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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF AGRICULTURE AND LIVESTOCK
REPUBLIC OF EL SALVADOR

THE STUDY
ON
COMPREHENSIVE FLOOD CONTROL
FOR
THE RIO GRANDE DE SAN MIGUEL
IN
THE REPUBLIC OF EL SALVADOR

SUPPORTING REPORT

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PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
NIKKEN CONSULTANTS INC., TOKYO
PASCO INTERNATIONAL INC., TOKYO

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A: Topography and Geology

Main objectives of topographical and geological study are to clarify the characteristics of topography and engineering geology in the Study Area in terms of the following.

i) Rock and soil soundness of the foundation for planning of the river facilities.

ii) Location and characteristics of the construction materials for planning such as concrete aggregate for structures and soil for embankment.

iii) Slope condition related to the slope stability and production of sediment.

iv) Activity of Quaternary faults related to the dam planning.

v) Topography and geology of the Study Area for the Study in general.

1. General Description

El Salvador is situated in the Circum-Pacific Volcanic Belt that is characterized by the activities of volcano and earthquake. It can be divided into four topographic regions that are roughly parallel to the coast line trending northwest west to southeast east, as follows:

- Honduras Range
- Lempa River Valley
- Central Volcanic Depression
- Coastal Plain

The Study Area, San Miguel River Basin, covers parts of Honduras Range, Central Volcanic Depression. The Central Volcanic Depression includes volcanic chain, some of which are still active. One of them is San Miguel Volcano located in the western part of the Study Area having smoke from the crater. This peak and its associated chain of cones, also of recent formation, are located in the west of San Miguel City and extend up to near San Salvador City. As a result of their activity, there are depressed basins formed by land subsidence due to eruption and formation of high volcanic peaks.

The San Miguel River is originated in the Honduras Range, flows generally from north to south with heavily meandering in the Central Volcanic Depression and pours into the Pacific Ocean. Its catchment area is 2,247 km^2.

Geology of the Study Area is composed of volcanic rocks and eruptive materials of several types and ages. It consists of fine tuff, lapilli tuff, vitric tuff, tuff breccia, volcanic breccia, and ignimbrite intercalated by basaltic and/or andesitic lava. Recent deposits such as floodplain, swamp, talus, and terrace cover the volcanic rocks and are located along the river and depression areas of Lake Olomega and Lake Jocotal.

2. Topography

Aerophotos and topographic maps are interpreted to realize the topography and slope condition of the Study Area. The results are shown in Figure A.1

The upper basin of the River is situated in the Honduras (mountain) Range where elevation ranges from 300 meters to 1000 meters and mainly characterized by the distribution of old volcanic rocks in Miocene epoch.

The middle basin to lower basin of the River are located in the Central Volcanic Depression which is mainly characterized by the active volcanoes such as San Miguel Volcano. There are depressed (low) lands caused by the volcanic eruption in the areas extending from near San Miguel City to Lake Olomega and around Lake Jocotal. Around Lake Olomega is a wide floodplain dammed up several times during the past geological age by the lava flow and pyroclastic flow (ignimbrite). The highest peak is the San Miguel Volcano of 2,130 meters above mean sea level.

The river mouth area is located in the west of the coastal mountain range. The range has an altitude of 100 meters in the western part and 600 meters in the eastern part with the highest peak of Mt.Monito of 882.95 meters. And also, swamp land and Mangrove forest are widely distributed in the river mouth area.

There is no large scaled landslide, rock-fall, and devastated and bare land. There are seven rock-fall sites in the Study Area. They have an area of about 0.5 to 0.9 km^2 and total is about 4.5 km^2. It only amounts to 0.2 % of the Study Area of 2,247km^2. It is too small to consider as main element of sediment production. All ground surface are covered by grass with trees and forest except along roads of under construction and small quarry sites. Sediment shall be considered on the basis of strength of rainfall, geological condition, vegetation, and slope.

The Study Area is classified into the following five (5) topographical regions (refer to Figure A.1).

Mountain 1	: gradient = over 30.5 degrees
Mountain 2	: gradient = 18.4 to 30.5 degrees
Mountain 3	: gradient = 11.3 to 18.4 degrees
Hilly	: gradient = 2 to 11.3 degrees
Undulated	: gradient = under 2 degrees
Fluvial low land	: gradient = approximately flat

Mountain 1 Region

It is merely distributed at the volcanic peaks of San Miguel Volcano, Usulutan Volcano, and other small volcanoes. A slope gradient is about 30 to 35 degrees continuing from Mountain 2 region.

Mountain 2 Region

It is distributed in the mountains of Honduras Range where covers the upper basin of the River, halfway up San Miguel Volcano, Usulutan Volcano, and small volcanoes.

Mountain 3 Region

It is widely distributed in the mountains of middle basin of the River and coastal mountains.

Hilly Region

It is widely distributed in the mountain foot and is mainly utilized as the pasture land with farm land.

Undulated Region

It is widely distributed between the mountain foot and rivers. It is mainly characterized by the talus and terrace deposits, and also utilized for the farm and pasture lands.

Fluvial low land

It is widely distributed along the river and depression areas of Lake Olomega and Lake Jocotal. It is mainly characterized by fluvial plain deposits, and also widely utilized by the farm and pasture lands.

3. Geology

Interpretation of aerial photographs and field reconnaissance were conducted to realize the engineering geology in the Study Area. The results are shown in Figure A.2.
Geology of the Study Area consists of various volcanic rocks in the various geological ages as shown in the following table.

Table A.1 Geology in the Study Area

Era	Period	Epoch	Formation	Sym	Lithology	Remarks
				rd	Recent river deposit	sand, gravel, clay
				sd	Swamp deposit	clay with organic matter
				al	Alluvial deposit	clay, sand with gravel
				ta	Talus, Terrace deposit	clay, sand, gravel
	Quaternary	Holocene		cd	Cone deposit	scoria, lapilli tuff,
			San Salvador	Lv	Lava flow	with volcanic neck
				Py	Pyroclastic flow	with lave flow
				Md	Mud flow	mud flow (brown), acidic
Cenozoic		Pleistocene		Ig	Ignimbrite	
			Cuscatlan	Lv	Lava	with volcanic neck
				Py	pyroclastic flow	with lava flow
		Pliocene	Balsamo	Lv	Lava	with volcanic neck
	Tertiary		Chalatenango	Vb	Volcanic rocks	with lava flow
		Miocene	Morazan	Lv	Lava	with volcanic neck
				Vb	Volcanic rocks	with Ignimbrite

Basement rock is composed of various volcanic formations, namely San Salvador Formation in Holocene Epoch, Cuscatlan Formation in Pleistocene to Pliocene Epoch, Balsamo Formation and Chalatenango Formation in Pliocene to Miocene Epoch, and Morazan Formation in Miocene Epoch. Each formation consists of cone deposit, lava flow, pyroclastic flow, mud flow with ignimbrite, and/or lava and volcanic rocks. These basement rocks are covered by the recent (Holocene Epoch) unconsolidated sediment, namely river deposit, swamp deposit, Alluvial deposit, and talus / terrace deposits.

River Deposit (rd)

It is distributed in the river bed that consists of sand and gravel with clay. Gravel consists of various well-rounded andesites and basalts of boulder to granule. The river deposit mainly consists of sand and clay without gravel, downstream part of the River.

Swamp Deposit (sd)

It is distributed near the lakes of Olomega and Jocotal and mainly composed of clay with organic matter. It forms a soft ground.

Alluvial Deposit (al)

It is distributed in the areas from San Miguel City to Lake Olomega and from El Delirio to the river mouth. It originates in floodplain deposits that mainly consists of fine materials of clay and sand, and locally consists of gravel transported by large floods. It is unconsolidated sediment and easy to become muddy or swampy during the rainy season.

Talus and Terrace Deposits (ta)

Talus deposit is mainly distributed on the mountain foot, and terrace deposit is distributed on the river side.

Talus deposit consists of clay, sand, and gravel that is angular to sub-angular of various sizes and rocks.

Terrace deposit consists of sand and gravel with clay.

Both deposits are unconsolidated sediments and their soundness are better than alluvial deposit.

Cone Deposit (cd)

It is distributed only in the San Miguel Volcano, Usulutan Volcano, Lake Aramuaca and other small volcanic craters formed by recent volcanic activities of San Salvador Formation. It is composed of unconsolidated pumice, scoria grains, and volcanic ash that fell on and covered the original ground.

Lava flow (La)

Lava flow is classified independently from each formation because of its usefulness for construction materials and/or its high permeability. Any formations of various geological ages have had lava flow consisting of dacite, andesite, and basalt. Lava has various lithological phases as follows:

- hard and fine rock for the central part of lava flow,
- chilled marginal rock, and
- polus rock and/or agromelatic rock of marginal part of lava flow.

Hard and fine lava is useful for construction materials, however, porous rock and/or aglomelatic rock are troublesome for dam foundation due to its high permeability. Lavas are widely distributed in the Study Area. It has been observed that lava flow had dammed up the river and changed its course in the past.

Pyroclastic Flow (Py)

Pyroclastic flow, intercalated with lava, consists of fine tuff, lapilli tuff, tuff breccia, volcanic breccia, and vitric tuff like welded tuff at Agua Zalca Village. These rocks are consolidated excluding fine tuff.

Mud Flow (Md)

Mud flow is formed by the volcanic eruption with a large volume of water. It was fluid material, and easy to flow farther from the volcanic crater than pyroclastic flow. It is normally distributed in the mountain foot and has a tendency to form gentle slope. Also, it is not well consolidated and is easily be eroded by heavy rainfall.

Ignimbrite (Ig)

Ignimbrite was self-welded in a high temperature volcanic ash flow caused by the eruption. The activity of Ignimbrite occurred in Cuscatlan Formation, and it is distributed near Lake Aramuaca and El Delirio. Ignimbrite contains various stages of weld from fragile to hard. But all Ignimbrite have a high internal angle in spite of different shear strength with a tendency to form cliffs. Ignimbrite exposed at El Delirio is possible to excavate by large back-hoes.

Volcanic Rocks (Vb)

From the viewpoint of rock soundness and depending on its consolidation, Volcanic rocks are classified as the old volcanic rocks of Balsamo, Chalatenango and Morazan Formation, and the new volcanic rocks of San Salvador and Cuscatlan Formation. These volcanic rocks are mainly distributed in the upstream part of the Basin and the coastal mountain ranges. They are well consolidated compared with the new volcanic rocks because of their long diagenesis. They consist of tuff breccia, volcanic breccia, and lava covered with the new volcanic rocks.
A surface parts of the rocks are weathered and fragile, but fresh part is hard and the use of dynamite is necessary to excavate.

4. Engineering Geology

Engineering property of each deposit and formation are summarized below.

Table A.2 Engineering Property

Geology	Lithology	Soundness	Excavation	Slope height / Gradient	Production of sediment	Construction materials
Recent river deposit	sand, gravel, clay	soft (loose)	backhoe of larger than 1.0 m^3, 32-ton bulldozer	less than 10m, 1:1.0-1:1.2	medium	aggregate, filter
Swamp deposit	clay with organic matter	very soft	backhoe of smaller than 1.0m^3	less than 5m, 1:1.2-1:1.5	big	–
Alluvial deposit	clay,sand with gravel	medium	backhoe of larger than 1.0 m^3	less than 10m, 1:0.8-1:1.2	big	soil (clay)
Talus / Terrace deposit	clay, sand, and gravel	stiff - very stiff	backhoe of larger than 1.0 m^3, 32-ton bulldozer	less than 15m, 1:1.0-1:1.5	big	soil (clay)
Cone deposit	scoria, lapilli tuff	soft (loose)	backhoe of larger than 1.2m^3	less than 10m, 1:1.0-1:1.2	medium	subgrade material
Lava flow	dacite, andesite, and basalt	hard rock, partly soft	dynamite, partly 32-ton bulldozer with ripper	more than 15m, 1:0.3-1:0.8	small	aggregate, rock
Pyroclastic flow	fine / lapilli / vitric tuff, tuff / volcanic breccia	soft rock	backhoe of larger than 1.2 m^3, 32-ton bulldozer	more than 15m, 1:0.5-1:1.2	small	subgrade material
Mud flow	volcanic ash with accidental gravel	stiff - very stiff	backhoe of larger than 1.2 m^3, 32-ton bulldozer	less than 15m, 1:1.0-1:1.5	medium	soil (clay)
Ignimbrite	welded tuff	soft rock, partly hard	32-ton bulldozer with ripper	more than 15m, 1:0.3-1:0.8	small	subgrade material
Volcanic rocks	old rocks of tuff breccia, volcanic breccia	soft to hard rock	32-ton bulldozer with ripper, partly dynamite	more than 15m, 1:0.3-1:0.8	small	subgrade material

They can be excavated mostly by normal back-hoe and or bulldozer with ripper. Dynamite is necessary to excavate lava and some part of Volcanic rocks. Sandy clay and clayey sand of Alluvial deposit, which are located along the San Miguel River and Alluvial plain, can be used for construction material of embankment.

5. Activity of Quaternary Fault

Big faults caused by the structural movement do not exist in the Study Area. Besides, there are many faults in the Study Area caused by the volcanic eruption in the Quaternary period. Volcanic eruption releases a huge volcanic materials, and forms ground subsides as a result. At that time, faults were formed here and there in the Quaternary period. These faults are not continuously active. In other words, they were active just after the volcanic eruption.

There are many photo lineaments, which might be quaternary faults, in the Study Area judging from the aerial photograph interpretation (refer to Figure A.3). But, photo lineament do not exist within the distance of 300 meters from the planned dam site. Large photo lineaments having a length more than 10 km do not exist within a circle with the radius of 10 km from the planned dam site. There is a big photo lineament at the north with approximate 15 km away from the planned dam site which has a length of about 10 km. However it is not a fault and corresponds partially with the lithological boundary. Consequently, dam planning is not affected by the existence of Quaternary faults that might move and make a occurrence of earthquake.

6. Sediment Production

Factors influencing the production of sediments are,

a) size of catchment area,
b) geological condition ; lithology, weathering condition, and rock-fall and landslide,
c) topographical condition ; altitude, undulations, and slope inclination,
d) vegetation,
e) characteristic of rainfall,
f) hydraulic characteristics of rivers, and
g) human activities; deforestation, reclamation, construction, etc.

There is not a large landslide, rock-fall, and devastated and bare land. There are seven rock-fall sites in the Study Area. Every site is an area of 0.5 to 0.9 km^2 and total is about 4.5 km^2. It only 0.2 % of the Study Area of 2,247km^2. It is small to consider as main source of sediment runoff.

Recent river deposit, swamp deposit, Alluvial deposit, talus deposit, terrace deposit, cone deposit, and mud flow are unconsolidated formations and they are easy to be eroded. In other words, they have a possibility to become a source of sediment runoff.

Recent river deposit, swamp deposit, alluvial deposit are distributed in a flat land. Sediments of these formations occur only at river banks.
Talus deposit, terrace deposit, cone deposit, and mud flow are distributed in a gentle slope. and greater part of the exposure of these formations is also covered by grass with trees, and utilized for farm and pasture land.
Consequently, sediment runoff is not large, under the present condition of the Study Area excluding mud flow area and some farm lands with poor vegetation like Heneken field.

Recommendation

Main sources of sediment are talus deposit, terrace deposit, cone deposit, and mud flow in a case of heavy rainfall, especially on the Heneken field. Main elements of erosion and sediment are the strength of rainfall and vegetation. To mitigate sediment production, reforestation shall be conducted in the areas of talus deposit, terrace deposit, cone deposit, and mud flow. Future land use on a gentle slope is recommended the agro-forest. Forest can mitigate a erosion by heavy rainfall. And also, river bank and bed protection works shall be considered in these areas.

7. Geological Condition Along the River

This clause aims to provide a basic data of geological condition for the planning of river improvement.
The result are shown in the following Table A.3 and attached Figures A.4, A.5.

Table A.3 Geological Condition Along the River

Soil Exposure		Rock Exposure	
Section	Soil Type.	Section	Rock Classification
184 ~ 134	sand, gravel	182 ~ 180	soft rock (pyroclastic flow)
134 ~ 124	sand	170	soft rock (pyroclastic flow)
124 ~ 104	sandy clay	166 ~ 165-30m	hard rock (lava)
104 ~ 96	sand, gravel	162+200m	soft rock (conglomerate)
96 ~ 92	sand	104	soft rock (volcanic breccia)
92 ~ 66	clay (swamp)	103+300m ~ SM102+300m	hard rock (lava)
66 ~ 58	sandy clay	SM102+300m ~ 97-480m	soft rock (ignimbrite)
58 ~ 31	sand	96	soft rock (Ignimbrite)
31 ~ 23	sand, gravel	58+100m ~ 56-350m	soft rock (volcanic breccia)
23 ~ 10	clayey sand	54 ~ 54-350m	soft rock (volcanic breccia)
10 ~ 3	sandy clay	30	soft rock (conglomerate)
3 ~ 1	clay	29+15m	soft rock (volcanic breccia)
		24+35m	soft rock (conglomerate)
		(OL1+300m)+180 ~ OL1+490m	soft rock (volcanic breccia)
		OL1+650m	soft rock (volcanic breccia)

Olomega channel : sandy clay, clay (swamp deposit)
Jocotal channel : sandy clay, clay (swamp deposit)

The classification of rock and soil soundness and recommended method of excavation are summarized in Table A.4.

Table A.4 Classification of Rock and Soil Soundness

Classifi-cation	Geology	Lithology	Soundness	Method of excavation	Slope height Gradient
Hard rock	lava	dacite, andesite, basalt	hard rock, partly soft	dynamite, partly 32-ton bulldozer with ripper	>15m 1:0.3-0.8
Soft rock	weathered lava, ignimbrite, pyroclastic flow, volcanic rocks	fine/lapilli/ vitric tuff, tuff breccia, volcanic breccia	soft rock, partly hard	backhoe of more than 1.2m^3 with breaker, 32-ton bulldozer, partly dynamite	>15m 1:0.8-1.2
Sand	recent river, Alluvium, talus, terrace	sand, sand with gravel, clayey sand	loose to medium	backhoe of more	<15m 1:1.0-1.2
Clay	Alluvium, talus	clay, sandy clay	medium to soft	than 1.0m^3	<10m 1:0.8-1.2
Soft clay*	swamp	clay with organic matter	very soft	backhoe of less than 1.0m^3	< 5m 1:1.2-1.5

* : There is a possibility of land subsidence caused by a consolidation.

Details are described in the cross sections and profiles attached hereafter.

8. Construction Materials

Sandy clay, clayey sand, and sand (locally with gravel) of Alluvial deposit, which distribute along the San Miguel River and Alluvial plain, can be used for construction material of embankment. Their relative engineering properties are shown in the following table.

Soil	Water content	Density	Cohesion	Friction angle	Workability
Sandy clay	high	small	large	small	bad
Clayey sand	high-medium	small	medium	medium	medium
Sand (with gravel)	low	large	small	large	good

However, there are two problems to be solved mainly to utilize alluvial deposit for an embankment material. One is a water content and another is a particle size distribution.

Problem for construction management

Sandy clay and clayey sand are mainly composed of volcanic ash and volcanic glass, their water contents are supposed to be high. It means that optimum water contents of them will be high, and compacting work shall be taken care to keep an optimum water contents in the dry season. On the other hand, workability is low in rainy season because of composition of fine materials and high water content. Stability and strength of embankment is not expected due to difficulty in sufficient compacting work.

Problem of Strength

Particle size distributions of sandy clay, clayey sand, and sand (locally with gravel) are not suitable for embankment material. Because they are well sorted deposits in nature. Strength of soil is mainly determined by natural compacting and a combination of cohesion and internal friction angle. Strength and water content are characterized by a ratio of fine material to coarse material. Strengths of compacted each soil are not expected.

Recommendation

It is necessary to adjust particle size distribution by blending sandy clay and or clayey sand (fine materials) with sand (coarse materials). Blending is effective to solve the problems of high water content and bad particle size distribution. Water content of blended materials will decrease and also strength of compacted materials will increase. It can simplify the construction and compacting management.

Before commencement of the construction work, soil test in laboratory and in-situ tests of blending and compacting shall be conducted to grasp the characteristics of embankment materials.

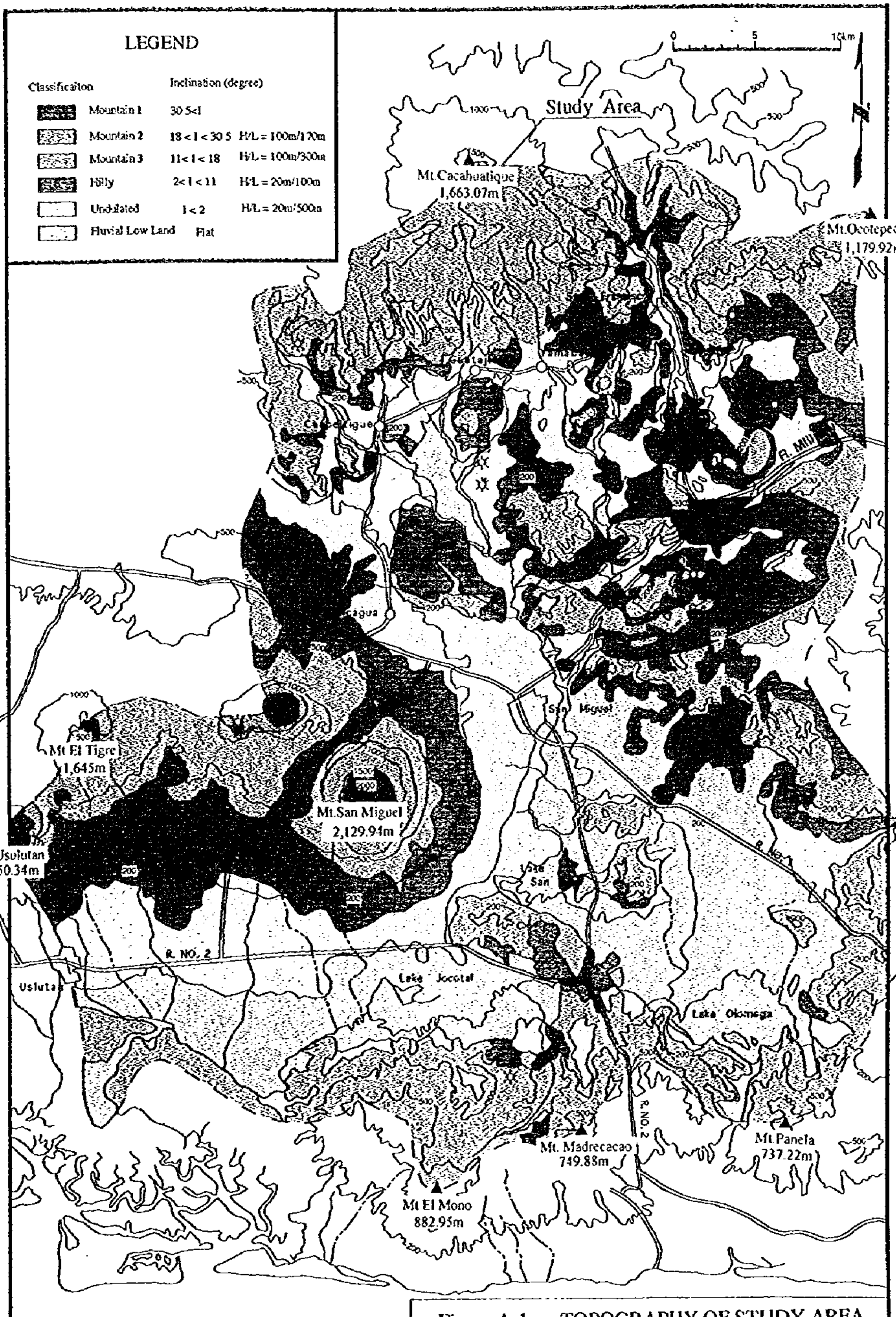

Figure A.1 TOPOGRAPHY OF STUDY AREA

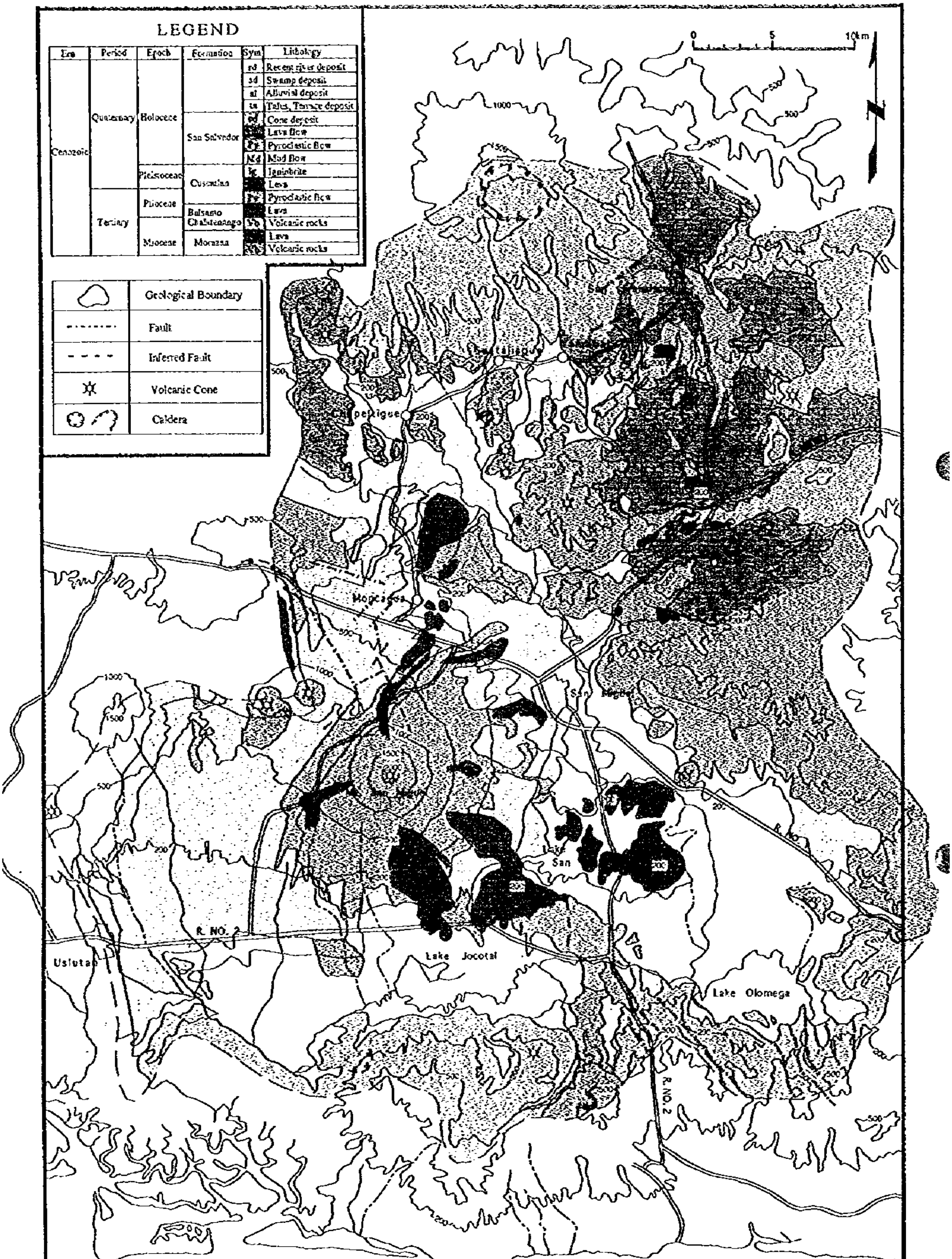

Figure A.2 GEOLOGY OF STUDY AREA

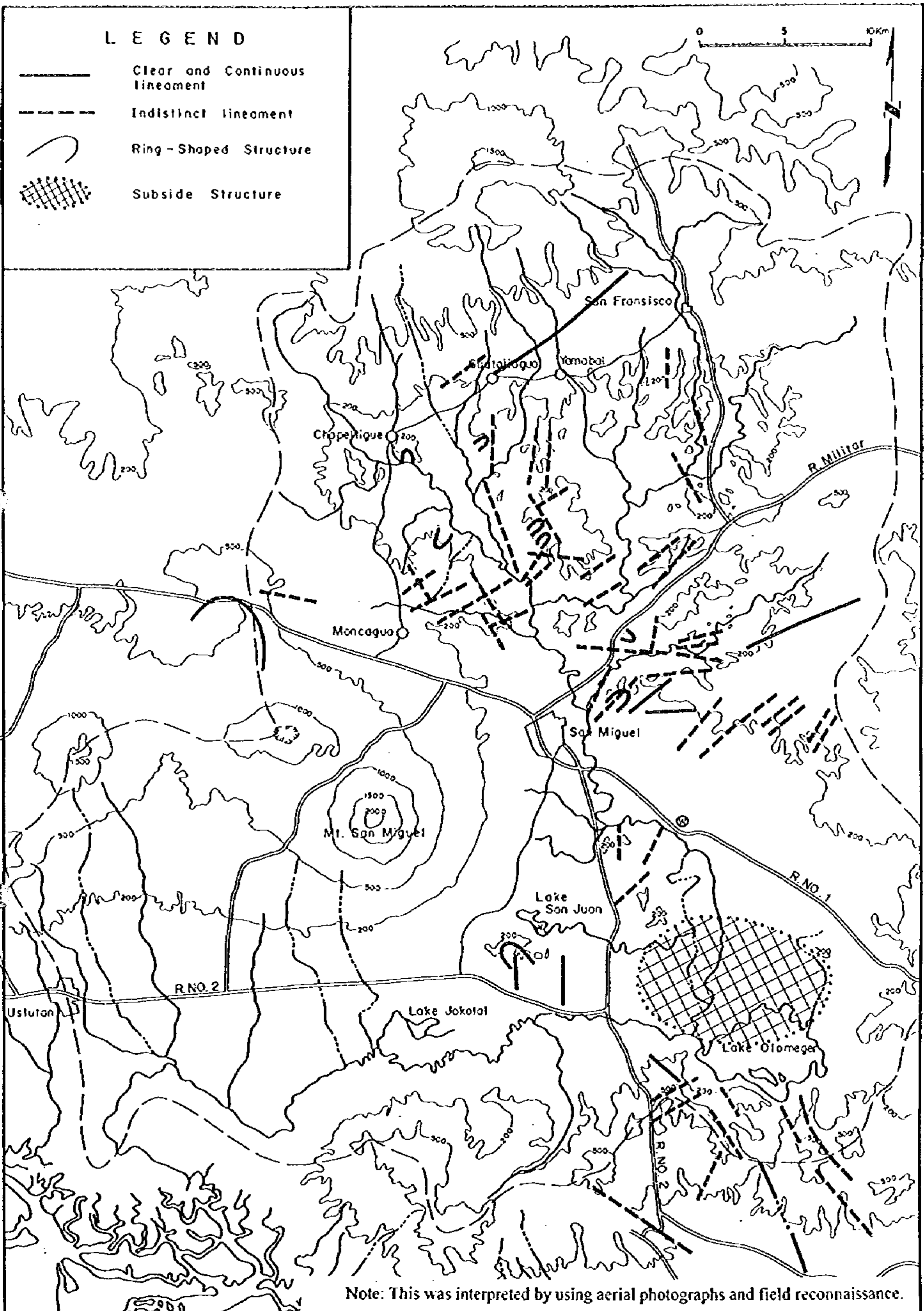

Figure A.3 GEOLOGICAL STRUCTOR OF STUDY AREA

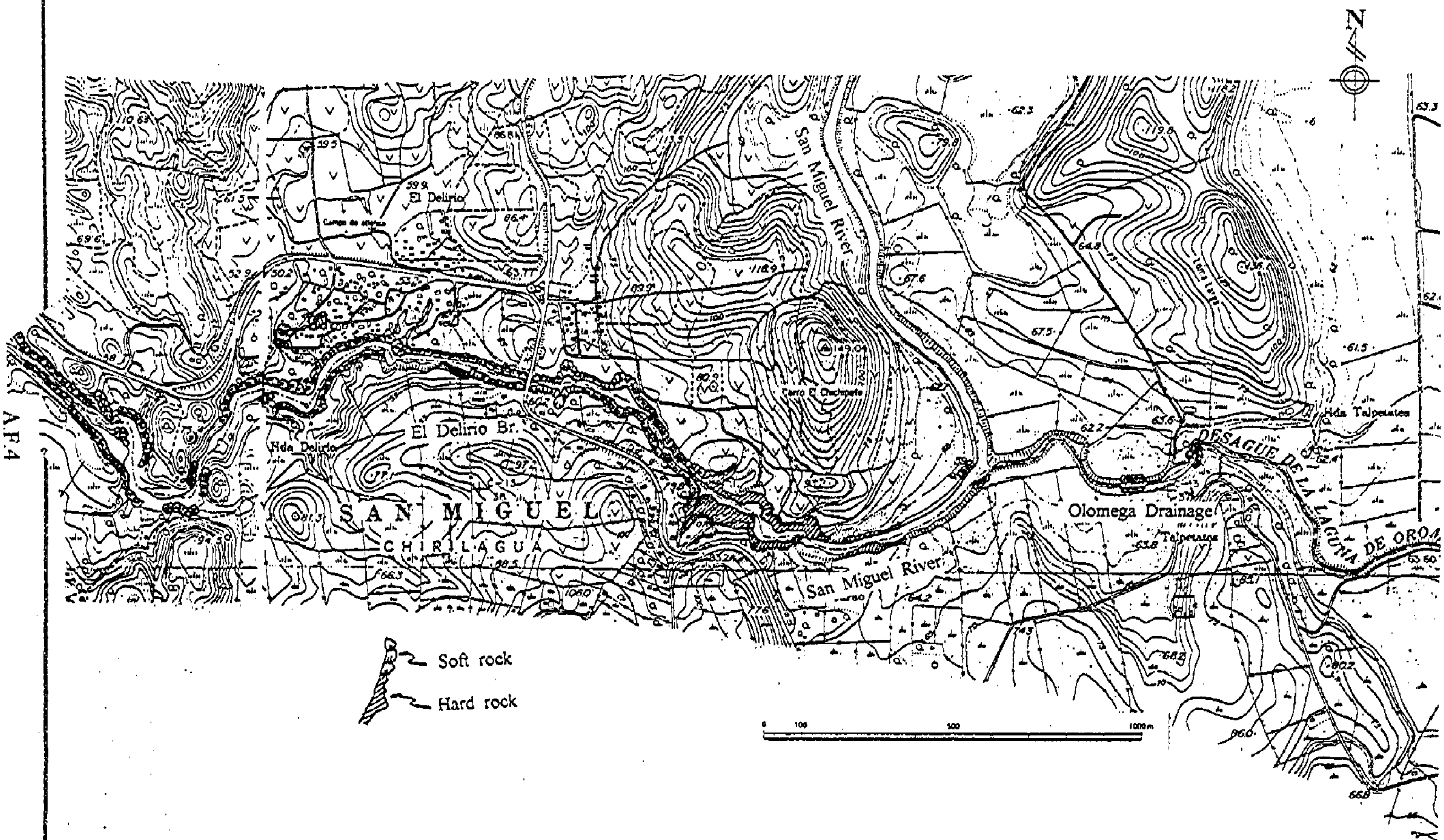

Figure A.4 LOCATION OF EXPOSED ROCKS: EL DELIRIO

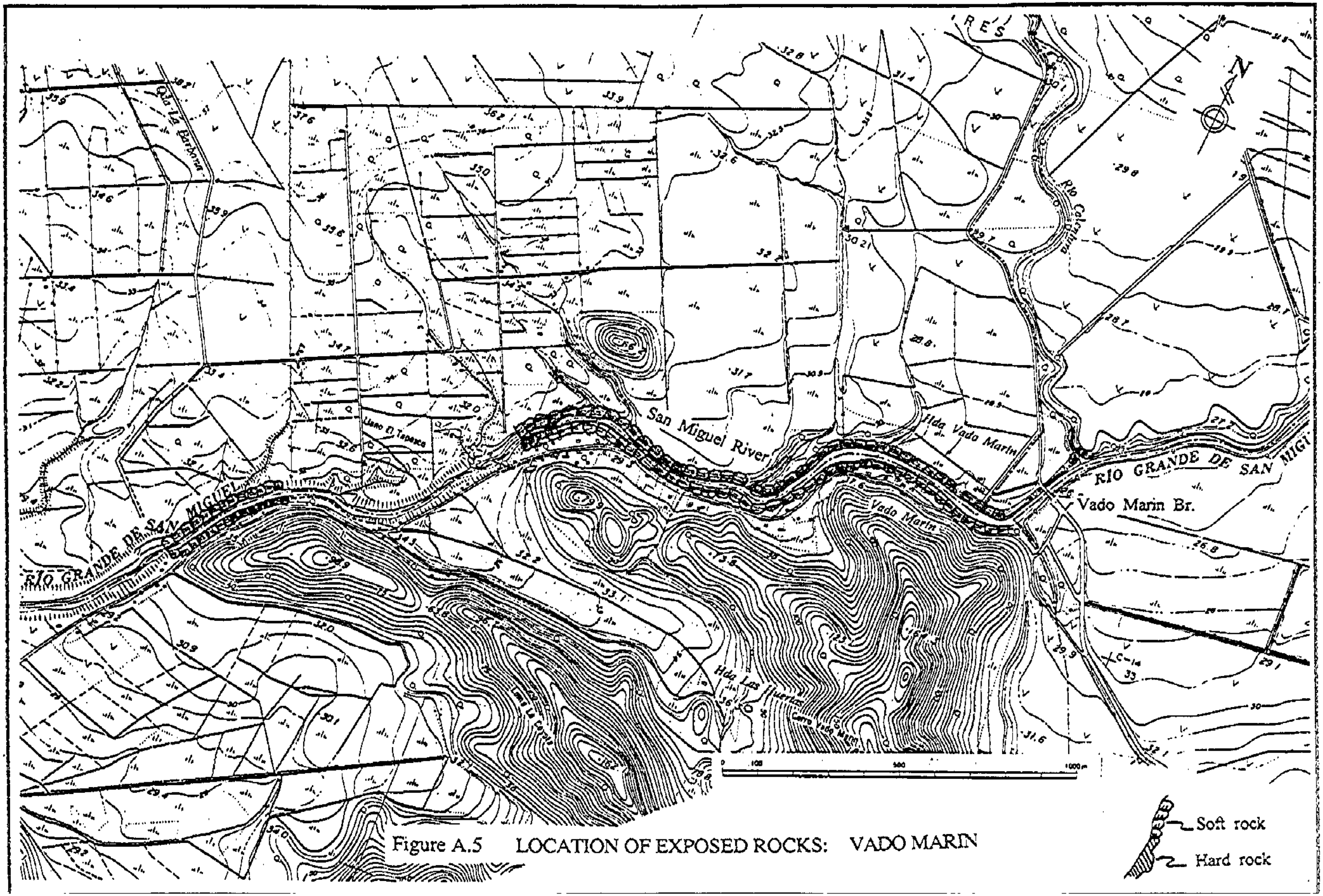

Figure A.5 LOCATION OF EXPOSED ROCKS: VADO MARIN

SUPPORTING REPORT

B: METEOROLOGY AND HYDROLOGY

Supporting Report B: Meteorology and Hydrology

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B: METEOROLOGY AND HYDROLOGY

1. METEO-HYDROLOGICAL DATA

1.1 Meteorological Data

Meteorological observations such as temperature, relative humidity , rainfall have been carried out by MAG at 3 meteorological observatories, San Francisco Gotera, El Papalon and Santiago de Maria in and around the Study Area as shown in and Figure B. 1 and Table B. 1.

1.2 Rainfall Data

There exist 21 rainfall stations excluding the above mentioned 3 meteorological observatories in and around the Study Area at which the daily rainfall amount has/had been observed at 7 o'clock every morning by MAG. The locations and the list of the above stations are shown in Figure B. 1 and Table B. 2, respectively.

Short duration rainfall observation has been conducted at the 3 meteorological stations and the 5 rainfall stations such as Beneficio La Carrera, Jucuaran, Hacienda San Jose, Sesori and Corinto. At 8 stations, annual maximum 5 minutes to 6 hours rainfall have been calculated by MAG.

The observations at the 21 rainfall stations were discontinued in 1980's.

1.3 Waterlevel And Discharge Data

In the Study Area there used to be 8 stream gauging stations operating (refer to Figure B. 2) Since 1995, only Vado Marin and Villerias have been functioning among them (refer to Table B. 3).

Waterlevel at the above stations has / had been recorded by automatic recorders. The recorded waterlevel is reserved as analog data on diagram.

Puerto Viejo station, that located at the southern part of Lake Olomega bank, was measuring waterlevel of Lake Olomega.

The waterlevel data of Lake Jocotal is not available.

Discharge measurement is carrying out at every station, except for Puerto Viejo, once a month using current meter by MAG. Discharge rating curve for converting waterlevel to discharge is made periodically by using the discharge measurement records.

1.4 Tidal Data

The lower reach from Las Conchas has gentle river bed slope. The fluctuation of tide level affects the flood waterlevel along the lower reach.

In 1996 there is one tide observatory at Cutuco (La Union) in El Salvador. Daily tide tables at Cutuco, La Libertad and Acajutla Port are published in Almanaque de Mareas by IGN every year.
The locations of these ports are shown in Figure B. 3.
Near the mouth of the San Miguel River there is El Triunfo Port, of which tide elevation can be estimated from the data of Cutuco.

2. HYDROLOGICAL MEASUREMENT

2.1 Rainfall

(1) Installation of raingauges

Figure B. 1 shows the locations of rainfall gauging stations in May, 1995. It can be found that around the lakes of Olomega and Jocotal, there is no rainfall station available.

Around Lake Olomega and Jocotal, it is recommended that raingauges are installed at Sta. Olomega (code N1) and Sta. Jucuaran (U13) near Lake Jocotal. Especially, Sta. Olomega is very appropriate to install because it had daily data continually since 1927.

The Study Team installed 2 rainfall gauges at Sta. Olomega and Sta. Jucuaran in 1996.

The installed rainfall gauges are self-recording rainfall gauges, which can continue measuring for 90 days with 1 roll of paper.

The maintenance will be carried out by MAG.

(2) Results

In order to examine the accuracy of manually measured data, the daily rainfall data by the self-recording gauges were compared with the simultaneously manually measured data by MAG. (Refer to Figure B. 4)

For both Jucuaran and Olomega stations, the locations of the manual gauge and the self-recording gauge are within 20m distance.

Olomega station(station code: N1)
The manually measured data were very well coincided with the self-recorded data. It is said that the person who is in charge of the manual measurement has been trained by MAG.

Comparison of monthly rainfall in mm at Olomega station in 1996

	September	October	November	Total
Self-recording(A)	303.0	304.5	85.0	692.5
Manual(B)	309.6	302.4	66.3	678.3
B/A	1.02	0.99	0.78	0.98

Jucuaran station(station code:U13)
The manually measured data were not so coincided with the self-recorded data from July 17 to August. The person who is in charge of the manual measurement has not been trained.

Comparison of monthly rainfall in mm at Jucuaran station in 1996

	July (16-31)	August	September	Total
Self-recording(A)	349.0	245.0	414.0	1008.0
Manual(B)	270.4	334.2	415.6	1020.2
B/A	0.77	1.36	1.00	1.01

The corelatious between manual recorded and self-recorded data at these stations are shown in Figure B. 5.

2.2 Waterlevel

(1) Installation of staff gauge

In the Study Area there used to be 8 stream gauging stations but only Vado Marin and Villerias among them are functioning at present. The remaining 6 stations are also recommended to start measurement again as soon as possible.

In order to study flood condition in detail in the Study Area, water level data at La Canoa, Las Conchas, Puerto Viejo and Lake Jocotal are needed.

At the following locations except for Lake Jocotal, where measurement had been suspended, staff gauges were reinstalled by the Study Team to resume measurement. Lake Jocotal, at which lake level had not been measured so far, was selected as an installation site because the data would be necessary for the flood control in the future.

Station Name	Name of colony	Operation
Puerto Viejo	Puerto Viejo	Started at June,1996
Lake Jocotal	El Borbollon	Installation completed
La Canoa	La Canoa	Installation completed
Las Conchas	Las Conchas	Installation completed

Material
Staff gage made of steel (length of 1 piece equal to 1.0 m with 0.1 m width) was used.

For the manual gage with staff gage, a scale was set so that a portion of it is immersed in the water at all times. The gage consists of a vertical scale attached to a structure that extends into the low-water channel of the stream.

(2) Measurement result

At Puerto Viejo the water level measurement started at the beginning of June 1996. The observed water level ,which was already converted to elevation above MSL, was shown in Figure B. 6.

2.3 Discharge

At La Canoa and Las Conchas , at which stream gauges were going to be newly installed within 1996 by MAG, discharge measurements were undertaken on June 10th, 1996.

Measurement items are as follows,

The river depth and river width at the cross sections near La Canoa and Las Conchas were measured using wire cable and measuring tape. Velocity was measured at using a current meter. The spacing between velocity measurements was at most 4 meters. The depth at each vertical point was measured using the cable or measuring rod. The number of velocity measurement at each vertical is as follows;

0-0.25m depth	1 point (at surface)
0.25-0.65 m depth	1 point (at 0.6 depth)
over 0.65 m depth	2 points (at 0.2 and 0.8 depth)

Measurement tools are as follows;

Velocity	Digital Current meter
Depth	Steel bars with scale
Width	Wire cable

The current meter contains a rotating element whose speed of rotation is proportional to the water velocity.

Discharge calculation

The discharge calculation was based on velocity-area method. Partial discharge for each measurement was computed and total discharge by summing the partial discharges for all segments was calculated.

(2) Measurement results

The results of June 10, 1996 measurement are as follows,

Location	Flow area (m^2)	Discharge(m^3/s)	Mean Velocity (m/s)
La Canoa	36.3	12.7	0.35
Las Conchas	40.4	32.6	0.81

3. METEOROLOGY

Climate of El Salvador which is a part of Central America is dominated by monsoons. During dry season, dry and cool air flows from land to warmer ocean and precipitation over the land is slight. During rainy season, moisture-laden air flows from ocean toward warmer lands, causing heavy rains due to the uplift air motion.

The distinct dry season prevails, when the monthly rainfall is less than 60 mm and it lasts for more than 2 months. Because tropical rain forests cannot survive this drought, the drought-resistant deciduous trees prevails.

The country is also subject to the tropical transient air circulation, i.e., depressions and tropical storms. Cumulonimbus clouds generated by intense air convection cause heavy rains of short duration. Tropical cyclones are the most energetic transient weather system of the tropics. Hurricane is an intensive tropical cyclone with wind velocity of more than 33 m/s.

In reference to the height over sea level, the country is divided into three climate zones according to Koppen, etc.

from 0 to 800 m above MSL, hot tropical savanna or hot land;
from 800 to 1,200 m above MSL, warm tropical savanna or moderate lands
from 1,200 to 2,700 above in MSL, high tropical climate.

The San Miguel River basin has an average elevation of 279.58 m above mean sea level; in other words, the 50% of its surface has an elevation under this mark. In general terms, the basin can be classified as a hot tropical savanna or hot land.

Monthly variation of temperature, humidity and rainfall in the basin is shown in Table B. 4, selecting some stations; one at El Papalon located in the central part of the Study Area and another at San Francisco Gotera in the upper basin.

Monthly averaged temperature on the coldest month is over 18℃ in the Study Area and it has rainy and dry seasons. Based on this criteria, The Study Area belongs to Tropical Savanna (Aw type climate).

Annual average temperature in the basin is 26.9℃ at El Papalon and 26.4℃ at San Francisco Gotera. On an average, the maximum temperatures are seen in April with values of 29.0℃ and 28.6℃ at El Papalon and San Francisco Gotera respectively, while the minimum temperatures are 25.8℃ in December and 25.3℃ in September correspondingly. The secondary peak of temperature is observed in July or August. (Refer to Table B. 4)

Throughout a year, the average and minimum relative humidity ranges form 58% to 82% at El Papalon and from 53% to 80% at San Francisco Gotera, respectively. The humidity does not show a significant difference between the two stations. They have two peaks in June and October, and the minimum value in January shows a similar tendency to the monthly rainfall patterns. (Refer to Table B.4)

At El Papalon, south wind predominates in the months from March to June and September to October. North wind predominates in other months. At San Francisco Gotera, north wind prevails throughout the year. During a day, the north-east wind occurs in the morning and the south wind in the afternoon.

Evaporation has been measured by MAG using class A pan at San Francisco Gotera, El Papalon and Sesori. At El Papalon, annual evaporation reaches 2,400mm. The maximum evaporation takes place in March, which is the end of dry season. The other 2 stations have the lower amounts of annual evaporation because they are located in the higher area.

Rainfall is the most distinctive climatic features of the basin, having a clear rainy season from May to October and a dry season for the rest of the year.

SEASON	STARTS	ENDS	LENGTH in weeks
Dry Season	Beginning of November	Midst of April	24
Dry-Wet Transition	Midst of April	End of May	6
Wet Season	End of May	Midst of October	19
Wet-Dry Transition	Midst of October	Beginning of November	3

Beginning of rainy season is associated with "Waves of the East", which are atmospheric zones of strong instability that transports from East to West crossing the country and electric storms and rainfalls in downpour ways. The rainy season starts two or three weeks later in the South East Region than in the Central and North West Regions.

In June the first maximum rainfall activity arises. The rainfall in May is attributed to the influence of the Waves from the East, and rainfall in June increases due to the combination of two most important phenomena in the production of rainfall in the tropics; the Waves from the East and Intertropical Convergence Zone (ITCZ). The ITCZ makes its first incursion to El Salvador in June, causing atmospheric situations called "Temporale" characterized by rainfalls not so much intense, but intermitted, occurring at any hour of the day.

The "dogs day" (caniculas in Spanish) cause diminution or significant interruptions of rainfall in July and August. They are the events caused by the dominion of decreasing atmospheric currents, which neutralize cloud formations that produce rainfall.

September has usually the heaviest rainfall of year. Again the Waves from the East and the Intertropical Convergence Zone are combine in order to favor rainfall during any hour of the day. The fact that September has heavier precipitation than June (which is the month having another rainfall peak), is due to the ITCZ which is closer to El Salvador in September rather than June. This allows ITCZ to enter easily the coast region in the Pacific Ocean, and then, to cause precipitation of greater magnitude showing the "storm days"

Dry season usually begins in major part of the country in the first days of November, delaying until fifteen days in the East Region of the country and from the Fonseca Gulf. The "Winds" that usually occurs in the months of November, December, January and February, can blow until 15 days or more, without interruption, reaching speeds up to 100 km/h in the mountainous zones.

4. HURRICANE

The rainfall types which would cause flooding in the Study Area are (1) hurricane and tropical storm coming from the Caribbean Sea, (2) tropical shower with high intensity, and (3) continuos rainfall with medium intensity.

Historically heavy storms have been brought in the basin especially when hurricanes passed by the basin in Caribbean Sea or Pacific Ocean.

The hurricane "Francelia" ,which passed by the basin in Caribbean Sea, influenced the 1969-flood and resulted in the recorded maximum discharge at Moscoso on September 4,1969.

The hurricane "Gilbert" , which passed by the basin in the Caribbean Sea, affected 1988-flood and brought about the recorded maximum 7-day rainfall at San Francisco Gotera and the second maximum at El Papalon on September 16,1988. The 1988 flood is one of the largest flood in the basin.

In 1988 the hurricane "Juan" also passed through the basin on October, however , heavy rainfall was not brought in the basin like "Gilbert".

In 1996 the basin had the hurricanes named "Cesar" and "Douglas" from the end of July to the beginning of August.

Hurricane "Cesar" caused at least 51 deaths and considerable destruction along its path through the southern Caribbean Sea and Central America. "Cesar" crossed Nicaragua and moved into the eastern North Pacific where it reintensified and became Hurricane "Douglas". Most of the deaths were attributed to heavy rainfall which caused flash flooding and mudslides. The death total includes 26 people in Costa Rica which was not in the direct path of the hurricane but was hit by floods and mud slides.

The "Cesar" and "Douglas" brought heavy rainfall also to the basin, especially in the Lower Basin of the San Miguel River. At Jucuaran rainfall station in the lower basin, 273.5 mm of daily rainfall was recorded on July 28-29, when the Hurricane "Cesar" just pass by the basin and moved to the Pacific Ocean.

According to the tracks of Hurricanes "Francelia" and "Gilbert" shown in Figure B. 7, the date of inundation happened to be the transition period from hurricane to tropical storm.

5. RAINFALL

5.1 Variation In Area

Figure B. 8 shows the isohyetal map of annual rainfall over the basin. The mean annual rainfall is 1,431 mm at El Papalon and 2,048 mm at San Francisco Gotera. (Refer to Table B. 4). The concentration of rainfall amount is predominant in the north part of the basin, mainly in the surroundings of San Francisco Gotera, with an annual average of 2,048 mm of precipitation; decreasing in the central region, between the volcano slopes and San Miguel City with an annual average rainfall of 1,539 mm.

Basin averaged annual rainfall is 1,673 mm and the sub-basin averaged annual rainfall in Upper , Middle and Lower basins are 1,792 mm, 1,556 mm and 1,635 mm respectively.

The rainfall variation in area was studied making areal reduction curves of 1 day and 7 days.

The rainfall amount at San Francisco Gotera was selected as a point rainfall and the corresponding averaged rainfall amount in area was calculated by Thiessen Polygon method.

The curves are shown in Figure B. 9 and Figure B. 10.

In the case of 1 day rainfall, the ratio of basin averaged rainfall to point rainfall ranges from 0.3 to 0.7. The rainfall of September 16, 1988 was one of the most widely distributed rainfall in area.

In the case of 1 day rainfall, up to the accumulated area of 1,000 km^2 the ratio decreases steeply and from 1,000 km^2 to the whole basin the ratios do not decrease as the area increases. The catchment area of 1,000 km^2 is corresponding to upper basin of the area.

In the case of 7 day rainfall, the ratio of basin averaged rainfall to point rainfall ranges from 0.5 to 1.4. The rainfall of September 10-16, 1988 was one of the most concentrated to the upper basin.

5.2 Variation In Time

The maximum monthly rainfall takes place in September followed by the secondary peak in June. During the rainy season, there is a period of relatively small rainfall from July to August. About 95 % of the annual rainfall concentrates in rainy season from May to October. The minimum rainfall occurs in January.

Rainfall in a day has a tendency to occur in the afternoon and night time. According to the rainfall records observed 3 times a day at San Francisco Gotera in 1995, 66% of rainfall events were recorded during 7 hours from 14:00 to 21:00 and 97% during 17 hours from 14:00 to 7:00 in the morning as shown below. Rainfall is rare in the morning and noon time. The same kind of data at Santiago de Maria has also a similar nature, though it is distributing more evenly.

(Frequency of Rainfall Time in a Day in 1995)

Station	7:00-14:00(7hrs.)	14:00-21:00(7hrs.)	21:00-7:00(10hrs.)
San Francisco Gotera(Z2)	3% (0.4%/hr)	66% (9.4%/hr)	31% (3.1%/hr)
Santiago de Maria(U6)	16% (2.3%/hr)	46% (6.6%/hr)	37% (3.7%/hr)

5.3 Major Events Of Rainfall

The annual maximum rainfalls by duration at Santiago de Maria, El Papalon and San Francisco Gotera were summarized in Table B. 5, Table B. 6 and Table B. 7 . The basin averaged rainfall was obtained using Thiessen Polygon method based on the 3 rainfall stations as shown in Table B. 8

The maximum daily rainfalls at the 3 stations are the following.

Station	1 day rainfall	Date	Period
San Francisco Gotera	122.2 mm	Sep.16,1988	1964-1995
Santiago de Maria	232.1 mm	Sep.20,1974	1963-1995
El Papalon	221.6 mm	Sep.16,1988	1964-66,1970-1995

The rainfalls of September 1988 are recorded as one of the most serious events of rainfall in the Study Area. At this time the most severe flooding took place in the Study Area.

Figure B. 11 shows daily rainfall during August to October in 1988 at 4 stations and Figure B. 12 shows mass curves of daily rainfall depth during September 10-16, 1988.

The rainfall peak of the 1988 flood occurred at the latter portion of the hyetograph, which is apt to heighten the runoff peak more.

Figure B. 13 shows isohyet lines of rainfall during September 10-16,1988. The larger amount of rainfall concentrates in the Upper basin.

5.4 Probable Rainfall

Probable rainfalls were calculated for the following return periods and stations.

Return Period: 2,5,10,20,50,100 and 200 years
Duration Time: 6 hours, 1,2,3,4,5,7,14 and 30 days
Station: San Francisco Gotera, El Papalon and Santiago de Maria plus Basin averaged

These 3 stations were selected because they have continuous daily rainfall data for over 30 years.

The frequency was evaluated using Log-normal probability paper. The Thomas plotting method was used.

In the case of 1 day rainfall, the amounts at El Papalon are larger than the other 2 station's even though it is located in the middle basin, however, in terms of 7 days rainfall the amounts at Santiago de Maria are larger than those of the other station's. (Refer to Table B. 9)

6. MONTHLY FLOW

Monthly discharges at stream gauge stations generally become the largest in September or in October. Especially at Vado Marin and Las Conchas the maximum monthly discharges take place in October. (Refer to Figure B. 14)

The monthly discharges in July slightly decrease compared with those in June , which correspond to reduction of monthly rainfall in July.

The waterlevel at Lake Olomega reaches the highest at October. (Refer to Figure B. 18)

The ratio of annual maximum discharge to annual minimum discharge ,which is generally called coefficient of river regime, is as follows.

Station	Period	Ratio
Villerias	1970-78	649
Moscoso	1963-80	440
El Delirio(La Canoa)	1963-80	184
Vado Marin	1959-80	50
Las Conchas	1970-80	69

In the Upper and Middle basins, the coefficients are over 400, however, in the Lower Basin they are about 50. The high ratios in Upper and Middle basins are mainly due to the existence of rainy and dry seasons and also they reflect fast runoff from the basins. The low ratios from El Delirio to Las Conchas are mainly due to inundation in Lake Olomega area and Lake Jocotal area and also due to groundwater flow to the river from the volcanic area during dry season.

7. FLOOD FLOW

7.1 Major Floods

At the following stream gauging stations in the Study Area, peak discharges and waterlevels are picked up from diagram and reserved as maximum discharges for each month of a year.

Station Name	Recording Period	Years
Villerias	1970,71,73-75	5
Moscoso	1965-1979	15
El Delirio(La Canoa)	1963,64,66,77-79	6
Vado Marin	1959,61-80	21
Las Conchas	1970-74,76-80	10

The annual maximum and minimum peak discharges at each station are summarized in Table B. 10 and Table B. 11, respectively. From Table B. 10, major floods in the past can be selected as follows.

September 1975 flood: The largest discharge recorded at Villerias.

September 1969 flood: The highest water level recorded at Moscoso. However, concerning the converted discharge it is too large compared with other year's discharge of Moscoso, so that it was reviewed.

September 1974 flood: The largest discharge on record at Vado Marin.

June 1980 flood: The highest water level on record at Las Conchas. However, concerning the discharge it is too large compared with other year's discharge of Las Conchas, so that it was reviewed. To consider the review of 1980 flood's discharge at Las Conchas, the September 1978 flood can be estimated to be the largest on record at Las Conchas.

7.2 Ranking Of Flood

Concerning the floodwater volume (maximum monthly volume) during 1959-1980, September 1969 is ranked as the largest at both Vado Marin and Moscoso and October 1973 is ranked as the second on record at Vado Marin.(Table B. 12)

After 1980, there are few discharge data available.

Regarding maximum monthly rainfall during 1959-1990, 1969 is ranked as the largest at San Miguel, however, at the other three stations, the rankings of 1969 are very low. The maximum monthly rainfalls in 1988 and 1989 are ranked as the higher position.(Table B. 13)

The maximum flood in the past was estimated as the following.

Table B. 14 shows annual maximum discharges at Vado Marin and the corresponding basin averaged 7 days rainfall during 1959 and 1980. It can be found that the maximum discharge at Vado Marin took place within a few days after the day when the basin-averaged maximum 7 days rainfall occurred.

If annual peak discharge at Vado Marin and basin averaged 7 days rainfall is selected as evaluation bases for flood, the ranking of floods in the Study Area is as follows,

Ranking of floods in the Study Area

Rank (1)	Rank (2)	Year	Peak Q at Vado Marin	Basin averaged 7 day rainfall
-	1	1988	-	326.8 mm
-	2	1992	-	299.8 mm
-	3	1982	-	285.3 mm
1	4	1974	307.9 m^3/s	271.8 mm
2	5	1969	296.0 m^3/s	-
3	6	1966	289.8 m^3/s	-

Rank(1) is based on annual maximum discharge at Vado Marin between 1959-1980. Rank(2) is based on both annual maximum discharge at Vado Marin between 1959-1980 and the basin averaged 7 day rainfall.

From the above table, September 1988 flood can be estimated to be the largest flood.

Again, after 1980 there is no discharge data available.

7.3 Travel Time Of Flood

Daily discharges and daily hyetographs in 1978 and 1980 are shown in Figure B. 16 and Figure B. 17, respectively. Flood hydrographs can be affected not only by rainfall distribution in time and area but also regional inundation. The hydrographs at Villerias and Moscoso have the rising rimb of 1 to 2 days and also depression of 1 to 2 days. The hydrographs at Vado Marin and Las Conchas have the rising rimb of 2 to 3 days and also depression of 2 to 3 days.

Generally the hydrographs at Vado Marin and Las Conchas are strongly affected by the inundation in the areas of Lake Olomega and Lake Jocotal.

The time lag between the peak at Villerias and the peak at Las Conchas can be seen as 2 to 3 days.

Under the existing condition, a flood flow travels from the upper basin to lower basin approximately 7 days.

8. TIDE

In order to find the respective values for Libertad and Acajutla, it is subtracted from the indicated one for high tide in the table of Cutuco, 26 minutes earlier for La Libertad and 25 minutes for Acajutla. For the minimum tide it is subtracted 3 minutes for Acajutla, meanwhile it for La Libertad is observed at the same time as Cutuco.

The tide of Cutuco comparatively has higher values because the port is situated in Fonseca Gulf. The tide values of El Triunfo, La Libertad and Acajutla are multiplied by 0.85, 0.67 and 0.64 , respectively to the values of Cutuco.

Name of port	Location	Time difference in minute		Height Difference ratio to La Union		MSL above LWL
		High	Low	High	Low	
La Union(Cutuco)	N 13.20. W 87.49	-		-		1.53 m
La Libertad	N 13.29 W 89.19	-26	0	0.67	0.67	1.01 m
Acajutla	N 13.34 W 89.50	-25	-3	0.64	0.64	0.98 m
El Triunfo	N 13.16. W 88.33.	-10	-10	0.85	0.85	1.28 m

In order to estimate Mean High and Low Water Spring at El Triunfo, from the Almanaque de Mareas between 1994-96, the high and low water springs at La Union were selected and converted to the values for El Triunfo as shown in Table B. 15 and Table B. 16.

The mean high and low water spring at El Triunfo is estimated to be 1.39 m and -1.43 m above Mean Sea Level (M.S.L.), respectively.

Review of High Water Spring Tide at El Triunfo Port

The design high water level at the river mouth is set to +1.40 m above mean sea level based on a mean value of high water spring tide at El Triunfo between 1994-1996.

In the basin, during dry season (November to April), no flood event can be expected.

The comparison of high water spring tide between dry and rainy season is as follows. Significant difference is not found among them.

By season	Average of High water spring tide
January-December(all the year)	1.39m above M.S.L.
May-October(rainy season)	1.41m above M.S.L.

9. LAKE WATERLEVEL

9.1 Lake Olomega

The peak waterlevel of Lake Olomega usually occurs in September or in October according to daily data during 1970-1978. For 13 years, the average of maximum waterlevel by year is MSL+ 65.88 m. Maximum waterlevel in Lake Olomega is shown in Table B. 17.

The probability waterlevel in Lake Olomega is calculated as follows.

Return Period in year	Waterlevel in meter above MSL
200	66.95
100	66.85
50	66.74
20	66.57
10	66.43
5	66.25
2	65.92

9.2 Lake Jocotal

Any measured data on waterlevel of Lake Jocotal is not available, however, the monthly averaged discharges at Vado Marin which is located downstream of Lake Jocotal show their peak value on September to October. From this phenomenon the peak waterlevel of Lake Jocotal is expected to occur in September or in October.

Collected information related with the waterlevel of Lake Jocotal in 1996 is as follows;

Date	Obtained Information	Estimated Lake Elevation
March 5-June 10,1996	The water was always lower than the lake bank and seemed to be constant.	MSL+24.0-0.5=MSL+23.5m
July 26,1996	The water level was about to reach the block along the access road.	MSL+24.0+0.50m=MSL+ 24.5m
July 26,1996	Backward flow from the Jocotal drainage channel to the lake was recognized.	MSL+24.0+0.50m=MSL+ 24.5m
October,1996	Maximum in 1996	MSL+26m
December,1996	Water level by topographic survey	MSL+23.16
December,1996	The waterlevel was always lower than the lake bank.	MSL+24.0-0.5m =MSL+23.5m

During dry season, the waterlevel in Lake Jocotal is maintained to be MSL+23.5 m. This is resulted by a plenty of spring water from the surrounding area.

10. FLOOD SIMULATION

10.1 General

In order to get hold of basin characteristics on rainfall and run-off relation, run-off simulation of the past floods, especially for 1995 flood was conducted. For this simulation, it is necessary to have both recorded rainfall and discharge data available at as many stations as possible. With respect to river discharge data, there is no data available between 1981 and 1994 in the Study Area.

The selected subject floods of the run-off simulation are as follows;

Date of flood	Descriptions
July-September, 1995	The inundation survey was intended to study this flood conditions.
June, 1980	The maximum discharge record at Las Conchas

Peak discharges of 1995 and 1980 floods are as follows.

Flood	Station	Date and time	Waterlevel	Discharge
1995 Flood	Villerias	1995/8/2 3:00	5.90 m	680.6 m^3/s
	Vado Marin	1995/8/4 0:00	2.41 m	110.2 m^3/s
	Vado Marin	1995/9/25 20:00	2.57 m	133.5 m^3/s
1980 Flood	Moscoso	1980/6/13 7:00	5.80 m	430.2 m^3/s
	Las Conchas	1980/6/25 0:00	3.14 m	217.5 m^3/s

10.2 Runoff Simulation

The San Miguel River Basin and its river channels were divided into 18 sub-basins and 12 channels. Sub-basins and river channels were configured in a runoff system diagram. Basin boundaries and runoff system diagram are shown in Figure B. 19. Basin areas and their overall slope are also shown in Figure B. 19.

Runoff from the sub-basin was simulated by storage functions expressed by the following equations:

$S_l = k \cdot Q_l^p$

$dS_l/dt = (1/3.6) \cdot f \cdot r \cdot A - Q_l$

$Q_l(t) = Q(t + T_l)$

where

S_l	: Basin storage (m^3)
Q_l	: Runoff from sub-basin (m^3/sec) in consideration of lag time(T_l)
k, p	: Basin constants
t	: Time in seconds
f	: Primary runoff coefficient
r	: Basin mean rainfall (mm/hr)
A	: Catchment area (km^2)
T_l	: Retarding time in hour

Retarding time of each sub-basin is obtained from the following formula commonly used in Japan.

$T_l = 0.047L - 0.56 \quad L \geq 11.9$ km

$T_l = 0 \quad L < 11.9$ km

T_l: Retarding time(hour)

L:Channel length (km)

Principally same fundamental equations as in the basin runoff were applied to the channel runoff calculation as follows:

$S_l = k \cdot Q_l^p$

$dS_l/dt = sum(f_i \cdot I_i) - Q_l$

where

f_i	: Inflow rate
I_i	: Inflow
$sum(f_i \cdot I_i)$	: Total of effective inflows

Basin constants (K) in the storage functions were derived from the following equation:

$K = 7.35 (N * L/I^{0.5})^{0.6}$

where

N	: Equivalent roughness of basin
L	: Slope length (km)
I	: Basin slope

Channel constants K and p were derived from Manning Formula.

Equivalent roughness (N) for each sub-basin was initially assumed referring to the standard values used in Japan as follows:

(Standard Equivalent Roughness)

Land use	N	Land use	N
Urban area	1	Fruits	3
Basic grain	0.3	Vegetable	0.3
Pasture	0.3	Forest	0.7
Coffee	0.3	Water	2
Sugar cane	0.3	Lava	1
Henequen	0.3		

Land use in 1975, 1980 and 1995 in the Basin (Unit:%)

Land use	1975	1980	1995	Land use	1975	1980	1995
Urban area	9	1.0	1.3	Fruits	0.7	0.6	0.4
Basic grain	14.2	11.8	4.9	Vegetable	8	0.7	0.4
Pasture	40.9	46.9	65.2	Forest	24.4	22.0	14.7
Coffee	5.2	5.5	6.2	Water	1.0	1.2	1.6
Sugar cane	8.1	6.5	1.7	Lava	2.2	1.9	1.2
Henequen	1.6	1.8	2.3				

Primary runoff coefficient f1

This parameter stands for the ratio of impermeable area to concerned total area of sub-basin. Usually this is obtained by the comparison between total rainfall and runoff depth or loss depth.

Figure B. 20 shows that the correlation between total rainfall and runoff depth of the selected floods at Villerias and Moscoso. Runoff depth in mm means the direct runoff volume divided by catchment area, which is obtained by separating base flow from each hydrograph.

The average runoff coefficient is 0.27 supposing that surface soil is saturated.

Floods to be selected for the calibration of runoff model were quite limited, since discharge data are not available for the period from 1981 to 1994. The following two (2) floods were selected for the calibration considering the magnitude of flood and availability of runoff and rainfall records.

- 1995-flood (July-September): The latest flood with relatively many data. This flood is a target flood for the inundation survey and the flood mark survey.
- 1980-flood (June): At Las Conchas, the maximum discharge was recorded.

Available rainfall data of respective floods for calibration are listed in Table B. 18. Since the flood events and data available were quite limited, the following procedures were taken for calibrating the runoff simulation model.

The upper basin consisting of sub-basin No. 1 through 8 was calibrated based on 1995-flood using runoff record at Villerias Station (Figure B. 21).

The middle basin consisting of sub-basin No.9 through 11 was calibrated based on 1980-flood using runoff record at Moscoso Station.

The lower basin consisting of sub-basin No. 16 through 18 was calibrated based on 1980-flood using runoff records at Vado Marin and Las Conchas stations (Figure B. 22).

The run-off computation was done based on hourly rainfall data. The stations which have only daily data were assumed to have an hourly distribution of the nearest station having recorded hourly data.

Basin and channel constants calibrated with 1995 flood are shown in Table B. 19. These constants are assumed under the present basin and channel conditions. In some portions of the runoff hydrograph, calculated and measured runoffs did not agree well. This would largely depend on the shortage of hourly rainfall records.

Concerning primary runoff coefficient of Middle and Lower Basins, geological feature was considered.

Sub-basin	Total area (km2)	Tertiary, Volcanic rocks with Ignimbrite	Other	
		f1=0.90	f1=0.65	f1
Upper Basin	910.0	240.0(26.4%)	670.0(73.6%)	0.72(=1.0)
Middle Basin	727.0	43.0(5.9%)	684.0(94.1%)	0.66(=0.9)
Lower Basin	609.8	0.0(0.0%)	609.8(100%)	0.65(=0.9)

10.3 Flood Simulation

Flood flow simulation model was prepared based on the one-dimensional unsteady flow formula. The model is used to evaluate the function of flood retention facilities such as dam and lake. The model was calibrated based on the data and information for the 1995-flood. Flood flow system diagram is shown in Figure B. 23.

Flood flow in the Study Area could be discussed independently dividing the basin into two, the Middle and Lower basins, at El Delirio where channel forms rapids with supercritical flow. The boundary conditions for the calculation were set as follows:

Middle Basin:

- Channel inflow: Discharge at Villerias
- Sub-basin inflow: Sub-basin No.9 through 14
- Water level at lower end: At El Delirio, assuming critical flow at section No.103

Lower Basin:

- Channel inflow: Outflow from the middle basin at El Delirio
- Sub-basin inflow: Sub-basin No.15 through 18
- Water level at lower end: At river mouth, assuming constant water level of H = 1.39 m above MSL

The flood flow simulation model was calibrated in the following procedures:

- Initial water level of Lake Olomega:
  MSL+65.0 m, based on the survey conducted by the Study Team in 1996.
- Channel:
  Cross section for flood flow simulation consists of river channel and floodplain. The cross section surveyed in 1996 by the Study Team was used as river channel, and the floodplain section was assumed based on the topographic map of scale 1/10,000.
- Manning's coefficient of roughness:
  Initially, n = 0.035 for the river channel and n = 0.7 to 1.0 for the floodplain were used and adjusted appropriately to let the simulated water level close with the surveyed flood level.

Calibration was made adjusting the channel conditions so that the calculated water levels and discharges agree with the recorded discharges at Vado Marin and water levels by flood level