. The upper subgroup consists of rhyolitic, andesistic to basaltic, and pyroclastic lava, volcanic mud, and tuff.

The Tertiary volcanic group varies markedly in thickness depending on its origin and areas of volcanic eruption. Rocks of this groups are highly fractured and form localized water-bearing zones.

The Quaternary volcanic group is divided into 3 subgroups of Pleistocene volcanics, Holocene volcanics and alluvial deposits.

The Pleistocene volcanics (Qp) are mainly composed of pumice sediments (fall and pyroclastic flow types). These pumice sediments are generally solidified and are partially accompanied with lake deposits. The intramountain basins in the Study Area are filled mostly by these pumice sediments and form major water bearing layers (main aquifer).

The Holocene volcanics (Qv) consisting of lava flow, volcanic mud flows (laharic deposits), tuff, cones and domes are exposed along the volcanic chain extending in the NW-SE direction near the southwest edge of the Central Plateau.

The alluvial deposits (Qa) are found mainly along valleys and lake shores, and are composed of secondary sediments of the volcanic materials mentioned above. The alluvial deposits in this area contain good aquifers.

2.1.3 Structure and History

As shown in Fig 2.1.2, the regional geological structure in the Study Area is characterized by lithological units consisting of basement group, Tertiary volcanics, Quaternary volcanics, and by fault systems comprising major faults, grabens and minor (local) faults. These lithological units, major fault systems, and grabens are situated across the Study Area in an east-west direction arching southward.

Fig 2.1.3 shows the palaeogeographical condition of the southern part of Guatemala in the early Cretaceous period. Up until the beginning of the early Cretaceous period, the southern part of Guatemala was estimated to have been composed of a mountainous region extending east-west (including the Sierra Madre, Sierra de Chuacús and Sierra de las Minas), and plains to the north and south of this mountainous region. These regions were mainly composed of Paleozoic clastic sediments. Then, from the late Paleozoic era to the Jurassic period, major fault systems (the Cuilco-Chixoy fault and Motagua-San Agustín fault) and grabens were formed through orogenic movement.

The movement progressed through the early Cretaceous period in the mountainous and plains regions as well as in the area of the recently formed grabens. This transgression continued up to the early Paleocene epoch. During this time, the Cretaceous series consisting of the lower calcareous subgroup (mainly massive limestone and dolomite), the middle volcanic subgroup (basaltic rocks), and upper clastic subgroup (conglomerate and calcareous radolarite) were widely deposited over the Study Area. The total thickness of this Cretaceous series is estimated at about 1,300 m.

From the late Cretaceous to the early Paleocene, igneous rocks consisting of granodiorite, quartz diorite, and quartz monzonite intruded into the Cretaceous series through the late Paleozoic metamorphic basement. This igneous activity originated a sharp geotectonic movement with extensive uplifting, local subsidence, faulting and folding of the region. Resulting from this geotectonic movement, the Study Area was lifted up and changed from a shallow marine area into an uplifted terrestrial area. The initial major fault systems (Cuilco-Chixoy fault and Motagua-San Agustín faults) were reformed with local faulting. The initial intramountain basins with localized grabens were also reshaped during this stage.

Although the Cretaceous series and igneous rocks in the Study Area are now exposed as raised and isolated blocks, it is assumed that these basement groups were distributed as shown in Fig 2.1.4. The Cretaceous series extends as a belt approximately 35-40 km in width from the northwest to the southeast. This belt is made up of 2 belts of igneous rocks.

The Cuilco-Chixoy fault system is situated at the northwestern border of the Study Area and extends in the east-west direction arching southward. The Motagua-San Agustín fault system runs roughly parallel to the Cuilco-Chixoy system, also arching southward. This fault system is located along the central and eastern extreme of the northern boundary of the Study Area. A leftward relative movement of the fault systems was caused by compression in the NE-SW direction due mainly to the igneous activity mentioned above, and the arching originated the combination of faulting in the SSW-NNE, N-S, and NNW-SSE directions with open fractures.

From the Miocene to Pliocene epochs, large volcanic eruptions occurred over the whole Study Area. The initial volcanic activity, mainly in the Miocene, spewed out vast amounts of latitic to dacitic tuffs, and welded tuffs. Secondary volcanic activity, mainly Pliocene, caused the eruption of immense amounts of volcanic materials consisting of rhyolitics, andesitics to basaltics, pyroclastics, volcanic muds (laharic deposits), and tuffs. It is estimated that the centers of these volcanic eruptions were located inside the present intramountain basins.

After the violent volcanic activity of the Neogene, a relatively calm geotectonical period lasted through the early Pleistocene. During this time the intramountain basins were enlarged through erosion.

From the later stages of the early Pleistocene, block movements, uplifting, faulting, and localized subsidence of areas began. This block movement is thought to have accelerated through the middle Pleistocene. Along with this movement, geotectonic basins and grabens were formed in the enlarged intramountain basins. At almost the same time, large volcanic eruptions again occurred erupting Pleistocene volcanics (Qp) along the Tertiary volcanic belt

(Tv). The Pleistocene volcanics which consist mainly of pumice sediments with clastic lake bed deposits, filled up the main part of the intramountain basins as well as the geotectonic basins and grabens. Lakes Atitlán and Amatitlán are probably caldera lakes formed after great amounts of pumice erupted from the original volcanoes.

After the plate movements and volcanic activities mentioned above, the young volcanic activities of the Holocene followed in the chain of Quaternary volcanoes (Qv) (e.g. Santa María, Fuego, and Pacaya) extending along the southern border of the Tertiary volcanoes. The Guatemala earthquake in 1976 resulted from plate movement in this area, and the faulting associated with the earthquake is primarily of the same tectonic origin as discussed above.

2.1.4 Climate

The Study Area is divided, from east to west, into 6 Departments: Guatemala, Sacatepéquez, Chimaltenango, Sololá, Totonicapán and Quetzaltenango. Most of these places are in the Central Plateau, except for the southern parts of Quetzaltenango.

The elevation of the Central Plateau varies from 1,500 to 3,000 m, and Guatemala City and Quetzaltenango City are located at 1,500 m and 2,500 m above sea level, respectively. The climate of the municipalities in the Study Area is either tropical or typical of a highland depending on their location.

The average temperature varies in the Study Area, from a minimum 18.8°C in January to a maximum 22.2°C in April at the Potrero Station, and from a minimum 11°C in January to a maximum 14.7°C in May at Labor Ovalle Station.

Rainy season is generally from May to October. The monthly rainfall has two peaks, June and September (Fig. 2.1.5). In general, most of the candidate municipalities in the Study Area have an average annual rainfall of between 1,000 and 1,200 mm, with the exception of areas in the southern part of Quetzaltenango, like Colomba which has over 3000 mm.

The average, maximum and minimum temperatures and annual rainfall at the 4 stations of INSIVUMEH, Santa Cruz Balanyá, Labor Ovalle and San Jerónimo, which are at the eastern, central, western and southern parts of the Study Area, respectively, are shown below.