社会開発協力部報告書

NO. 07

REPUBLIC OF GUATEMALA

MUNICIPAL WATER SUPPLY CORPORATION

OF GUATEMALA CITY (EMPAGUA)

FEASIBILITY STUDY ON THE GROUND WATER DEVELOPMENT PROJECT (FOR EMERGENCY I)

VOLUME 2
APPENDIX I

SEPTEMBER 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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FEASIBILITY STUDY
ON
THE GROUND WATER
DEVELOPMENT PROJECT
(FOR EMERGENCY I)

LIST OF REPORTS

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受入月日 '86.10.03

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CHAPTER I

INTRODUCTION

1.1 Survey Objectives

The objective of this Study is to explore the feasibility of groundwater develoment of 1m ^{3}/sec in the study area for achieving the objectives of Emergency Plan I of PLAMABAG. Within the range described in Section 1.3, the groundwater characteristics were clarified through reanalysis of existing materials, various types of geophysical surveys and test wells to determine the optimum development approach on the basis of the groundwater characteristics and the develoment potential as identified in the course of the Study.

1.2 Republic of Guatemala

1.2.1 Location and Land Area

Guatemala is located roughly between north latitudes 14 $^\circ$ and 18°, and west longitudes 88° and 92°. The country is situated south of Mexico and northwest of Honduras and El Salvador on the Central American isthmus, and encompasses a land area of 108,889 sq. kms. extending between the Atlantic and Pacific oceans.

1.2.2 Topography

The Sierra Madre range extends south from Mexico parallel to the Pacific coastline and includes numerous high volcanic peaks among which are Tajumulco (4,220m; the highest peak in Central America), Tacana (4,093m), Acatenango (3,960m), and Fuego (3,835m). Guatemala City is situated on the central plateau at the southeast portion of this range.

To the north of the Sierra Madre runs the Cuchumatanes range. As a consequence, the southern half of the country is comprised essentially of mountainous terrain. The northern half of the country extends into the Yucatan Peninsula, and consists of flat, forested land.

1.2.3 Rivers

Rivers flowing from the central mountain belt to the Caribbean Sea are relatively large with a slow moving current, while those emptying into the Pacific Ocean are generally swift flows. Principal rivers are the Usumacita flowing into the Gulf of Mexico, the Dulce and Motague emptying into the Gulf of Honduras, and the Suchiate which forms the the border with Mexico and empties into the Pacific Ocean.

1.2.4 Lakes

Major lakes include Izabal, the largest in Guatemala; Peten Itza, which is located close to the ancient ruins in the north; as well as the volcanic lakes of Atitlan, Amatitlan and Guiya which are noted for their scenic beauty.

1.2.5 Climate

Guatemala may be broadly classified into two meteorological zones. One comprises tropical lowlands and the other consists of tablelands of temperate climate. Temperatures in the former range between 25 °C - 30°C while those in the latter are 16 °C - 20°C. The rainy season is from May to October. Average annual rainfall for the country as a whole is 1,670mm of which 1,610mm is concentrated in the rainy season.

1.3 Location of Project area

Guatemala City is located at 14°38'00'' north latitude and 90°31'00'' west longitude on a plateau of altitude 1,500m formed through volcanic activity.

Metopolitan Guatemala includes Guatemala City itself and the surrounding urban centers of Mixco, Villa Nueva, Patapa, Santa Catarina Pinula, Villa Canales as well as one portion of Chinautla, and encompasses a total area of 470km^2. This is equivalent to approximately one half of the total 800km^2 of the Guatemala City Valley.

The Guatemala City Valley comprises two horseshoe-shaped portions lying north and south respectively of the continental divide which runs WNW - ESE through the center of the valley. Rivers in the northern part of the valley (Las Vacas, etc.) flow into the Caribbean Sea, while those in the south (Villalobos, etc.) empty into the Pacific Ocean via Lake Amatitlan. Rivers in the valley course through eroded ravines of 50 to 80m in depth.

On the basis of the study and analysis of the hydrogeologic, topographic, geologic, and environmental conditions, etc. prevailing in the Guatemala City Valley and neighboring basin to the east, the study area for the subject Study was determined as encompassing 815km ^{2} comprised principally of the Guatemala City Valley but which i) excludes the Lake Amatitlan and Michatoya river catchment areas in the south of the valley and ii) includes, due to considerations of groundwater circulation patterns and faulting configuration, the neighboring basin to the east of the Guatemala City Valley. This area is equivalent to 0.7% of the total land area of Guatemala. As indicated in the Fig. I-1, a macroview of the subject area shows it located at the juncture of the Cocos, North American and Caribbean plates.

The Study area is divided into 3 sectors; namely, the area to the northeast of the Guatemala City Vally referred to as the "eastern sector", the area of the Guatemala City Valley to the north of the continental divide referred to as the "northern sector", and the area of the valley located to the south of the continental divide and referred to as the "southern sector".

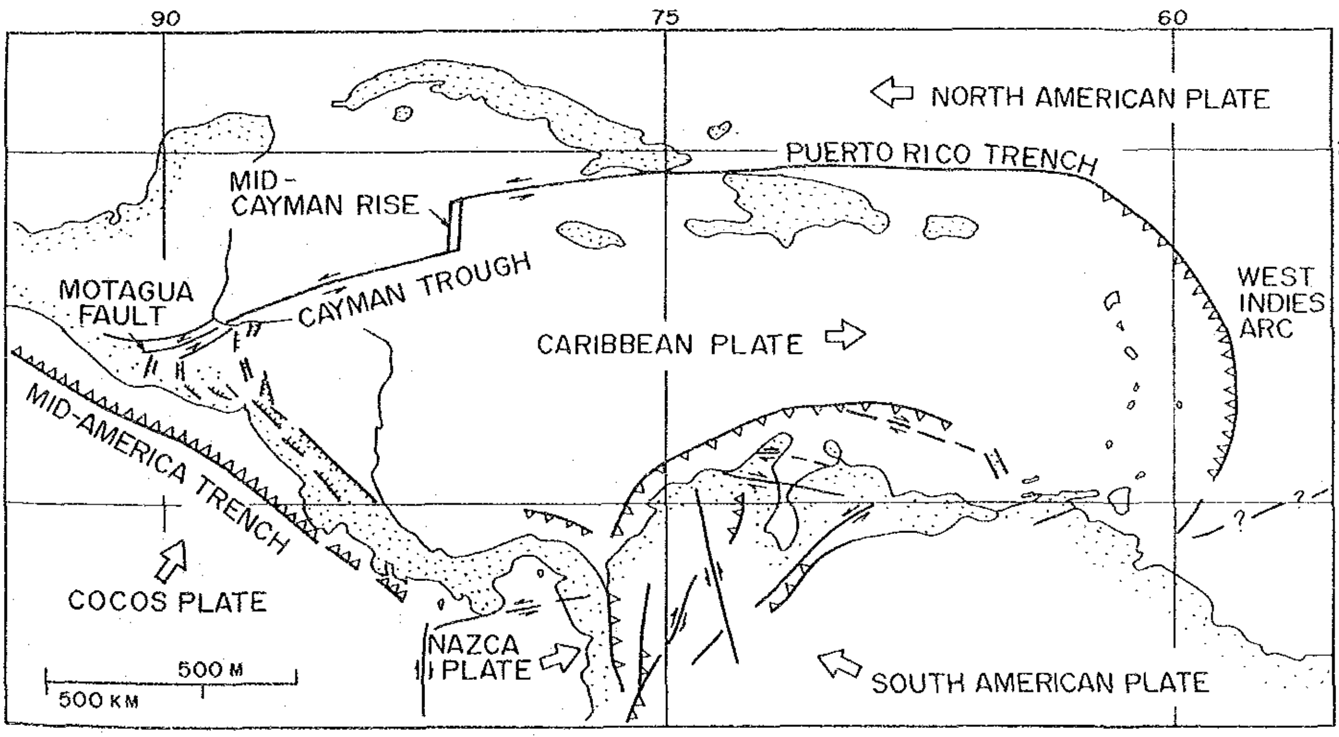


FIG. I-1 Continental Plate System

1.4 Survey Components

The survey was carried out in cooperation with EMPAGUA counterparts. Principal works are outlined below.

	WORK ITEM	CONTENTS
1	Data collection	ING (National Geographic Institute): Aerophotos - 1/10,000; taken after the 1976 earthquake Topographical maps - 1/50,000 Geological maps - 1/50,000 INSIBUMEH (National Institute of Seismology, Volcanology, Meteorology and Hydrology): Reports - (Study on Groundwater in the Guatemala City Valley) Meteorological data Well data
2	Field survey	Topographical survey; geological survey Well and spring discharge survey River discharge survey
3	Geophysical survey	Electrical prospecting Electro-magnetic prospecting
4.	Test wells	Test boring Electrical logging Test pumping

CHAPTER II

STUDY OF EXISTING DATA

2.1 Existing Studies

Results of existing studies on groundwater resources in the Guatemala City Valley are contained in the INSIVUMEH report of 1978 and the TAHAL report of 1982. Study areas and study components of the said reports are as indicated below.

STUDY TITLE	STUDY AREA	STUDY CONTENTS
INSIVUMEH (1978)	North area: Las Vacas basin ($235km^2$) South area: Michatoya basin ($571km^2$) Total: $806km^2$	1 Hydrogeologic study 2 Geophysical study 3 Hydrologicl study
TAHAL (1982)	Guatemala City Chinautla Mixco Villa nueva San Miguel Petapa Villa Canales Santa Catarina Pinula Total Area: $470km^2$	1 Population and water demand 2 Water resources 3 Eduction lines and pump station 4 Net distribution 5 Program of analysis of alternatives, economic evaluation and site selection 6 Water treatment 7 Dam and hydroelectric potential 8 Project planning and financial analysis

2.2 Existing Study Contents

In order to determine the orientation of the subject Feasibility Study, careful review was conducted of existing reports, particularly with regards to hydrogeologic and physical studies. The study concentrated on the previously mentioned INSIVUMEH report since the TAHAL report contained less detailed information.

2.2.1 Groundwater

The groundwater bearing layers of the study area are further classified into an upper aquifer and a lower aquifer. The upper aquifer is composed principally of Quaternary pyroclastics and at times gravel and site sediments. Aquifer thickness ranges from several to 250 meters, being generally thick in the central portion of the Study area. The aquifer extends throughout the entirety of the Guatemala City Vally. Coefficient of transmissivity is 50 - 750m ^{2}/day and the storage coefficient is 0.02 - 0.4. The upper aquifer is accordingly considered to be an unconfined one.

The upper aquifer is underlain by a lower one comprised of tertiary or earlier sediments of lava and limestone. Lower aquifer thickness is generally around 200m, being particulary thick in the vicinity of Lake Amatitlan. Although the transmissivity coefficient is 500 - 5,000m ^{2}/day, the storage coefficient remains unidentified. On the basis of hydrogeologic factors, the lower aquifer is estimated to be confined.

Water level data from observation wells at 332 sites indicates that groundwater flow adheres to a pattern in conformity with topographical configuration. In other works, in keeping with the horseshoe-shaped topographies north and south of the continental divide as delimited by mountains to the east and west of Guatemala City as well as by the aforementioned continental divide itself, goundwater flow converges from the east and west and, in the case of the northern section of the Guatemala City Valley, flows northward, while in the southern section of the valley the converged flow moves south to Lake Amitatlan where it then changes direction to the southwest.

Current water consumption in the Guatemala City Valley for surface and groundwater combined is 350 mm (200 x 10^6 m^3; 6 m^3 sec). Of this, 1.5m^3 sec (or 25%) consists of groundwater consumption from Quaternary deposits. Subsequent development under the envisioned Project of the aquifer in Tertiary fracture zone and volcanic rock would yield at least an additional 1 m^3/sec provided that careful groundwater management and conservation of the natural recharge cycle are performed.
(INSIVUMEH REPORT, 1978)

Groundwater reserves in the southern sector are calculated at 57,430,000m^3/year (1.82 m^3/sec). This calculation is based on the assumption of a 200m thick layer of andesitic formation underlaying 112m of alluvial deposit. The transmission coefficient for the andesitic formation is estimated at 2,500m^3/day/m and that of the alluvial deposit at 3,000m^3/day/m. Groundwater discharge from Lake Amatitlan is calculated at 1,920,000m^3/year (0.061m^3/sec). In the northern sector (Las Vacas basin), the transmission coefficient for granite (including a small portion of pyroclastic material) is assumed at 20m^3/day/m with groundwater reserves accordingly estimated at 2,650,000m^3/year (0.084m^3/sec).

Combined groundwater drafting from deep wells, shallow wells and springs during the one year period 1976 - 1977 in the southern and northern sectors was 50.63m^3 x 10^6 and 16.53m^3 x 10^6, respectively.

2.2.2 Seismic Prospecting

Seismic prospecting was carried out at 29 locations, principally in the vicinity of Lake Amatitlan. With a testing line length of 900m at each site, prospecting covered a total extent of 29km. Analysis was accomplished through a cross-comparison of boring logs.

This type of prospecting applies artificially generated elastic waves to determine the physical properties of the ground structure. Depending on the characteristics of waves employed, seismic prospecting is classified into the reflection method and the refraction method. In the subject study, refractive waves were employed to determine high elastic wave velocity layers of ground structure (P waves were utilized).

On the basis of elastic wave velocity, ground structures of the study area were classified into 4 groups.

i) 1st group: Surface layers; 300 - 400 m/sec

ii) 2nd group: Quaternary pyroclastic materials; 800 - 1000 m/sec

iii) 3rd group: Sand and gravel layer (compact pyroclastics); 1500 - 1800 m/sec

iv) 4th group: Lavas and andesites; 3000 m/sec

On the basis of a cross-comparison of boring logs, the depth of each group was projected as follows: the first group to a depth of 50 m, the second and third groups to a depth of 150 m, and the fourth group to deeper than 150 m. These results may be applied as one index for resistivity evaluation.

2.2.3 Gravity Prospecting

Due to its relative ease and low cost of implementation, gravity prospecting was employed to determine the distribution extent, depth and geologic character of sediments.

A Lacoste and a Romberg gravimeter were utilized for measurements at 250 sites in the Guatemala City Valley. On the basis of the residual gravity map prepared from the survey results, the following assumptions were made.

In general, gravity anomalies recorded on the surface appear as longer wavelengths for the deeper the anomalous mass. Consequently, gravity anomalies of short wavelength are the result of anomalous masses in shallow ground.

Low gravity anomalies of long wavelength were observed at two locations, one of which evidenced wide distribution inside Guatemala City, and the other including Lake Amatitlan and environs (see FIG. II-1).

These findings indicate distributions of rock of low specific gravity, and imply structural subsidence of basement rock.

On the basis of the A - A' profile, the entire Guatemala City Valley is considered to be comprised of pyroclastic and welded tuff sediments to extensive depth. On the periphery of this area, high gravity anomalies of short wave length were observed. Particularly between Guatemala City and Lake Amatitlan, uplifting of ground structure is believed likely.

2.2.4 Resistivity Prospecting

In the northern portion of Guatemala City and its environs, resistivity prospecting was carried out at only scattered locations, being concentrated instead principally in the southern portion of Guatemala City and in the vicinity of Lake Amatitlan. Prospecting was by the Schlumberger method, with AB up to 1000 m.

Relationship between apparent resistivity and rock type is as follows.

Geologic time	Rock	Apparent resistivity	Remarks
Alluvium	gravel, sand silt, clay	80 - 150 Ωm	Saturated alluvial layer
Quaternary	pumice, ash sand	150 - 300 Ωm	Fracture zone: 300 - 400 m
Tertiary	lava, andesite dacite etc.	over 3000 Ωm	

Apparent resistivity of 100 m or less is distributed by depth as follows.

Depth from Surface	Guatemala City	Vicinity of Lake Amatitlan
30 m	limited distribution stradding the continental divide	wide distribution until vicinity of Ojo de Agua
50 m	intermediate distribution from the west side	"
100 m	large distribution throughout urban area	"

Ground structure projected from the representative VES curve is given below:

Measurement site	Layers	Type	Remarks
Lake Amatitlan delta area	4	110 > 22 < 56 < 450	0 - 230 m: alluvium below 230 m: lava, andesite
Michatoya River	4	34 < 50 > 28 < 102	0 - 185 m: alluvium below 185 m: lava, andesite
Ojo de Agua	3	9 < 840 > 80	from surface on down: pyroclastic material water level: 85 m
Villa Nueva	4	17 < 1680 > 1260 < 3600	0 - 260 m: pyroclastic material below 260 m: lava, andesite

2.2.5 Water Balance

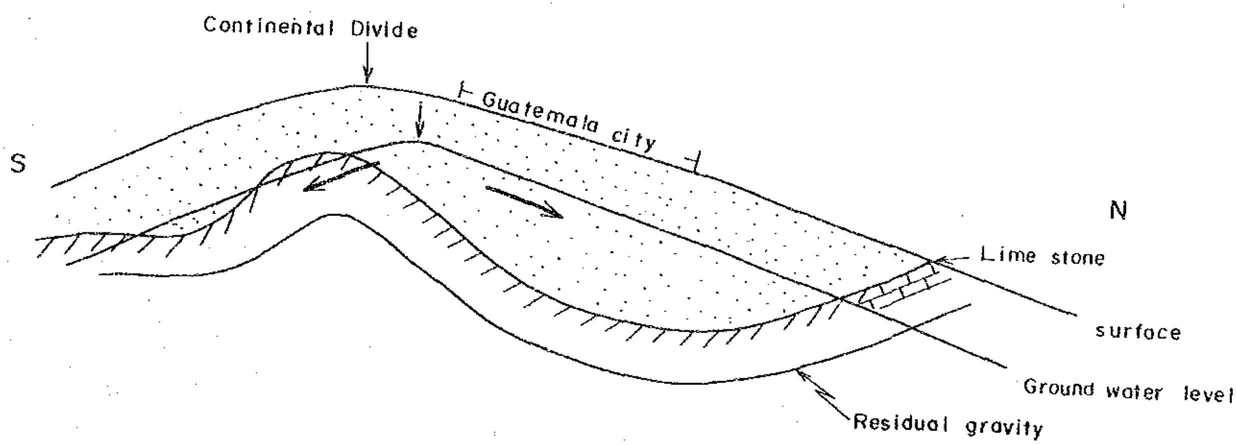
According to the INSIVUMEH report, groundwater potential in the southern sector of the Guatemala City Valley in the vicinity of Lake Amatitlan and in the Las Vacas basin of the northern sector is estimated at a total of 111.04 million m^3/year. Water resources by northern and southern sector are as follows.

	Southern sector ※ million m^3/year	Northern sector ※ million m^3/year
Surface water	10.48 (0.33 m^3/sec)	40.48 (1.28 m^3/sec)
Groundwater	57.43 (1.82 m^3/sec)	2.65 (0.08 m^3/sec)
Recharge to Lake Amatitlan	-58.61 (1.85 m^3/sec)	-
Usable potential	9.3 (0.3 m^3/sec)	43.13 (1.36 m^3/sec)

※ million m^3/year.

2.3 Considerations on Findings of Previous Studies

First, on the basis of the residual gravity map derived from previous gravity prospecting, the following rough diagram of ground formation was drawn.



As limestone outcroppings are in evidence to the north of Guatemala City, depth of limestone deposits was estimated from the residual gravity map. As indicated in the rough diagram above, residual gravity dip structure bears no relation with groundwater level.

The specific gravity of limestone is over 2.6 g/cm which precludes water passage through the rock itself. Nevertheless, in many cases the limestone constitutes water bearing strata. As indicated in the above diagram, variations in groundwater level are not evident even where distributions of limestone are found, and groundwater flow is northward (towards Las Vacas river).

As further depicted in the above diagram, Guatemala City is situated atop a residual gravity dip structure with basement rock accordingly located at relatively considerable depth. This dip is assumed to consist of thick sedimentation of pyroclastic materials and welded tuff, considered as comprising the upper aquifer. As the permeability of these materials is high, groundwater development requires drafting from the deep aquifer to avoid ground subsidence.

Secondly, water balance was calculated for the roughly 77 km^2 in Guatemala City designated for groundwater development in PLAMABAG. Existing well number is 113, with water recovery potential of 781.84 l/sec. On the basis of INSIVUMEH data, precipitation in this area is estimated at 1200 mm and evapotranspiration at 800 mm. From these criteria a basic water balance calculation is derived as follows:

$$2.93 - 1.95 - 0.78 = 0.2 \ m^3/sec$$

In other words, new groundwater development in this area is extremely limited.

Thirdly, in the case of vertical resistivity prospecting where AB = 1000 m, evaluation is reliable only to a depth of approximately 100 m. Particularly in the case of Guatemala City, for which basement rock is located at relatively great depth (as discussed earlier), AB = 3000 m is considered necessary. However, due to a potentially large margin of error in measurement results caused by noise interference, electrical prospecting is not considered a viable means of accurately identifying ground structure within Guatemala City itself.

Fourthly, in consideration of the water balance to the south in the vicinity of Lake Amatitlan, new development of groundwater in the southern portion of Metropolitan Guatemala is concluded as unfeasible as only 0.3 m^3/sec is available for development.

To summarize the principal points made in this section:

i) Guatemala City is situated over a dip in basement rock formation overlain with pyroclastic sediment deposits. This poses the danger of grounds subsidence in the event of significant groundwater development;

ii) Groundwater availability for further development within Guatemala City and its immediately vicinity is extremely limited;

iii) Electric prospecting for groundwater presence cannot be performed within Guatemala City and its immediately vicinity due to the noise factor; and

iv) Groundwater availability for further development in the southern basin (Lake Amatitlan) is extremely limited.

The above discussion underlies the crucial need to carefully study the entire Guatemala City Valley and environs for appropriate areas of groundwater development potential.

2.4 Background for Definition of Project Area

According to PLAMABAG, the projected population for Guatemala City by 1990 will be 1.82 million with a per capita water demand of 225 l/day, or a total demand of 409 million m^3/year.

Water production by EMPAGUA for the five year period 1980 - 1984 was 75.9 million m^3/year. Of this amount, slightly less than 30% was groundwater recovered from wells and springs, while the remaining 70% was diverted from surface resources.

The relationship between water supply and demand for the five year period 1980 - 1984 is indicated below.

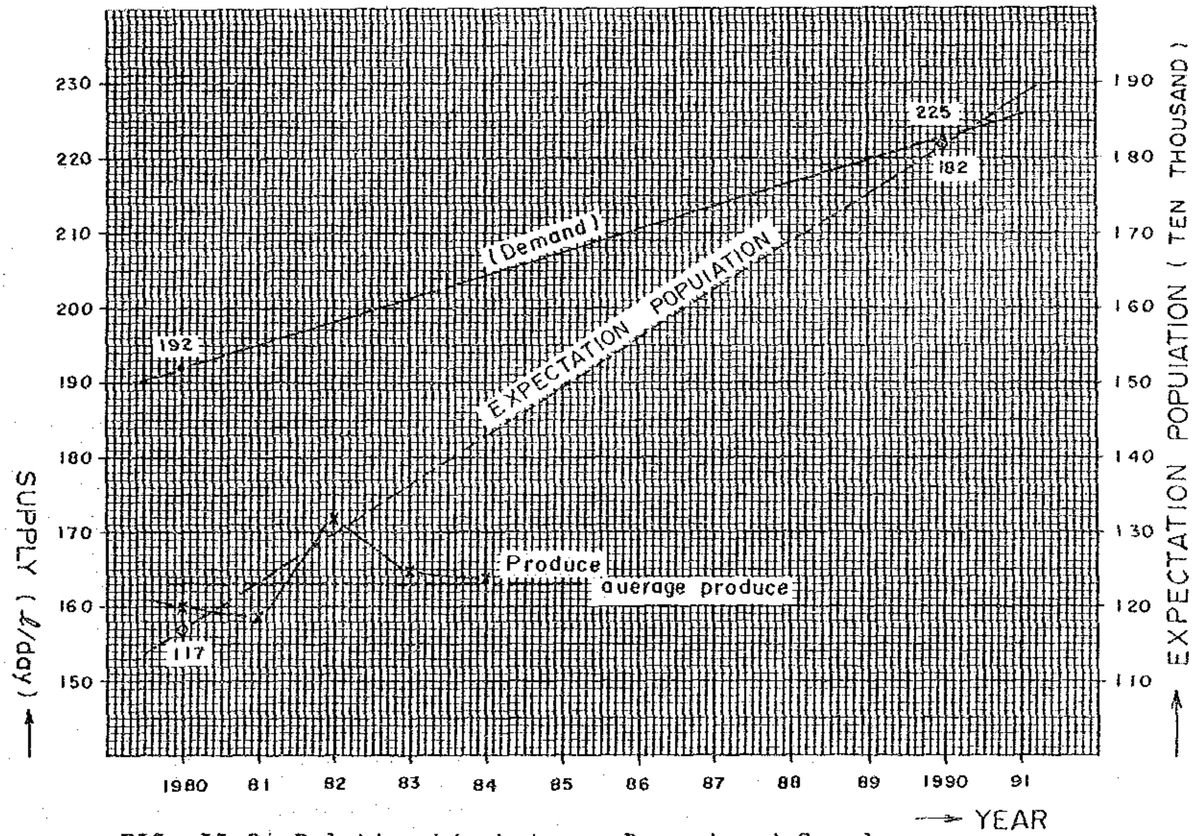


FIG. II-2 Relationship between Demand and Supply

As can be seen in the above figure, production is clearly not sufficient to meet demand.

In order to develop urgently required water resources to address the *serious shortage* problem Guatemala faces over the next 10 - 15 years, PLAMABAG calls for groundwater development targeted at $84km^2$ in central Guatemala City straddling the continental divide. The subject Feasibility Study has as its objective exploration of the feabibility of such groundwater development.

However, as it was first necessary to identify the area within which a development study would yield the optimum results, the following investigation was undertaken.

Groundwater flow patterns were investigated principally on the basis of topographical factors, and indicated a concentration of groundwater at 3 locations. Namely, the northern and southern sectors of Guatemala City Valley and the basin to the east of the valley.

Southern Sector:

As of 1978, water balance in the southern portion of Guatemala City Valley in the vicinity of Lake Amatitlan (including Ojo de Agua) allows for available resources of only 0.3 m^3/sec, or 9.3 million m^3/year. According to the 1978 INSIVUMEH report, in addition to the surface flow of the Villalobas river which empties into Lake Amatitlan, 58.61 million m^3/year of groundwater recharge into the lake is essential to maintain its current water level.

As of 1978, 1.82 m^3/sec of groundwater was being exploited in the southern area, making any new development a potential cause of a water level drop in Lake Amitatlan. The threat of ground subsidence is also present. However, in the Ojo de Agua block of this sector, it is expected that the (lower aquifer) groundwater has the nature of a confined aquifer.

Northern Sector:

Regarding the north of Metropolitan Guatemala, INSIVUMEH calculates water balance in the Las Vacas basin at 0.08 m^3/sec (1978). In 1982, EMPAGUA constructed 7 wells in Zone 6 with successful drafting of a total of 0.25 m^3/sec. This groundwater also has the possibility of the lower aquifer having the nature of a confined aquifer.

However, as indicated in Fig. II-1 and discussed in section 2.3, groundwater in the north of Metropolitan Guatemala and that currently being drafted inside Guatemala City are part of the same aquifer system which signifies that excessive groundwater development in the northern area would possibly lower groundwater levels under Guatemala City, with even conceivable drying up of wells.

Guatemala City is situated directly above a residual gravity dip formation in the ground structure. In consideration of directions of groundwater flow and geological profile:

i) Groundwater flow direction is to the north and to the south, respectively, on each side of the continental divide.

ii) Ground structure beneath Guatemala City is composed of thick sediment deposits with good permeability.

iii) There are 113 wells (EMPAGUA and private) within the 77 km^2 area with well density of 1 well/0.68 km^2. Accordingly, the potential for interference between well regimes is present.

iv) Basic water balance calculations for the 77 km^2 area indicate that 0.2 m^3/sec is available for new development.

v) Reliable results from resistivity prospecting in the city center area cannot be a obtained due to high voltage line and noise interference. Furthermore, prospecting procedures are highly inefficient as they must be carried out at night.

On the basis of the above factors, the said area proposed in PLAMABAG and consisting of 84 km^2 of central Metropolitan Guatemala in the vicinity of the continental divide is not considered appropriate for new groundwater development.

If, as indicated above, development of groundwater in the southern and northern (including central Guatemala City) sections of Metropolitan Guatemala is not feasible, the basin to the east of Guatemala City Valley subsequently becomes the principal candidate sector for further groundwater study.

As a supplemental area, however, the northern sector in the vicinity of Cerro el Naranjo where existing wells are relatively few also merits investigation in view of achiving PLAMABAG's objective of 1 m^3/sec.

2.5 Definition of Study Area

Selection of the study area was made in July 1985 following consultations with EMPAGUA officials concerned. The said study area for Emergency Plan I is defined as 815 km^2 including the northern sector of Guatemala City Valley, the southern sector of Guatemala City Valley excluding Lake Amatitlan and vicinity, and the adjacent basin to the east of Guatemala City Valley.

The results of the analysis and the various surveys for the study area are discribed in detail in the following chapter, and were used as the basis for selecting the areas favorable for groundwater development.

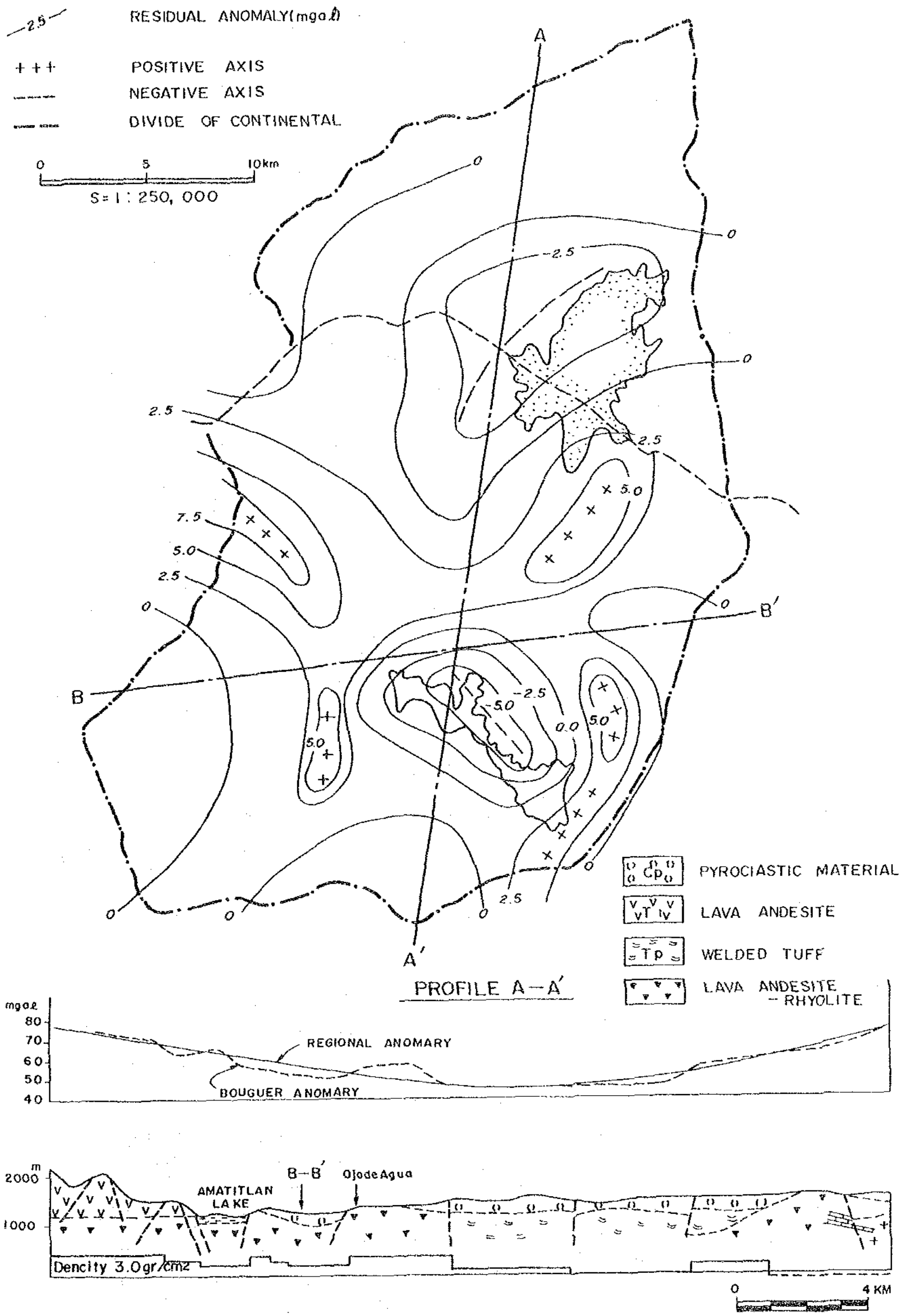


FIG. II-1 MAP OF RESIDUAL GRAVITY

CHAPTER III

GROUNDWATER CONDITIONS

3.1 Physiography

Topography and Drainage

The area can be divided into six distinct physiographic regions composed of five major units and a less extensive unit:

a) The undulating hills of Mixco, to the west.

b) Densely populated plateau of the Guatemala City Valley.

c) Wooded highland in the center of the area.

d) Elevated and dissected plateau of San Jose Pinula to the east.

e) Lowland of Amatitlan to the south.

With a minor topography unit:

f) Highly dissected north-south trending escarpment along the east boundary of the area.

The first unit is composed of low rolling hills of Tertiary volcanic rocks and carboniferous sediments. In general, these are flat-topped ridges with uniform heights and are apparently the dissected remains of a mature plainland. The drainage of the area is mostly sub-parallel pattern.

The second physiographic unit, the Guatemala City Valley, is a plateau with elevation ranging 1,200-1,600m above sea level, and mainly composed of Quaternary pyroclastics. Along the eastern boundary, a distinct lineament reflecting the Santa Catarina Fault is clearly observed.

The rivers running over the plateau form a sub-parallel drainage system incised on the plateau, the course slightly east of north indicating the structural pattern of the basement rocks.

The third unit, the central highland, is a dissected mature plainland of Tertiary volcanics similar to the aforementioned first unit with elevation ranging 1,600-2,000m above sea level. The drainage of the unit features deeply incised valleys with flow mainly to the north.

The fourth unit, the dissected plateau of San Jose Pinula, is an elevated plateau of thick Quaternary volcanic pile with elevation ranging 1,400-1,800m above sea level. The rivers of the area form a sub-parallel pattern and mainly run to the north.

The fifth unit, the Amatitlan lowland, is area surrounding the Amatitlan lake including the fan formed by the Rio Villalobos. The altitude of the lake is 1,188m, and the average elevation of the fan is 1,200m. Along the south coast of the lake, rhyo-dacitic domes are developed forming irregular hilly terrain.

The sixth unit, the dissected escarpment, is a refection of the Teocinte/Palencia fault trending N-S - NNE - SSW. The escarpment is a steep slope facing west, and composed of Tertiary volcanics including welded tuff.

3.2 Geology

3.2.1 Regional Geological Features (See FIG. III-2)

The regional geologic structure consists of one of the largest lithological units of the country: the so-called volcanic belt. This formation is found principally to the south of the Cuilco rivers in the west, and Motagua in the central and northeast part of the country. It constitutes a belt extending 200km in length, formed from west to east with north-south width varying from 40-80km.

The area encompasses mountain chains, high plateaus and mountain valleys formed by a thick sequence of volcanic rock of the upper Tertiary; Mio-Pliocene. A chain of Quaternary volcanoes extends along the entire extent of the southern border of the belt essentially parallel to the Pacific coast line. Within this chain are certain active volcanoes: Santiaguito/Santa Maria, de Fuego and Pacaya.

Structurally, besides the building-up and collapsing directly related to volcanic processes, the area that encompasses this lithological unit has been demarcated by the effect of the large tectonic systems of the country. The Cuilco-Chixoy system of faults is located in the western extreme of the northern boundary of the area. The fault system of Motagua-San Agustin is found in the central and northeastern part. To the south of this system and parallel to it at some 20-25 km stretches the Jocotan fault, well in evidence in the east and probably extending to the central part of the belt in the environs of San Lucas Sacatepequez. The Jalpatagua fault system stretches from southeast to northwest beginning near the national border with El Salvador and passing in the vicinity of the town of Valpatagua. To the west, the said fault system passes the northern border of Lake Amatitlan and subsequently intersects the Motagua system at Chichicastenango.

Systems of minor faulting, yet still important locally, extend with orientation north-south throughout the entire area, certain of which constitute significant eruptive zones.

The Guatemala City Valley and its areas of influence are situated within the wedge formed by the fault lines of the Motagua-San Agustin and Jalpatagua systems in the western third of the above described belt.

3.2.2 Geology of the Study Area (See FIG. III-1, III-3)

The geological sequence of the Study area can be divided into three groups. These are namely the basement group, the Tertiary volcanics and the Quaternary volcanics (in ascending order).

The first group includes metamorphic basement, Cretaceous series and intrusive rocks. The metamorphic basement composed of phyllite and schist is probably of the upper Paleozoic, with an approximate thickness of 800 m.

The Cretaceous series is composed of three members. The lowermost calcareous member, composed of limestone and dolomitic limestone of the lower Cretaceous, appears in massive form with weak stratification. This member is heavily faulted and fractured, the thickness is estimated as much as 500m. The middle basaltic lava member is also highly fractured with an estimated thickness of 350m. The upper clastic member composed of conglomerate, greywacke and calcareous radioralite with an estimated thickness of 450m is considered to be upper Cretaceous in age.

The Cretaceous series extend as a belt approximately 2km in width from northwest to southeast, present in the study are as raised blocks outcropping on the surface as isolated hills. The discontinuity of blocks may be attributed to the effects of tectonic activity which has determined the relative subsidence of blocks along the length of the limestone belt. Zones corresponding to sunken limestone blocks are covered by volcanic formations, ashes and tuffs.

An extensive body of intrusive igneous rock is found exposed in the northern part of the study area, extending regionally as a belt from nourthwest to southeast with an average width of 7.5km, with outcrops in an area approximately 60km ^{2}.

The rock area composed by quartz monzonite, granodiorite and quartz diorite.

The second group is totally composed of volcanic rocks of Miocene-Pliocene age. This group has been called San Jose Pinula group, which includes two formations. The upper part, which is called Sanguayaba formation, is comprised of two members as follows.

- Rhyolitic lava flows (Try), exposed northeast of Santa Catarina Pinula, which are generally vesicular and show a clear flow-banding, light gray to pink in color, with a thickness estimated at 300m.
- Andesite-basalt lava flows (Tab) and upper member of Sanguayaba formation, basically comprising andesitic and basaltic lava flows, volcanic mud flows, and tuff sediments. Stratigraphically it is estimated hat this member is later than the San Jose Pinula formation, with thickness of 200m and 250m.

The lower part of the group is called the San Agustin formation, within which there are 10 lithologic members, consisting of basically siliceous tuffs, ignimbrites, lava flows and tuff sediments. The members that cover the greatest areas are:

- Welded glassy tuff (Tvt) whose composition varies from latite to dacite, with a thickness between 200 and 300m.
- Welded tuff (tgb), composed of glass, quartz and biotite, which comprises the roof of the San Agustin formation and is believed to be the result of a massive landslide. This rock is in general smooth and brittle, with an approximate thickness of 300m.

The San Jose Pinula group has quite a variable total thickness, which results from its origin and area of its members, reaching in general several hundred meters. Rocks of this group are highly fractured.

The third group is composed of pyroclastic sediments, ash fall deposits, solidified pumice sediments and alluvial deposits, all of the Quaternary in age. The thickness is locally over 150m.

3.2.3 Geological Structure

The present geologic configuration of rocks found in the Project area was affected by highly regional tectonic processes, whose local expression has been defined by:

- The area comprising the northern portion of the Study area near the Motagua-San Agustin fault system, which appears with east-west direction and with a convex arch southward. The main fault line is seen with a leftward relative movement. During the Feb. 1976 earthquake, this fault suffered a maximum displacement of 3.40m. The convexity of deformations which induced this system resulted in traction efforts southward and especially originating in the conjugated faulting SSW/NNE, N/S and NNW/SSE with open fracture inside the area.
- The area comprising the southern portion of the Project area near the Jalpatagua fault system which also shows convex lines with south-west direction, that is, the main line changes from ESE/WNW direction to SE/NW. The displacement of the system is basically vertical, normal with a sinking on the south side. On the northern edge of Amatitlan Lake, this fault shows a fault scarp with a displacement of over 400m.
- Within these two fault systems, there are other minor ones with predominantly north/south direction, which form graben-horst-graben structures, that is, the Guatemala City Valley graben and the San Jose Pinula graben, east of the first one. These structures form successively the faults of Mixco and Santa Catarina Pinula for the Guatemala City Valley graben, and the faults of San Jose Pinula and Teocinte/Palencia for the San Jose Pinula graben.

The faults in the Project area are Santa Catarina and San Jose Pinula and Teocinte/Palencia, whose vertical movements produced relative displacements of 400m, 250m and 500m, respectively.

These fault systems form a structure of uplifted and subsided geologic blocks. In this sense, it can be said that the Guatemala City Valley and the San Jose Pinula Valley are two subsided blocks, with a relative vertical displacement of 200m between them, the lower one being the Guatemala City Valley located at approximately 1,500m above sea level.

Between these two blocks there is an uplifted one, which apparently presents a northward inclination. This concept is supported by the slope of pumice plateaus where the town of Canalitos is located, and the plateau located to the west whose line of maximum slope has a N/S direction.

The above described fault systems define secondary systems of great complexity and with which are associated significant dense fracture networks of caused mainly by tensional forces.

The structure resulting from such tectonic conditions corresponds to a system of blocks of small to medium area and varied geometric shape, which have experienced a great variety of movements and relative displacements between juxtaposed blocks: vertical, horizontal, rotational, etc. In this sense, it can be said that the pumice basin where the central part of Monjitas, Canalitos and Agua Tibia river courses run, corresponds to a great subsided block limited to the north by uplifted blocks formed by the Cretaceous limestone, which emerge up to 1,560m above sea level, and to the south by a set of uplifted blocks in a steplike manner; these blocks are the Tertiary volcanic rocks reaching an altitude of 2,000m above sea level. Of the main patterns of secondary faulting, approximately 60% has an orientation between SSE/NNW and SSW/NNW, and 25% has orientation between WSW/ENE and ESE/WNW.

On the basis of gravity survey results, it is considered that basement structure of the Study area is characterized by the existence of two basin structures, one consituting the vicinity of Guatemala city and the other in the vicinity of Lake Amatitlan. Both basins are composed of thick Quaternary pyroclastic sediment, ash fall deposit, solidified pumice sediment and alluvial deposit. Moreover, a saddle shaped structure running underground roughly east-west between these two basin structures is believed to play a signifiant role in conditioning the circulation pattern of the deep aquifer.

3.3 Hydrogeology

The presence of groundwater resources in the Project area is basically controlled by:

a) Lithological factors, basically characterized by their origin and manner and sequence of deposits;

b) The structural setting defined by the great faults of Motagua and Jalpatagua and fault systems derived therefrom; and

c) Potentiality of hydrological resources, expressed as average rainfall of approximately 1,400mm.

(1) Lithological Factors

The basements of the gross sequence of the Tertiary volcanic rocks is formed by limestone, plutonic and metamorphic rocks, which crop out over an extensive area south of the Motagua fault borderline, setting a hydrogeological barrier to the north of the Study area. Other than this zone, the rocks that form the basement are not superficially evident within the Study area. From a hydrogeologic point of view, the importance of these besements resides in the fact that it constitutes a massive body which tends to limit the subsurface runoff towards the north, to function as an impermeable barier.

This basement is comprised of compact rock of high degree of consolidation, whose hydrogeologic interest is associated with the continuous zones of high degrees of fracture and fissuring.

The hydrogeologically important space is defined vertically, over 1,100m above sea level, with a thickness of approximately 400m. This column is normally formed in ascending order, and in variable proportion depending on its geographic position, Tertiary volcanic tuff, ignimbrite and lava flows and Quatenary pyroclastic sediments. Ignimbrites of lower Tertiary, consisting of latite-dacite tuff and welded tuff form good aquifer lagers due to their high degree of porosity and fractures. Andesitic and basaltic lavas are good aquifer materials due to their nature, deposit forms, consolidation processes, and susceptibility to open fracture due to their hardness. Quatanary Pyroclastic sediment two units can be found which are basically classified according to form of deposition and by granulometric structure: One unit comprises the ash flow deposits composed of materials of varied granulometry and a high percentage of fine grain deposited in massive formation in the lower parts of pre-existing topography. The degree of compaction and consolidation of these materials is variable, and may in some cases be affected by fracture. The second unit consists of the ash fall deposits formed by pumice rock stratifications with a certain degree of vertical granulometric uniformityand and which are regularly found in areas of higher elevation. The combined thickness of these two units can reach 250m.

The described pyroclastic sediments form a medium of interstitial porosity and permeability.

From a lithological viewpoint, since tuff has been frequently transformed into clay, it is not a good aquifer material except for areas of high consolidation where open fracturing is prevalent.

(2) Structure

The hydrogeological structure of the Study area is conditioned by regional and local tectonic events. The structure is basically a system of subsided and uplifted blocks which hydrogeologically are connected mainly by open fractures, orthogonal fault planes, and through horizontal joints. Storage and active circulation zones are represented by subsided blocks of regional continuity, which are fed from the recharge that takes place in uplifted blocks and transmitted by a network of fissures and lateral fracture interconnecting the blocks. The water stored in volcanic ash is transmitted directly from the porous material to the network of fissures and fractures.

Groundwater recharge of this subsided block is assured basically by the uplifted and steplike blocks that exist south of it. Recharge sources also located in the south are subsided blocks of higher elevation, partially covered by ash and pumice sediments, where recharge occurs through a system of faults and fractures with directions between NNW and N.

According to the pyroclastic structure map drawn for the INSIVUMEH/IGM/PNUD Guatemala Valley groundwater study and the results of interpreting results from 61 sites of vertical electrical prospecting carried out within the Study area and the area of hydrogeological interest, the pumice basin described above represents the eastern stretch of the Guatemala City recharge, reaching a minimum depth of 200m between the basins of the Las Vacas River and the Canalitos-Monjitas River. Now, according to geomorphological and structural features mentioned before, the Santa Catarina Pinula fault located west of the uplifted block that separates the Guatemala City Valley graben from the San Jose Pinula graben appears to constitute a hydrogeological boundary, particularly as regards the transfer of underground flow between the two basins. This is determined by the uplifted block which at its base is probably formed by consolidated volcanic tuff, in addition to the fact that the fault planes themselves would apparently form an impermeable seal. However, it is very likely that the uplifted block shows a northward slope, and that it is cut by a fault system with WSW/ENE orientation which defines blocks sunk stepwise in the neighborhood of the aforementioned boundary. Under these conditions, hydrogeological communication between the said hydrographic basins could take place partially through the pyroclastic refill and through the system of fault and fracture orthogonal to the plane of the Santa Catarina Pinula fault, essentially through the spaces opened by traction.

Another zone of storage and concentration of underground flows, but relatively unimportant due to its distance from the areas of high water consumption, is located over a section west/east, approximately 3.5km wide, on the axis UTM: 1,619.50N, and near the town of Mixco. This zone is fed from the San Jose Pinula Valley, through a system of fault and fracture developed northward, and through the alluvial sediments and volcanic ash concentrated in the valleys of Teocinte river tributaries.

(3) Rainfall

The high potential of groundwater resources is assured in the Project area by very favorable rainfall conditions, especially over the main recharge zone located in the southeast of the area. In this area, the average yearly rainfall is around 1,500mm, with average maximum and minimum of 1,600mm and 1,200mm, respectively.

3.4 Groundwater

3.4.1 Aquifers

Lighological units and structural conditions define basically two types of aquifers:

(1) The first type constitutes the topmost proximate and generalized aquifer formed by refill of loose pyroclastic materials of the Quaternary period, which is a free aquifer (unconfined aquifer) of around 50m thickness with highly variable hydrogeological characteristics. The average production of this aquifer is around 12 l/sec (200G/m) for a phreatic level abatement of several tens of meters. This aquifer is the most exploited one due to its accessibility. In uplifted blocks and higher parts of topography, this type of free aquifer is commonly exploited for domestic use. Phreatic level in these areas is generally very close to the surface, approximately within the first 20m and shows great seasonal variations.

(2) The second type comprises the lower (confined) aquifer formed by consolidated volcanic material, lava and Tertiary tuff, as well as Cretaceous limestone highly affected by fault, fractures, and fissures. The aquifer is located approximately between 1,000m and 1,300m above sea level and the lateral extent is controlled by the location and density of the tensional fault.

This type of aquifer is relatively unknown and consequently very little exploited. However, in the few cases in which this aquifer has been reached by drillings and properly designed wells, its productive importance has been evident, with a volume of 63 l/sec (1,000 G/m) frequently obtained in these aquifers.

An example of this is the deep well No. 139 Ojo de Agua (EL 1,300 m, depth 274 m) in the southern sector. This well becomes fractured andesite at depths below 110 m, with artesian flow from the cracks in the rock. This suggests that the water has the character of confined aquifer with a water head level slightly higher than the elevation of 1,300 m.

Furthermore, the deep well No. 2 Project 4-3 (EL 1,467, depth 274 m) of the northern sector is fractured limestone at depths below 115 m. Here, the water level is 167 m, and there is a pump-up volume of 63 l/sec. The water level elevation is 1,300 m and the same as the former well.

This indicates the possibility of groundwater like a confined (lower) aquifer existing in the basement rock of this sector, and that the water head of this aquifer is roughly the same as the elevation of 1,300 m. In other words, it means that a lower aquifer can be extracted from the basement below EL 1,300 m.

3.4.2 Groundwater Circulation in the Study Area

According to the characteristics of the regional hydrogeological structure, it is understood that there exists a regional circulation pattern of groundwater flow, which within the Study area from the boundary with the Guatemala Valley basin at a UTM coordinate point 772.00E/1,619.00N would have a ENE direction (see FIG. V-5, V-2, V-3, TABLE IV-4).

Locally the circulation in its most generalized from is expressed as follows: from the main recharge zones of the south a movement begins with directions varying from NNW to north, and subsequently towards the northeast under the ash basin.

Circulation in the lower aquifer follows the preferential ducts of high density fracture, according to the main fault patterns, while in the upper aquifer it conforms to permeability vectors. In the latter case, the flow is more uniform.

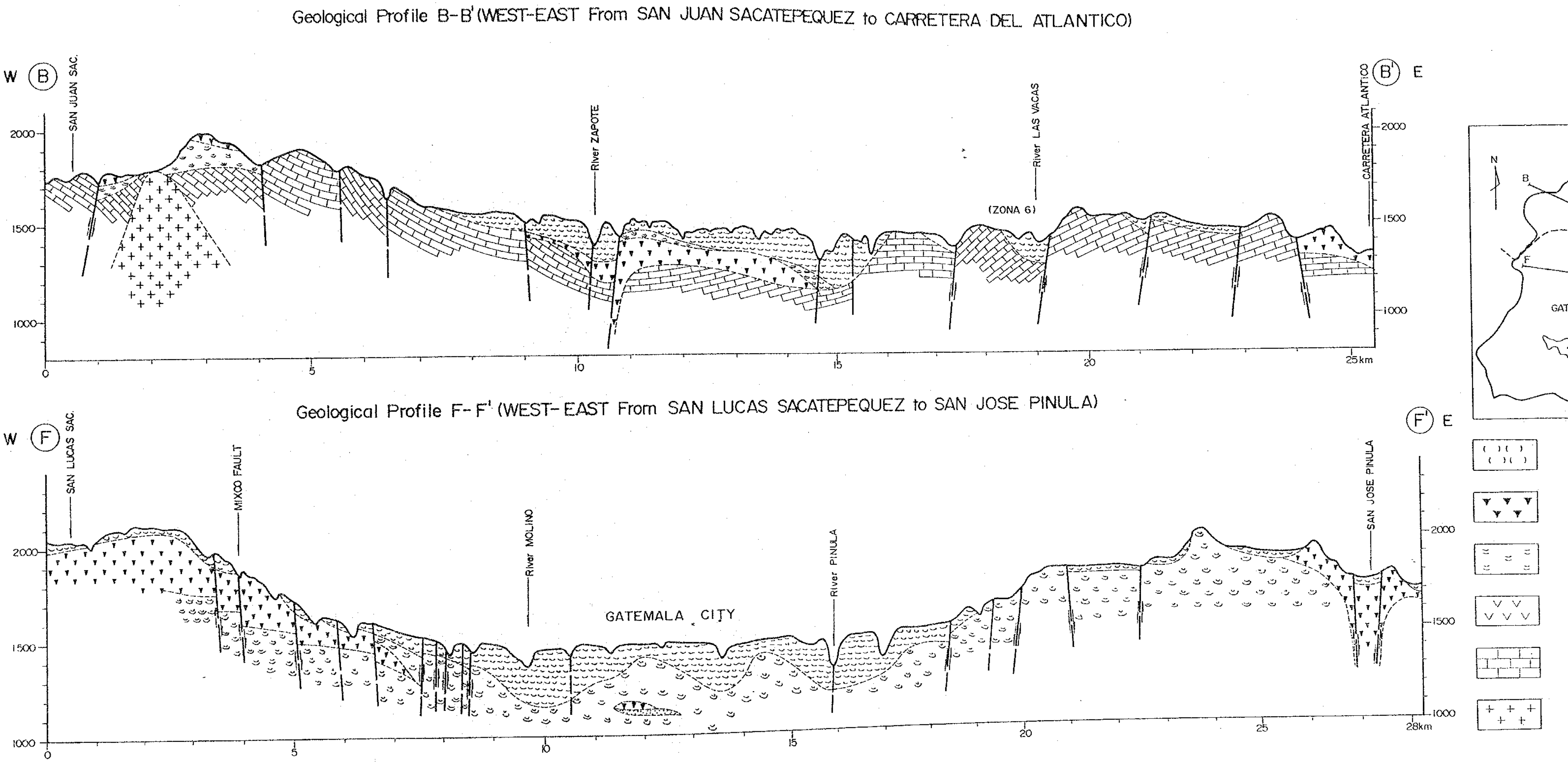


FIG. III-1 GEOLOGICAL PROFILE OF STUDY AREA

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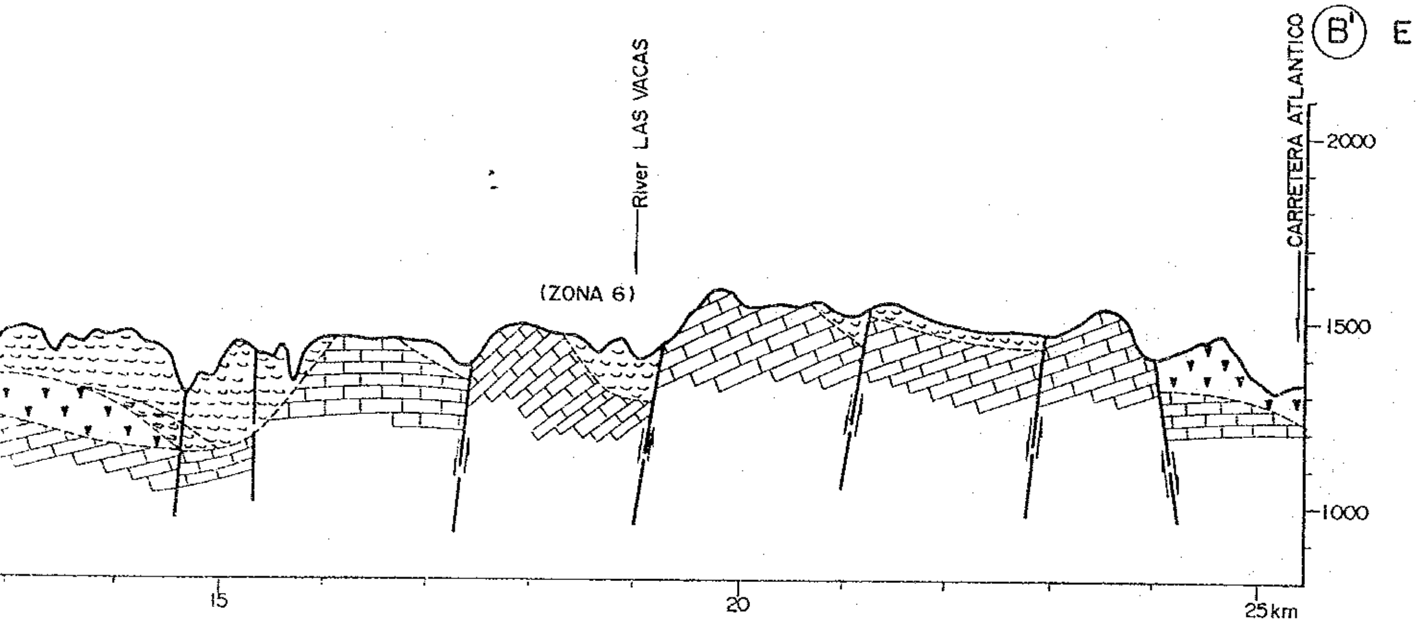
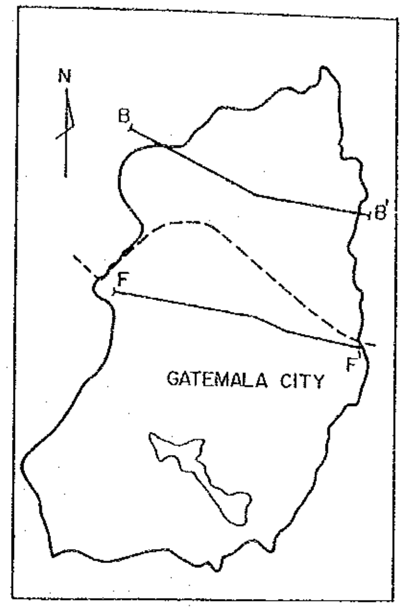
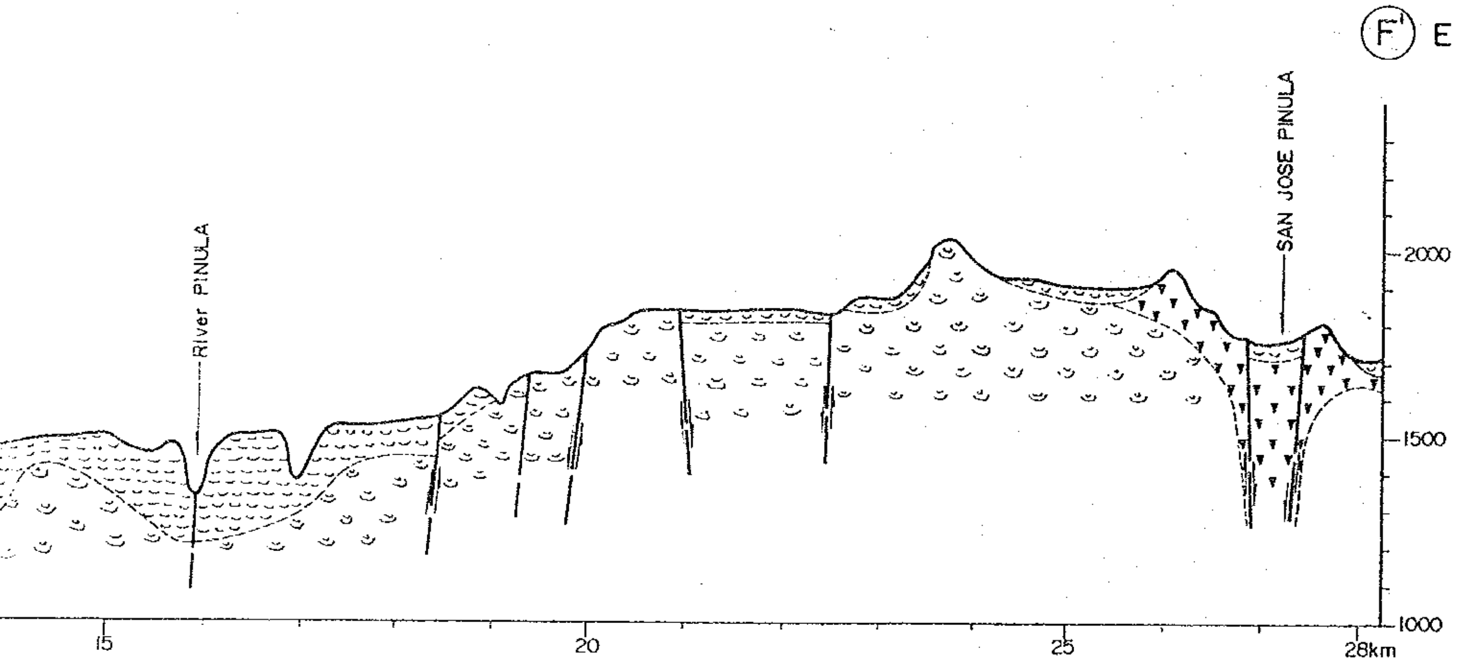
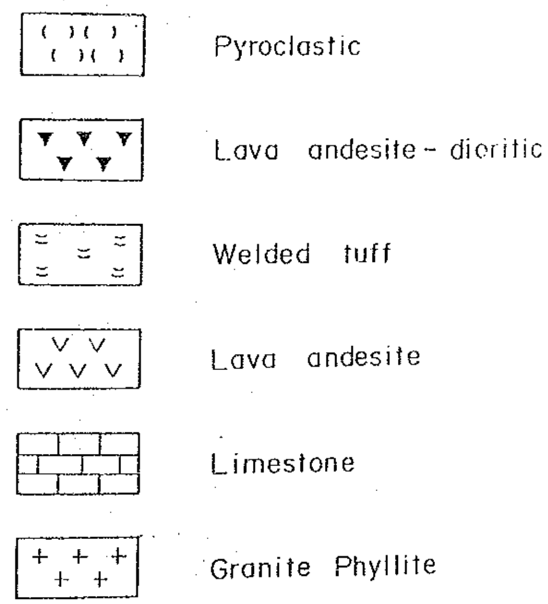




CAS SACATEPEQUEZ to SAN JOSE PINULA)





GICAL PROFILE OF STUDY AREA

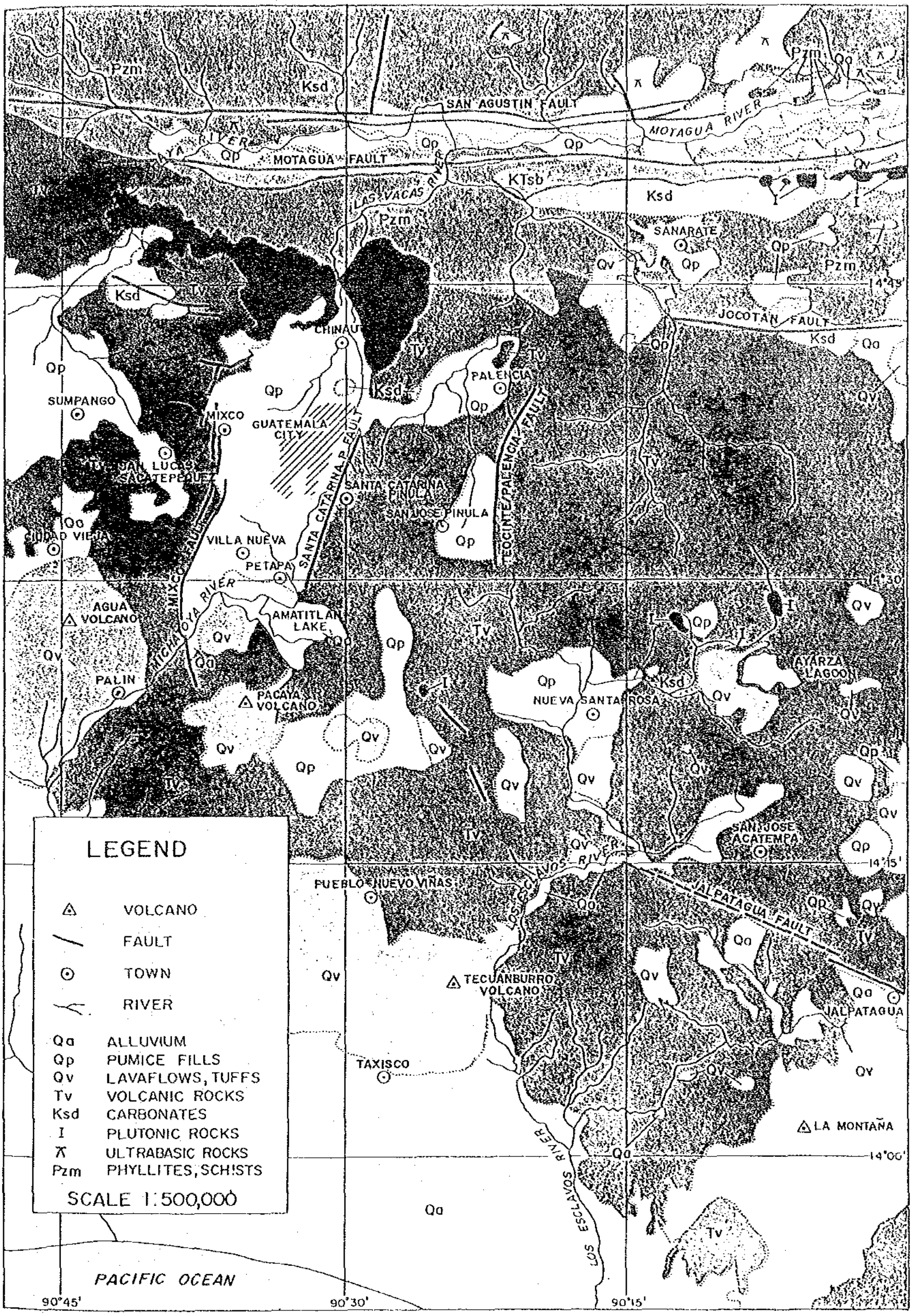


FIG. III - 2 GEOLOGICAL MAP OF THE STUDY AREA

Period	Group / Division	Formation	Geology	Thickness	note
Quaternary				250 m	Aluvium sediment Solidified pumice sediment Ash flow Pyroclastics
Plio-miocene	San Jose Pinula Gr.	Sanguayaba F		250 m	Andesite , tuff Basalt mudflow
				300 m	Visicular, ryolite
		San Agustina F		300 m	Glassy quartz , welded tuff
				300 m	latite-Dacite tuff welded glassy tuff
Cretaceous	upper			450 m	Conglomerate Radiolaria limestone Greywacke Conglomerate
	middle			350 m	Basalt lava
	Lower			500 m	Massine of stratiformed limestone and Dolomite
Paleozoic				+ 800 m	schist phylite Granite

Note : Gr. ··· Group F ··· Formation

FIG. III-3 GEOLOGICAL COLUMN OF GUATEMALA AREA

CHAPTER IV

HYDROLOGY AND METEOROLOGY

The Project area and particularly the hydrographical basin of Las Canas river is not covered by an observation network, and consequently proper hydrological records with the detail required for a hydrogeological study are not available.

The regional hydrometeorological network, covering approximately 1,600 km^2, has only 10 stations with records of adequate continuity. Of the 10 stations, only one is of the first order, station 6.1.0.P, National Observatory; one is of the second order, station 6.12.1, San Pedro Ayampuc; and the remaining stations are of the fourth order.

As for the measurement of rainfall volume, the basin does not have permanent control and record stations. Sporadic measurements have been performed only for the main tributaries. The only hydrographical station with similar conditions of exposure and hydrological regime is station 03.01.01.H. El Tesoro, on Pixcaya river which covers an area of 150km ^{2}.

Controls and measurements important for hydrogeological studies,such as evapotranspiration and infiltration parameters, have not been studied in the Project area nor in hydrologically similar areas.

4.1 Meteorology

Meteorological data was obtained from INSIVUMEH. Rainfall records were available from 1970 to August 1985, of which the 15-year period from 1980 to 1984 was selected for analysis. As regards temperature, humidity, evaporanspiration, solar radiation and wind velocity, records were available only at INSIVUMEH's no. 6.1.0 station (latitude 14°35'11"; longitude 90°31'58") and station no. 6.12.1 at San Pedro Ayumpuc (latitude 14°46'35"' longitude 90°27'17").

4.1.1 Rainfall

Based on rainfall data at 30 stations for the 15 year period 1970 - 1984, monthly mean rainfall amounts were calculated as indicated in TABLE IV-1.

Furthermore, annual mean rainfall amounts were calculated for 19 of the above 30 stations and values are as shown in TABLE IV-2. Incomplete records at the remaining 11 stations precluded their inclusion in the said annual mean rainfall calculations.

Rainfal data was gathered at a further 13 points in addition to the above 30 stations, although the results have not been included in the tables. Records from these points were utilized as supplementary data in preparation of FIG. IV-1.

Monthly mean rainfall values for the above cited 15 year period are predominantly above 100 mm for the rainy season from May to October. By contrast, during the four months for the dry season beginning in November, monthly mean rainfall drops sharply to around 10 mm (with the exception of the months of November and April which are somewhat influenced by the rainy season).

Records at station no. 6.1.0 indicate monthly mean rainfall of 169 mm for May - October during the subject 15 year period, with average rain days per month at 18.

Annual mean rainfall values, on the other hand, vary from station to station. At station no. 18.8.1 (Santa Isabel) the annual average is high at 1812.2 mm, with a value of 2264.5 mm observed for 1979. However, at stations no. 12.4.1 (Sanarata Fegua) and no. 12.5.1 (La Montanita), annual mean rainfall is extremely small at 730.32 mm - 748.0 mm.

Annual mean rainfall at Guatemala City is relatively great at 1400 mm. That at Ojo de Agua and Amatitlan is around 1100 mm.

The annual mean rainfall for the entire Study area is 1200 mm.

For the purposes of water balance calculation, area size and precipitation amounts were derived from FIG. IV-2 for each river basin, and rainfall volumes were accordingly calculated as shown in TABLE IV-3.

Annual average rainfall volume over the subject 15 year period in the Study area is as follows.

northern sector (total for N-II, N-III):	188 x $10^6 m^3$/year
southern sector (total for S-I, S-II, S-III):	349.9 x $10^6 m^3$/year
eastern sector (total for E-V, E-VI and E-VII):	429.8 x $10^6 m^3$/year
Total	968.1 x $10^6 m^3$/year

4.1.2 Temperature

Temperature records are available only from stations no. 6.1.0 and no. 6.12.1. Data is available from 1970 to 1985, and the 15 year period 1970 - 1984 was selected for analysis.

Station no.6.1.0 : (latitude 14°35'11"' longitude 90°31'58")	maximum temperature	31.1°C
	minimum temperature	5.8°C
	monthly mean maximum temperature	24.2°C
	monthly mean minimum temperature	14.5°C
	15 year mean temperature	18.7°C
Station no. 6.12.1 : (latitude 14°46'35 longitude 90°27'17")	monthly mean maximum temperature	27.2°C
	monthly mean minimum temperature	15.1°C
	15 year mean temperature	21.5°C

A 3° differential in mean temperature exists depending on station location. Maximum temperature shows almost no variation from rainy season to dry season. However, minimum temperatures exhibit a 5° variation, with that during the dry season being lower.

4.1.3 Evapotranspiration

Evapotranspiration records are available only from stations no. 6.1.0 and no. 6.12.1. Evapotranspiration values are extremely inportant in calculation of water balance.

Evapotranspiration calculated on the basis of findings of the INSIVUMEH report (1978) yields a value for evapotranspiration over 50% of the mean rainfall.

Where the average rainfall for a 32 year period is 1265mm, evapotranspiration is accordingly calculated at 828 mm by the Turc formula and at 803mm by the Thornthwaite formula. The INSIVUMEH report subsequently indentifies the value according to the Turc formula as being the most applicable. Furthermore, average evapotranspiration in the Villalobos river and Las Vacas river basins for the period 1974 - 1977 is reported as follows.

	1974/75	1975/76	1976/77 (mm)
Villallos river basin	767	709	725
Las Vacas river basin	763	777	-

Records at station no. 6.1.0 inside the Study area indicate that annual mean evapotranspiration for the 10 year period 1970 - 1979 as observed in the shade was 1583.3mm. The 5 year annual mean value for 1980 - 1984 was observed at 905mm. However, the differential in these recorded values is considered too excessive to be reliable.

On the other hand, observation of evapotranspiration according to the standard pan evapotranspiration yielded an average 1458.1mm for the 9 year period 1971 - 1979, and 1498.4mm for the 5 year period 1980 - 1984. These values are, nevertheless, are deemed overly large given conditions in the study area and are likewise considered unreliable.

Observed mean evapotranspiration values in the shade at station no. 6.12.1 in the Study area are 1145.1mm for the 10 year period 1970 - 1974 and 1177.3mm for the 5 year period 1980 - 1984. These values also are considered excessively high and consequently unreliable.

As the Project area lacks systematic and continuous observation, the data obtained at Observatorio Nacional (latitude 14 °35'11", longitude 90°31'58:, EL 1,502 m) from 1980 through 1984 was utilized for evaluation of evapotranspiration. From the average evapotranspiration observed (905mm/year), the actual evapotranspiration in the Project area is estimated at 720mm/year (905 x 0.8), where 80% was considered as an appropriate value for the pan coefficient.

For reference, the following table has been included which indicates evapotranspiration values calculated by the Team on the basis of latitude and mean montly temperatures over the 15 year period 1970 - 1984 at station no.6.1.0. Total annual mean evapotranspiration thus derived is 880mm, which approximates the value considered appropriate above.

Month	Mean temperature	Latitude	Correction for latitude	Evapotranspiration	a x b
	°C				
1	17.5		0.97	57.8	56.07
2	18.0	14°35'11"	0.91	61.23	55.72
3	19.8	=15°	1.03	74.37	76.60
4	20.9		1.04	83.04	86.36
5	21.0		1.11	83.85	93.07
6	20.1		1.08	76.69	82.82
7	19.6		1.12	72.85	81.59
8	19.7		1.08	73.61	79.50
9	19.7		1.02	73.61	75.08
10	19.7		1.01	73.61	74.35
11	18.5		0.95	64.75	61.51
12	17.7		0.97	59.17	57.39
		total			880.06

4.1.4 Humidity, Solar Radiation, Wind

1) Humidity

Monthly mean humidity recorded over the 15-year period 1970 - 1984 at station no. 6.1.0 was 79%. The monthly mean values for September and October were a high 88% and 83%, respectively. On the other hand, the value for January - February was a low 71%, and indicated the difference between rainy season and dry season humidity.

Records at station no. 6.12.1 indicate a monthly mean humidity of 74% for the subject 15-year period. Monthly mean values for September and October are 81% and 79%, respectively. That for January to February is 70%. As can be seen, values are slightly lower than those for station no. 6.1.0.

2) Solar Radiation

Daily mean solar radiation for the 13-year period 1972 - 1984 as recorded at station no. 6.1.0 is 0.33 cal/cm^{2}min, with the solar radiation amount being fairly constant throughout the year. The mean daily maximum solar radiation recorded for the 13 year period was 1.67 cal/cm^2.min. Mean daily maximum values show a decline from year to year, with that in 1974 being 2.07 cal/cm^{2}min as opposed to 1.60 cal/cm^{2}min in 1984. The monthly average for solar radiation per hour over the 15-year period 1970 - 1984 is 209.2 cal/cm^{2}hour.

3) Wind

Average wind direction for the 15-year period 970 - 1984 at station no. 6.1.0 is N - NNE. Annual mean maximum wind speed for the 10 year period 1970 - 1979 is 75 km/h. That for the 5-year period 1980 - 1984 is down 50% at 37.6 km.h. Monthly mean wind speeds for the above two periods are at 15.2 km/h and 12.4 km/h, respectively.

4.2 Hydrology

4.2.1 Surface Runoff

Evaluation of surface runoff is essential in a groundwater survey. Flow density for each river basin in the Study area was investigated, and is as indicated in FIG. IV-2. Flow density is the ratio of total river length (km) per unit area (km^2).

River discharge was observed at the 33 locations shown in FIG. IV-2. River discharge is an indirect computation based on the product of the flow cross-sectional area and flow velocity.

TABLE IV-4 presents results of discharge observation for the period August 1985 - February 1986. As continuous observation for discharge is not available for these rivers, a differential in discharge volume between rainy and dry season is not so readily evident. Nevertheless, it can be seen that in general maximum discharge occurs in September (1985). Observed discharge during February (1986) in the dry season is apparently 50% - 80% less than that in September (1985), indicating a sharp difference in discharge volume between rainy and dry seasons. The implication here is that surface flow would not serve as a stable water source.

As the Project area lacks systematic discharge records, surface runoff is estimated using the data collected in TABLE IV-4. Here it should be pointed out that the data collection was done during the rainy season, which implies an overestimation.

Consequently, the three-month average should be reduced in value to obtain the annual average discharge. For this purpose, the comparison of the three-month average with the annual discharge data of the Pixcaya river was done. The average discharge recorded for the Pixcaya river in a 150 km^2 river basin is 74 $l/sec/km^2$.

The resulting estimations of the annual average discharge of each recharge and circulation area are 5.42 $l/sec/km^2$ for the northern area, 720 $l/sec/km^2$ for the southern area and 9 $l/sec/km^2$ for the eastern area.

4.2.1 River and Spring Water Quality

River and spring water quality was investigated. Results are indicated in TABLE IV-5. In comparison to spring water, river water exhibits 3 times the suspended substances (substances over approximately 1 micron in size). In contrast to total iron content of 0.191 mg/l for spring water, that for the San Juan river is extremely high at 9.25 mg/l. This value is well in excess of the WHO standard of 0.3 mg/l.

Likewise, B.O.D. for the Las Vacas and San Juan rivers is high at over 80 mg/l, and would require costly treatment to render the water suitable for consumption.

Water analysis survey is reported on in greater detail in APPENDIX WATER QUALITY INVESTIGATION IN GUATEMALA VALLEY.

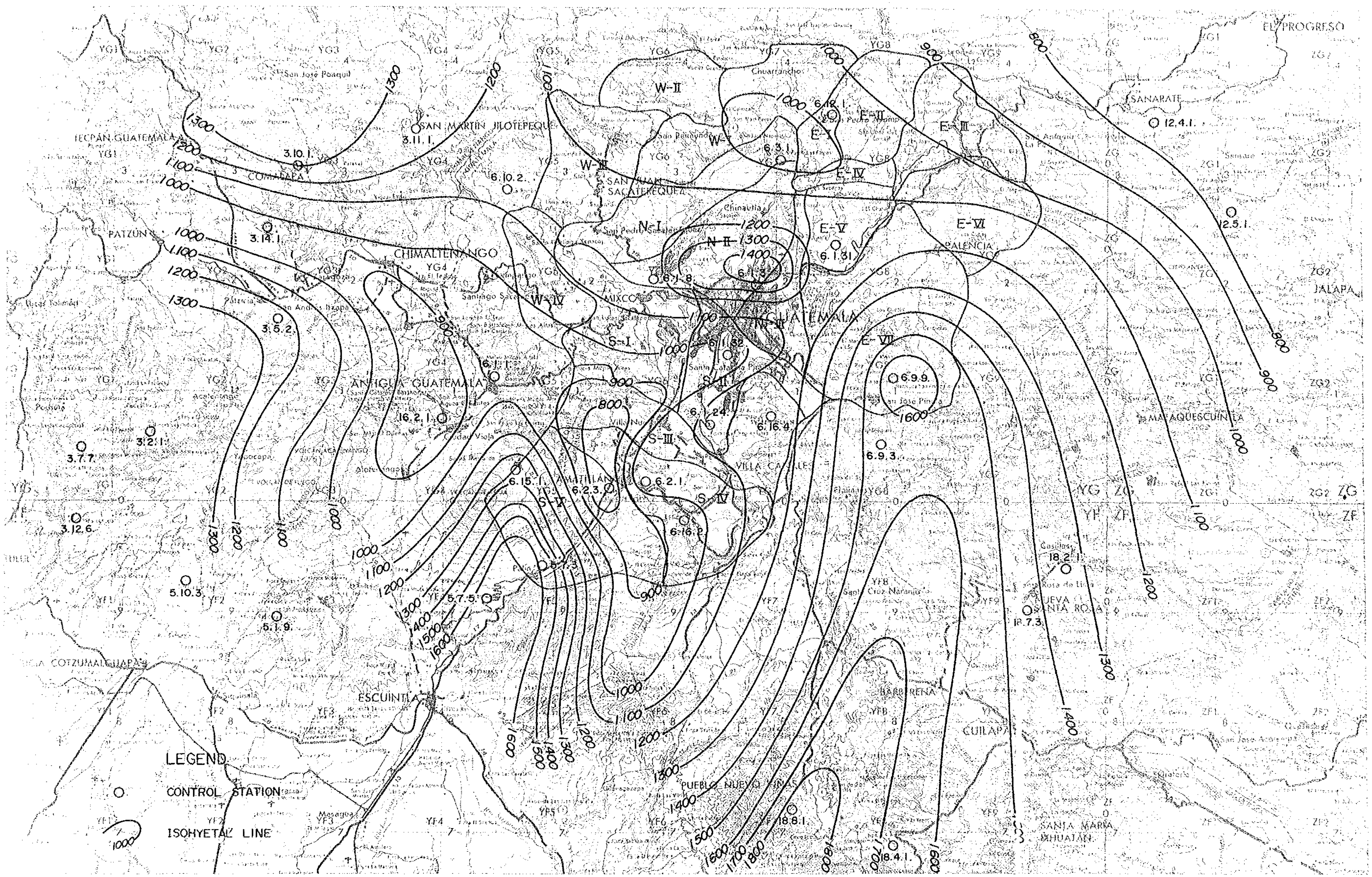


FIG. IV-I ISOHYETAL MAP OF ANNUAL PRECIPITATION (1970-1984)

BASIN	AREA KMS²	LENGTH OF RIVER	DENSITY
N－I	86.82	84.67	0.975
N－II	96.34	74.42	0.772
N－III	56.90	38.08	0.669
S－I	119.16	77.50	0.650
S－II	73.05	45.30	0.620
S－III	125.93	135.10	1.075
S－IV	96.26	16.00	0.166
S－V	166.75	69.60	0.417
E－I	20.81	21.40	1.028
E－II	69.98	39.50	0.564
E－III	82.88	65.50	0.790
E－IV	17.00	16.70	0.982
E－V	46.87	39.16	0.836
E－VI	80.55	30.00	0.372
E－VIII	209.48	191.75	0.915

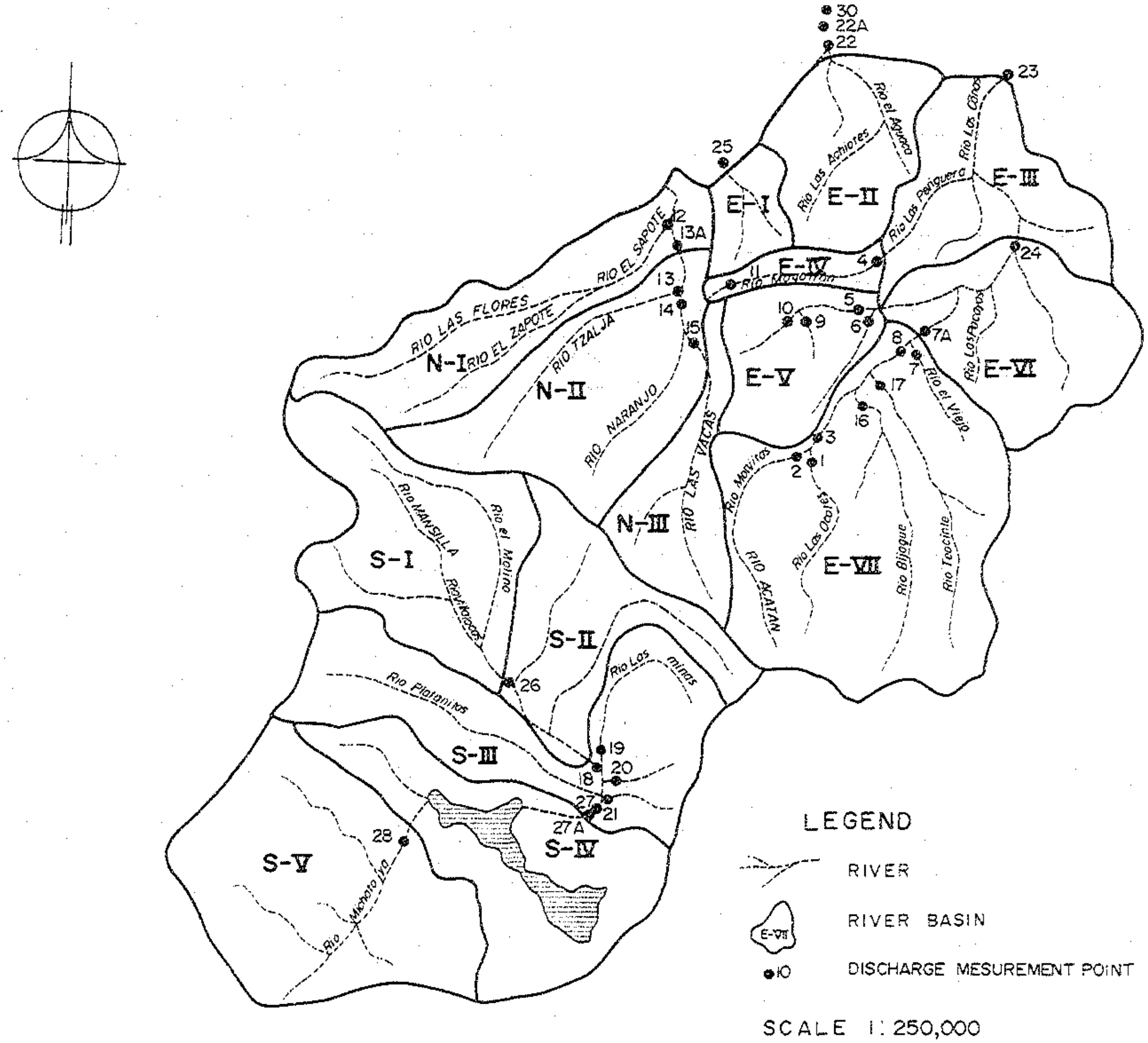


FIG. IV-2 RIVER BASIN

TABLE IV - 1 MONTHLY PRECIPITATION (1970 - 1984)

Nº	NAME	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
6.1.0	Observatorio Nacional	3.81	4.83	7.05	19.57	107.70	216.99	169.11	159.51	249.86	111.33	17.73	4.03
6.1.2	Guatemala FEGUA	3.45	0.92	7.34	20.34	110.47	210.03	146.05	161.86	211.72	99.29	20.08	3.41
6.1.3	Guatemala E.E.	4.4	4.67	13.2	29.37	155.7	283.33	204.97	220.13	323.06	147.80	28.30	7.17
6.1.5	Timoteo Santiago Z. 6	4.36	4.43	9.29	28.14	134.21	245.93	191.50	186.86	247.21	134.50	20.79	6.36
6.1.10	Tanque El Guarda	3.4	0.5	9.7	21.9	105.9	198.9	156.9	177.3	215.2	103.7	17.9	5.1
6.1.12	Planta Santa Luisa	5.53	9.15	18.27	26.38	153.82	216.98	164.53	170.87	291.88	127.03	22.1	9.45
6.1.17	Florinda	7.17	6.56	12.11	29.55	159.21	270.36	181.39	195.79	294.12	135.19	23.43	4.65
6.1.20	Fábrica de Tubos	3.5	0.60	8.8	17.6	83.0	218.3	161.1	200.4	226.0	122.8	23.8	9.0
6.1.21	Presa Teocinte	10.62	8.58	8.53	28.92	121.49	247.32	188.06	217.49	249.67	130.4	35.19	6.52
6.1.24	Ojo de Agua	4.51	16.59	10.74	24.1	109.28	232.57	169.86	158.53	252.44	112.55	18.99	4.75
6.1.31	Planta Las Ilusiones	3.8	1.1	8.3	33.7	145.1	231.2	151.6	184.7	223.4	135.2	24.4	8.4
6.1.32	Estación Radio Sonda	5.18	8.44	17.23	15.22	91.90	199.58	148.77	121.59	248.73	99.93	15.30	5.03
6.2.1	Amatitlán E.E.	4.1	6.67	12.47	20.17	111.11	221.70	172.8	179.2	246.0	81.83	10.2	0.73
6.2.3	Jardines Mil Flores	6.76	0.98	4.93	29.58	87.32	203.55	121.67	172.72	220.41	72.95	13.66	3.15
6.2.7	Compuertas Amatitlán	1.9	1.4	6.9	23.0	96.3	190.4	144.2	156.2	210.5	81.6	15.2	1.6
6.3.1	San Antonio Las Flores	2.16	7.64	31.34	15.44	111.20	120.5	112.70	171.16	267.18	148.18	48.58	14.24

TABLE IV - 1 MONTHLY PRECIPITATION (1970 - 1984)

Nº	NAME	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
6.9.3	La Soledad	15.01	5.09	5.01	27.31	163.87	326.30	252.89	232.0	314.45	194.84	36.68	12.97
6.9.8	El Maguey	3.71	0.4	3.03	25.04	135.20	283.84	225.05	264.04	269.84	142.54	35.94	4.56
6.9.9	La Negra	11.79	11.88	11.26	23.70	149.09	324.1	215.57	241.40	381.82	155.29	41.79	7.76
6.10.2	El Pilar	4.08	6.58	17.33	27.34	118.32	239.95	175.18	171.40	213.66	127.81	18.37	13.65
6.12.1	San Pedro Ayampuc	3.67	4.27	10.91	23.07	108.98	219.27	145.12	147.20	215.41	123.37	23.59	7.5
6.15.2	Aldea Piedra Parada	8.70	1.9	6.9	37.2	135.60	219.3	204.6	242.9	288.2	140.3	34.8	15.1
6.16.2	Laguna E.E.	2.67	5.6	8.67	19.03	88.60	193.93	162.23	176.57	225.93	85.07	10.03	0.2
6.16.3	Morán Villacanales	0.68	1.07	5.55	16.49	87.57	275.56	188.29	191.89	223.38	93.48	7.02	0.54
6.16.4	San Agustín Las Minas	6.01	5.75	14.91	23.7	19.29	246.35	187.91	203.22	239.06	102.07	19.70	3.026
12.4.1	Sanarate FEGUA	1.64	2.24	0.513	16.11	88.16	167.32	87.48	107.06	179.21	83.36	12.93	1.913
12.5.1	La Montañita El Progreso	7.22	3.40	6.04	18.61	80.186	165.36	104.84	92.34	125.0	99.36	17.313	10.94
18.10.1	Portezuelo Santa Rosa	0.00	4.28	21.2	41.2	160.88	220.49	134.10	144.05	214.82	116.82	20.54	1.924
18.8.1	Santa Isabel Santa Rosa	3.18	12.433	19.506	50.746	188.89	340.05	196.94	264.10	411.19	249.78	71.95	6.606
18.8.4	La Morena Santa Rosa	2.366	5.50	7.20	33.80	160.81	317.23	226.76	258.96	384.83	177.73	36.816	3.60

TABLE.IV - 2 ANNUAL PRECIPITATION (1970-1984)

Nº	NAME	1978	1979	1980	1981	1982	1983	1984	Resumen
6.1.3	Guatemala E.E.	1255.0	1494.0	1488.0	1340.5	1336.0	1546.0	1490.0	1427.4
6.1.24	Ojo de Agua	1114.9	1201.9	1221.5	1168.0	1202.0	1238.9	1054.0	1110.1
6.1.8	Presa La Brigada	---	---	1118.3	983.6	1170.0	1214.9	1325.7	1162.5
6.1.32	Radio Sonda	905.4	1008.7	763.2	978.5	1201.2	1110.0	982.2	976.8
6.2.1	Amatitlán E.E.	1200.0	1090.0	718.0	1215.0	1063.0	1136.0	1129.5	1067.0
6.2.3	Jardín Mil Flores	917.0	1007.3	876.1	1106.2	1131.7	1187.8	1029.6	971.1
12.4.1	Sanarate FEGUA	828.2	864.1	533.5	801.3	661.1	611.9	979.3	748.0
6.12.1	San Pedro Ayampuc	882.0	1231.6	1183.0	1069.4	1243.9	1258.7	1238.7	1038.4
6.3.1	San Antonio Las Flores	---	---	1078.2	1488.9	883.8	809.4	1091.3	976.6
12.5.1	La Montañita	743.7	594.0	794.6	804.4	608.8	411.2	701.8	730.32
6.1.31	Planta Las Ilusiones	1171.8	1456.6	1071.0	1074.6	1064.5	875.6	1519.2	1138.4
6.9.9	La Negra	1790.4	1752.4	1338.9	1699.7	1856.6	2162.5	1984.0	1606.6
6.16.4	San Agustín Las Minas	1155.7	1014.4	1078.7	1372.5	1204.3	1202.4	1200.5	1171.0
6.9.3	La Soledad	---	---	1382.9	1880.1	1358.4	1398.0	1659.3	1577.7
6.16.3	Morán FEGUA Villacanales	1327.5	937.2	1388.6	1226.1	1050.4	1320.3	993.3	1098.3
6.16.2	La Laguna E.E.	919.5	1026.0	1008.0	1313.5	1068.0	1095.0	1086.0	984.0
18.10.1	Portezuelo	971.3	1510.4	916.2	1205.9	1169.4	913.0	1340.4	1038.8
18.8.1	Santa Isabel	1733.5	2264.5	1610.0	1714.0	2003.7	1798.5	1812.5	1812.2
18.4.1	La Morena	1585.5	2187.0	1820.0	1739.5	1577.0	1394.0	1493.2	1615.5

TABLE IV - 2 ANNUAL PRECIPITATION (1970-1984)

Nº	NAME	1970	1971	1972	1973	1974	1975	1976	1977
6.1.3	Guatemala E.E.	1770.0	1565.0	818.0	1899.0	1213.5	1553.5	1715.0	928.0
6.1.24	Ojo de Agua	---	---	---	---	1118.0	974.6	923.2	1093.0
6.1.8	Presa La Brigada	---	---	---	---	---	---	---	---
6.1.32	Radio Sonda	---	---	---	---	---	984.3	1058.9	775.2
6.2.1	Amatitlán E.E.	1131.0	1106.0	781.5	1516.6	1358.0	1023.0	849.0	688.0
6.2.3	Jardín Mil Flores	995.1	996.5	635.9	1402.6	959.6	756.5	828.7	736.4
12.4.1	Sanarate FEGUA	840.5	852.1	555.0	956.6	658.1	696.5	732.5	648.6
6.12.1	San Pedro Ayampuc	1020.5	808.2	586.6	1112.1	982.7	1023.6	1118.5	815.9
6.3.1	San Antonio Las Flores	---	---	---	---	1736.7	273.5	450.9	---
12.5.1	La Montañita	988.2	908.9	603.9	892.7	807.1	939.7	599.2	556.6
6.1.31	Planta Las Illusiones	---	---	909.5	1377.9	970.8	1093.9	1382.7	831.7
6.9.9	La Negra	---	1733.8	1126.6	1680.2	1266.6	1132.9	1589.7	1377.7
6.16.4	San Agustín Las Minas	1480.1	1365.7	1002.7	1423.4	1098.7	1000.8	1072.6	892.9
6.9.3	La Soledad	1706.6	1673.9	1189.7	2037.7	1687.2	1786.6	1310.2	1439.4
6.16.3	Morán FEGUA Villacanales	987.1	1149.3	698.9	1443.4	1098.3	878.3	1011.1	964.0
6.16.2	La Laguna E.E.	1085.0	1110.5	722.0	1191.0	1017.5	757.0	832.0	528.5
18.10.1	Portezuelo	1028.4	1179.7	673.3	1525.1	1149.0	828.3	986.6	859.6
18.8.1	Santa Isabel	1945.7	2128.5	1806.1	2331.7	1730.6	1538.3	1361.9	1404.1
18.4.1	La Morena	1769.0	1939.0	1058.0	1949.0	2015.5	1335.7	1301.0	1068.5

TABLE.IV - 3 ANNUAL PRECIPITATION FOR EACH RIVER BASIN

(1970 - 1984)

RIVER BASIN		AREA (km^2)	PRECIPITATION (mm)	VOLUME (m^3)	REMARKS
N-I	(1)	13.17	1,000	13.2×10^6	6.3.1.
	(2)	65.67	1,050	69.0×10^6	
	(3)	7.98	1,125	9.0×10^6	
		86.82	1,072	91.2×10^6	
N-II	(1)	5.568	1,050	5.8×10^6	6.1.8.
	(2)	36.968	1,150	42.5×10^6	6.1.3.
	(3)	35.768	1,250	44.7×10^6	
	(4)	0.968	1,400	1.4×10^6	
		96.34	1,240	117.4×10^6	
N-III	(1)	4.92	1,150	5.7×10^6	
	(2)	14.42	1,250	18.0×10^6	
	(3)	6.32	1,350	8.5×10^6	
	(4)	23.42	1,250	29.3×10^6	
	(5)	5.92	1,250	7.4×10^6	
	(6)	1.9	1,100	2.1×10^6	
		56.9	1,248	71×10^6	
S-I	(1)	13.21	1,075	14.2×10^6	
	(2)	105.95	1,150	121.8×10^6	
		119.16	1,141	136.0×10^6	

RIVER BASIN		AREA (km^2)	PRECIPITATION (mm)	VOLUME (m^3)	REMARKS
E-III	(1)	8.19	900	7.4×10^6	
	(2)	69	950	65.6×10^6	
	(3)	5.69	1,000	5.7×10^6	
		82.88	950	78.7×10^6	
E-IV	(1)	15.45	1,050	16.2×10^6	
	(2)	1.55	1,100	1.4×10^6	
		17.00	1,023	17.39×10^6	
E-V	(1)	15.92	1,050	16.7×10^6	6.1.31.
	(2)	29.41	1,150	33.8×10^6	
	(3)	0.72	1,225	0.9×10^6	
	(4)	0.82	1,200	1.0×10^6	
		46.87	1,118	52.4×10^6	
E-VI	(1)	16.77	950	15.9×10^6	
	(2)	27.37	1,050	28.7×10^6	
	(3)	22.37	1,150	25.7×10^6	
	(4)	13.37	1,250	16.7×10^6	
		80.55	1,091	87.9×10^6	
E-VII	(1)	4.95	1,075	5.3×10^6	6.9.9
	(2)	5.65	1,150	6.5×10^6	
	(3)	40.75	1,250	50.9×10^6	
	(4)	57.85	1,350	78.1×10^6	
	(5)	47.65	1,450	69.1×10^6	
	(6)	43.15	1,550	66.9×10^6	
	(7)	3.26	1,600	5.2×10^6	
	(8)	5.16	1,200	6.2×10^6	
	(9)	1.06	1,225	1.3×10^6	
		209.48	1,382	289.5×10^6	

RIVER BASIN		AREA (km²)	PRECIPITATION (mm)	VOLUME (m³)	REMARKS
S-II	(1)	0.56	1,325	0.7×10^6	6.1.24 6.1.32
	(2)	5.46	1,250	6.8×10^6	
	(3)	4.46	1,150	5.1×10^6	
	(4)	43.2	1,050	45.4×10^6	
	(5)	4.26	1,000	4.3×10^6	
	(6)	15.6	1,150	17.3×10^6	
		73.05	1,144	79.6×10^6	
S-III	(1)	9.61	1,075	10.3×10^6	6.16.3
	(2)	43.35	1,150	49.9×10^6	6.16.4
	(3)	4.66	1,225	5.7×10^6	
	(4)	42.25	1,075	45.4×10^6	
	(5)	26.06	1,125	29.3×10^6	
		125.93	1,114	140.3×10^6	
S-IV	(1)	2.55	1,000	2.6×10^6	6.2.1.
	(2)	77.16	1,050	81.8×10^6	6.6.2.
	(3)	16.55	1,150	19.0×10^6	
		96.26	1,074	103.4×10^6	
S-V	(1)	126.37	1,050	132.7×10^6	6.2.3.
	(2)	40.38	1,125	45.4×10^6	
		166.75	1,068	178.1×10^6	
E-I	(1)	20.81	1,025	21.3×10^6	6.12.1.
		20.81	1,025	21.3×10^6	
E-II	(1)	35.59	1,050	37.4×10^6	
	(2)	34.39	1,025	35.2×10^6	
		69.98	1,037	72.6×10^6	

TABLE IV-4 RIVER DISCHARGE

No	Name of River	Discharge (m^3/s)						
		August	September	October	November	December	January	February
1	Los Ocotes	0.686	2.410	0.495				
2	Bebedero (Rio Monjitas)	0.464	1.587	0.493				
3	Los Ocotes	1.140	3.997	0.998				
4	Mogollon (El Fiscal)	0.302	0.518	0.124		0.013	0.009	0.006
5	El Purgatorio	0.336	0.882	0.138		0.037	0.024	0.019
6	El Toro (El Chato)	0.424	0.658	0.216		0.258	0.230	0.198
7	El Viejo	0.174	0.441	0.210				
7A	Rio Las Canas (Puente)					0.502	0.261	0.218
8	Las Canas	3.320	--	2.895				
9	El Jute	0.032	0.133	0.039				
10	Los Vados	0.141	0.479	0.211				
11	Mogollon (Reyes)	0.079	0.166	0.046				
12	El Zapote	--	2.989	0.792		0.137	0.057	
13	Tzalja	--	1.039	0.496			0.111	
13A	Las Vacas (Puente Hamaca)					2.548	1.604	
14	Chinautla	--	1.390	0.468			0.559	
15	Las Vacas (El Porvenir)	--	3.417	2.731		1.887	1.350	
16	Bijague	--	--	0.511				
17	Teocinte	--	--	1.396				
18	Villalobos (Moran)	--	--	2.353		0.290	0.316	0.246
19	Rio Moran	--	--	0.688				
20	Tuluja	--	--	0.255				
21	El Bosque	--	--	0.072				
22	Rio Los Acoles (Quixal)	--	--	--	0.291	0.056		
22A	Los Acoles					0.091		
23	Rio Las Canas (Cucajul)	--	--	--	4.900	1.277	0.774	
24	Rio Las Canas (Agua Caliente)	--	--	--	3.773	1.305	0.738	
25	Aguacate					0.034		
26	Villalobos (el Frutal)					0.189	0.204	0.165
27	" (Cementerio)					0.135	0.104	0.067
27A	Toma Rio Villalobos (Cementerio)					0.143	0.121	0.131
28	Michatoya					5.155		
29	"					5.600		
30	Las Vacas (Petaca)					3.200		

TABLE IV-5 River and Spring Water Quality

	Las Vacas river (San Antonio Las Flores)	San Juan river (El Chato bridge)	Las Canas river (Palencia bridge)	Agua Tivia Spring
Aspect	Turbid	Turbid	Turbid	Clear
Colour (TCU)	400.0	1,600.0	147.0	3.0
Turbidity (t, U)	50.0	500.0	65.0	1.0
Odour	Organic material	Organic mterial	Earthly	Non-detectable
pH	7.8	7.8	8.2	6.8
Temp (°C)	22.0	21.0	20.0	20.0
Total hardness (mg/ℓ as $CaCO_3$)	152.0	200.0	96.0	72.0
Albuminoid nitrogen (mg/ℓ)	0.146	0.137	0.098	0.018
Ammonia nitrogen (mg/ℓ)	0.044	0.045	0.021	0.008
Nitrite nitrogen (mg/ℓ)	0.028	0.050	0.005	0.000
Nitrate nitrogen (mg/ℓ)	0.023	0.500	0.056	0.181
Chloride (Cl^-/ℓ)	36.500	47.000	16.500	16.000
Fluoride (mg/ℓ)	0.450	0.600	0.370	0.360
Total iron (mg/ℓ)	3.971	9.250	3.177	0.191
Sulfate (mg/ℓ)	37.5	82.0	8.0	3.5
Total solids (mg/ℓ)	497.0	557.0	191.0	183.0
Suspendid solids (mg/ℓ)	86.0	96.0	72.0	2.0
Total alkalinity (mg/ℓ)	236.0	330.0	104.0	90.0
Detergent (mg/ℓ)	1.10	0.45	0.06	0.08
B.O.D (mg/ℓ)	100.0	80.0	5.0	12.0
Dissolved oxygen (mg/ℓ)	5.0	2.2	9.4	6.0

CHAPTER V

GROUNDWATER LEVEL

Groundwater level, conductivity and pH values were observed for shallow wells and springs in the study area, sited principally in the eastern sector thereof.

Groundwater levels were plotted from data of existing wells, and hydro-isobath maps prepared. A water table elevation and ground elevation relational map was also prepared. Findings of these efforts are presented below.

5.1 Shallow Wells and Springs (See FIG. V-1 and TABLE V-1)

Observation sites were selected on a 1:50,000 topographical map at a frequency of 2-3 wells and/or springs per 1 km^2.

In order to strengthen the accuracy of elevation survey by precision altimeter, the elevation of existing bench marks was checked 3 times at both morning and evening. Measurement averages were computed, and measurement differential distributed in determining the elevations of observation points.

Water level is defined as the distance from the surface to the groundwater table, and water level elevation is calculated by subtracting the water level from the observation point elevation.

Water level, conductivity and pH values were recorded at each observation point. In measuring conductivity, a handy-type conductivity meter (HPK-22) and the Horiba type DS-7 were used. The pH was determined by colorimetry and water level measurements made by water-gauge.

5.1.1 Conductivity

Conductivity is the reciprocal of resistivity, and is measured in units of mho/cm (℧/cm). As mho are excessively large units for the resistivity of natural water, such has been conventionally measured in: 10^{-6}mho = micro mho (μ℧). Recently, however, expression in S/cm has become widespread. For example, conducivity value of 56 μ s/cm is equivalent to 56 x 10^{-6} mho/cm.

Specifically, conductivity indicates the ease with which eletric current passes over a 1 cm interval in a given substance.

As conductivity varies with temperature, appropriate correction must be made. As standard temperature, 18 °C, 20°C and 25°C are advocated; for the purpose of the subject study 25 °C was adopted.

A rough gauge of ground conductivity values is as follows:

10 m/m ←———————— 100 μ ————————→ 1 μ

strong electrolitic properties	weak electrolytic properties
high electric conductivity	low electric conductivity
high saline content	low saline content

Test results indicate values of 80 μ s/cm to 200 μ s/cm over 59% of tested area.

5.1.2 Hydrogen Ion Concentration

The pH serves as one index for expressing water characteristics. A pH value of 7.0 indicates a neutral state, with higher values of 8.0 and 9.9 signifying alkalinity and smaller values of 6.0 and 5.0 denoting acidity.

A pH value of 7.0 is present throughout 27% of the test area, pH 6.0-6.5 in 52%, and pH 5.5 in 11%. In other words, 63% of the test area yielded slightly acidic results. A pH value of 8.0 was obtained over 10% of the test area, indicating limited acidity. As Guatemala City standards call for pH in a range of 6.5-9.2, pH values observed within the Study area do not pose a problem.

5.1.3 Hydro-Isobath Map

The free-surface isobath map was prepared from shallow well and spring groundwater levels and is shown in FIG. V-1. This indicates that groundwater flows from cliffs, etc. to the surface where it is released as springs. Thin clayey layers exist throughout the Quarternary strata that form the major surface strata and the presence of spring water at the steep cliffs following the line of these strata is also indicated.

Accordingly, the tendency is to be in conformity with the landform, thereby tending to flow from south to north-east.

5.2 Analysis of Existing Well Data

The degree of homogeneity of the Guatemala City Valley aquifer was examined by plotting the relationship between water table elevation (vertical axis) and ground elevation (horizontal axis). According to Gustafsson, Y. (1968) of Sweden, the resultant graph yields a straight-line relationship, indicating parallelism between topography and groundwater level.

Such graphs were prepared for the northern and southern sections of the Study area (see FIG. V-2, V-3, V-4).

If a 45° line is entered on the graph for the northern section, the plotted points are virtually all to the right thereof, indicating homogeneity of the aquifer, or rather, an free aquifer.

The same procedure for the graph of the southern section likewise denotes a homogeneous free aquifer for the greater part, as for the northern sector. However, a number of plotted points lie either on or to the left of the 45° line, indicating that the water level at certain locations is higher than ground surface. This in turn implies the presence of artesian flow from water having the nature of a confined aquifer.

An example of this is the deep well No. 139 Ojo de Agua (EL 1300 m, depth 274 m) in the southern sector. This well becomes fractured andesite at depths below 110 m, with artesian flow from the cracks in the rock. This suggests that the water has the character of a confined aquifer with a water head level slightly higher than the elevation of 1300 m.

Furthermore, the deep well No. 2 project 4-3 (EL 1467, depth 274 m) of the northern sector is fractured limestone at depths below 115 m. Here, the water level is 167 m, and there is a pump-up volume of 63 l/sec. The water level elevation is 1300 m and the same as the former well.

This indicates the possibility of a confined aquifer in the basement rock of this sector, and that the water head of this aquifer is roughly the same as the elevation of 1300 m. In other words, it means that a lower aquifer can be extracted from the basement below EL 1300 m.

5.3 Hydro-Isobath Map

Water level elevation was calculated from existing well data and well locations and hydro-isobath were plotted on a 1:50,000 topographical map. Direction of groundwater flow is at right angles to hydro-isobath alignment.

Groundwater flow is basically north-south to south of the continental divide and south-north to the north thereof, which is in keeping with the INSIVUMEH study (see FIG. V-5).

Northern sector (north of continental divide):

Groundwater flow from the recharge zone (higher ground) to the west moves north along the course of the Las Vacas river. The groundwater flow is assumed to be subsequently obstructed by the granite formation (impermeable layer) to the north, with a certain portion of flow diverting to the east.

Southern sector (south of continental divide)

Groundwater flow from the recharge zone in the west is to the south as indicated by arrows in the above mentioned figure. The groundwater divide (vicinity of boring site 21), however, is slightly north of the surface flow continental divide.

Eastern sector

The eastern and western boundaries of this sector have faults running north-south, and the sector is thought to have a basement with an upheaval formation over the entire sector. Because of this, the groundwater in this sector is thought to have little input from this sector, even if there is output. However, a drop in the groundwater is predicted to be caused by the east-west faults developing in the central part, implying that part of the groundwater from the west is diverted to the east along the fault.