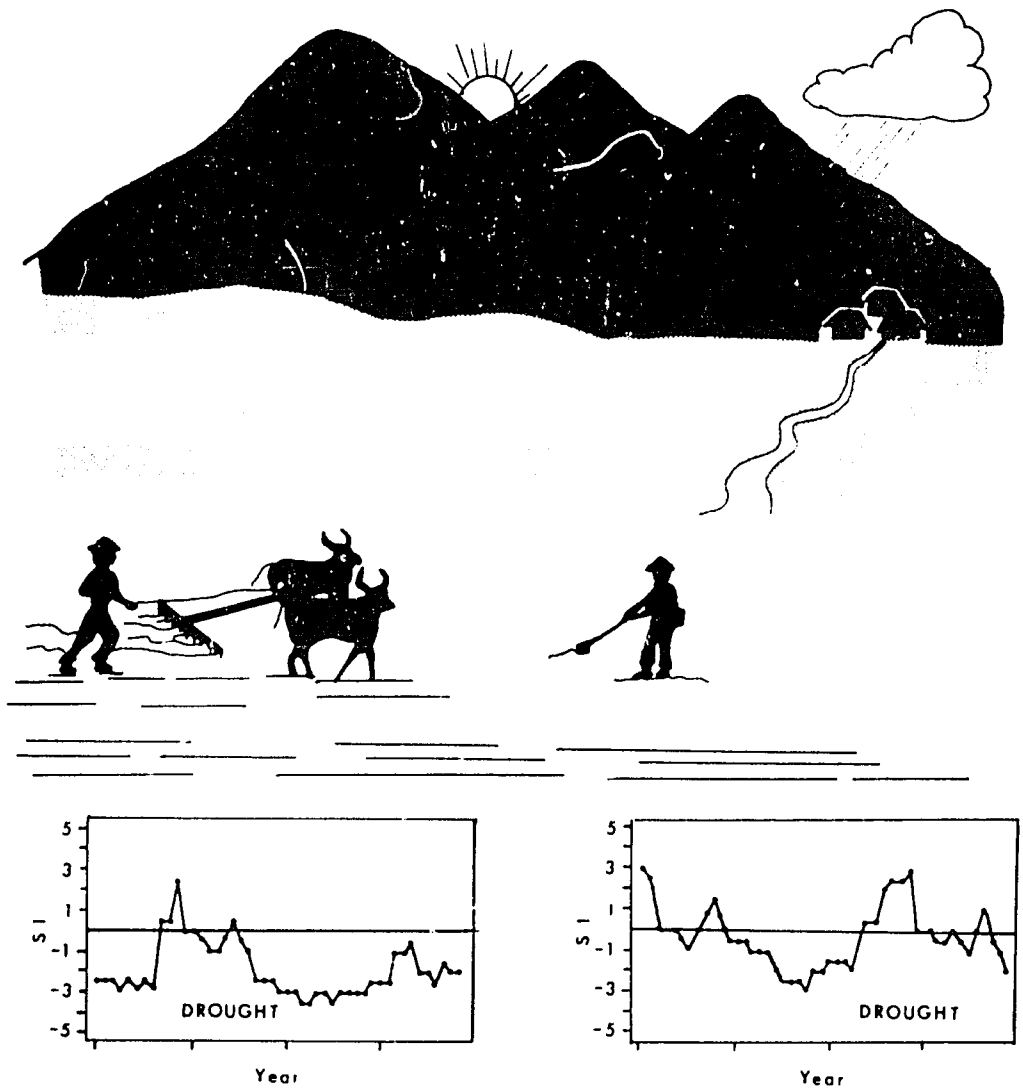
PN-AAB6-485
PAUL F. KRUMPE
1985

AGROCLIMATIC CROP CONDITION METHODS
FOR
ASSESSING DROUGHT/FOOD SHORTAGES
IN
EL SALVADOR



JUNE 1984 JOSÉ D. FUENTES

FINAL REPORT

AGROCLIMATIC CROP CONDITION METHODS FOR ASSESSING DROUGHT/FOOD SHORTAGES IN EL SALVADOR[1/]

by

Jose D. Fuentes
WMO Fellow

1/ Report prepared for the Assessment and Information Services Center of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service. Portions of the study was supported by funds through the University of Missouri-Columbia, Atmospheric Science Department through Grant USDOC/NOAA NA 84-AA-H-0003 through NOAA/USAID PASA BOF-0000-P-CC-3062-02.

FOREWORD

This report by Mr. Jose D. Fuentes, WMO fellow from El Salvador is the result of an intensive six week orientation program on Agroclimatic Models and Climatic Impact Assessment Technology. This program was conducted in Columbia, Missouri by the Models Branch of the Assessment Information Services Center (AISC) in cooperation with the University of Missouri Atmospheric Science Department.

The agroclimatic assessment models developed by Mr. Fuentes for El Salvador can be used as the scientific foundation for planning, organizing and implementing a regional climatic impact assessment program. The data resources for such a program already exist in El Salvador. With support, a national project can be established to demonstrate the economic benefits to decision makers.

This project was supported in part by NOAA/NESDIS Assessment and Information Services Center and by the Agency for International Development, Office of U.S. Foreign Disaster Assistance (USAID/OFDA), Washington, D.C. The basic goal of the project is to transfer agroclimatic modeling and assessment technology to developing countries and to encourage the development of an in-country program. This technology can improve food security by increasing disaster preparedness and early warning, as well as by contributing to land use planning for agricultural and rural development, and mitigating socio-economic vulnerability to climatic extremes such as drought.

It was a pleasure for us to work with Mr. Fuentes during his training tour. His professional dedication and long hours of hard work were responsible for the results in this project report.

Andres C. Ravelo
Project Leader
Atmospheric Science Department
University of Missouri

Clarence Sakamoto
Chief, Models Branch
NOAA/NESDIS/AISC

ACKNOWLEDGEMENTS

The technical orientation program in Agrometeorological Assessment Indices took place at the Models Branch of the Assessment and Information Services Center (AISC), Columbia, Missouri. The program is part of training in meteorology, or subjects related to meteorology, provided to fellowship members of the World Meteorological Organization (WMO).

Special thanks are due to Dr. Clarence Sakamoto, Chief, Models Branch, for all the administrative and technical support provided during the program. It is a pleasure to acknowledge the particular contributions made by Dr. Andres C. Ravelo, Research Associate, Atmospheric Science Department, University of Missouri-Columbia (UMC), whose dedication and efforts on this report were extremely valuable. Acknowledgement is also extended to Dr. Sharon LeDuc, Senior Statistician, and Albert van Dyk, Remote Sensing Specialist.

The author wishes to thank the following individuals for their valuable help in making this report possible: Joan Darkow, Research Laboratory Technician, edited and compiled the report; Sue Monteer, Administrative Assistant and Tyeece Little, Word Processor II, had the patience and courage to type the manuscript; Rita Terry, Writer Editor-Librarian, edited the report and Jerry Wright drafted the figures.

EXECUTIVE SUMMARY

José D. Fuentes

Agriculturally oriented economies are highly vulnerable to annual variations in climate, particularly in El Salvador where 60 percent of the rural population, engages in agriculture. Severe or extreme drought, such as in late June and early July 1975, can lead to crop failures and tremendous economic losses. The vulnerability of climatic extremes is frequently compounded not only by the precipitation regime, but also by deforestation and soil erosion.

Increasing agricultural commodities and reducing losses due to abnormal climatic conditions can be both economically and socially beneficial. This report focuses on some of the climatic impact assessment methods which can be used by land use planners and managers to mitigate potential climatic impact and reduce climatic vulnerability. Historic climatic data, primarily monthly precipitation, were used to develop five different types of agroclimatic indices for Acajutla, San Salvador, and Los Andes. These include: Yield Moisture Index, Soil Moisture Index, R-Index, Crop Condition Index, and Palmer Drought Index. Moreover, three different methods to compute potential evapotranspiration, Penman, Hargreaves and Thornthwaite, were studied in great detail for 23 weather stations throughout El Salvador. Potential evapotranspiration values were calculated for the year 1975 using monthly values of temperature, relative humidity, solar radiation, and wind speed. The potential evapotranspiration values for selected weather stations are presented in the Appendix. Furthermore, some meteorological satellite data were briefly analyzed. Two types of indices, the Vegetation and the Normalized Vegetation, were concisely described.

Some potential short or long term economic benefits of climatic impact assessments to decision makers can be inferred from this report. For instance, early warning of drought impact on agricultural production can be provided at least one month prior to the beginning of the crop harvest. This kind of information can contribute to agricultural production forecasts and provide a lead time of one to several months before the actual economic impact of drought. This lead time allows decision makers to establish in advance preparedness plans to mitigate climatic impact on socioeconomic conditions. Furthermore, farmers can be given crop weather advisories and be advised on recommended planting dates and scheduling of irrigation, wherever irrigation is feasible.

Agroclimatic indices are powerful tools in land use studies to help determine the regionally appropriate crop, its optimum planting data, and crop stage conditions. The information the indices provide helps to reduce climatic vulnerability and reduce the risk of crop failure. This kind of information has important implications to decision makers and planners involved with agricultural and rural development programs in El Salvador.

Probably, in the near future, some agroclimatic models can be implemented as well as the agroclimatic indices discussed in this report. Both are simple to implement in either a main frame computer or a microcomputer. The author suggests that agroclimatic models and agroclimatic indices are essential in formulating long term economic goals for agriculture and rural development with the ultimate objective of self-sufficiency in food production.

d

CONTENTS

		Page
	LIST OF TABLES	i
	LIST OF FIGURES	ii
I.	INTRODUCTION	1
II.	AGROCLIMATIC BACKGROUND	2
	A. Physical Environment	2
	B. Climate	5
	C. Agricultural Regions and Crop Distribution	7
	D. Agricultural Practices for Main Crops	11
	1. Coffee	11
	2. Cotton	12
	3. Sugarcane	12
	4. Staple Crops	14
	E. Importance of Agriculture to El Salvador	15
	F. Climatic Impact on Agriculture	15
	G. Technology Changes in the Past 15 Years	17
III.	DATA AND METHODOLOGY	18
	A. Meteorological Data	18
	1. Selection of Data	18
	2. Capabilities and Limitations	18
	3. Episodic Events	20
	B. Methodology	20
	1. Climatic Analysis for El Salvador	20
	2. Agroclimatic Tools	24
	3. Agroclimatic Indices	35

Page

a. Yield Moisture Index 35

b. R-Index. 35

c. Soil Moisture Index. 36

d. Palmer Drought Index 37

e. Crop Condition Index 40

4. Application of Indices 42

5. Meteorological Satellites. 44

IV. RESULTS AND DISCUSSION 49

A. Potential Evapotranspiration 49

B. Agroclimatic Indices 64

1. Crop Condition Index 64

2. Yield Moisture Index 68

3. Palmer Drought Index 68

4. Soil Moisture Index. 73

5. R-Index. 73

6. Vegetation Index 79

V. CONCLUDING REMARKS 80

REFERENCES 82

Appendix 85

LIST OF TABLES

Table		Page
2.1	Estimated Crop Calendar for Main Crops in El Salvador . . .	13
3.1	Crop Coefficients (kc).	32
3.2	Palmer Drought Index (PDI) Classes for Wet and Dry Periods.	41

LIST OF FIGURES

Figure		Page
2.1	Administrative Divisions in El Salvador.	3
2.2	Volcanos and Major Fresh Water Bodies in El Salvador	4
2.3	Major Natural Regions in El Salvador	6
2.4	Soil Map of El Salvador (Adapted from FAO-UNESCO, 1972). . .	8
2.5	Vegetation and Land Utilization in El Salvador	9
2.6	Distribution of Major Commercial and Subsistence Crops in El Salvador	10
3.1	Selected Weather Stations in El Salvador	19
3.2	Mean Position of the ITCZ During June-August, 1958 (Adapted from Rudloff, 1981).	22
3.3	Mean Position of the ITCZ During December, 1957-February, 1958 (Adapted from Rudloff, 1981).	23
3.4	Comparisons of VI 1982-1984 for El Salvador.	48
4.1	Potential Evapotranspiration (PET) for Beneficio La Carrera During 1975.	50
4.2	Potential Evapotranspiration (PET) for La Galera During 1975	51
4.3	Potential Evapotranspiration (PET) for Nureva Concepcion During 1975.	52
4.4	Precipitation Analysis for La Union.	53
4.5	Precipitation Analysis for Cojutepeque	54
4.6	Precipitation Analysis for Acajutla.	55
4.7	Precipitation Analysis for Santa Ana, El Palmar.	56
4.8	Total Precipitation (in mm) During the Month of June, 1975 .	57
4.9	Total Precipitation (in mm) During the Month of July, 1975 .	58
4.10	Total Evaporation (in mm) During the Month of June, 1975 . .	59
4.11	Total Evaporation (in mm) During the Month of July, 1975 . .	60
4.12	Difference Between Precipitation and Evaporation (in mm) During the Month of June, 1975	61

Figure		Page

4.13 Difference Between Precipitation and Evaporation (in mm) During the Month of July, 1975. 62

4.14 Crop Condition Index (CCI) for San Salvador 65

4.15 Crop Condition Index (CCI) for Los Andes. 66

4.16 Crop Condition Index (CCI) for Acajutla 67

4.17 Yield Moisture Index (YMI) for Corn During the Period of May Through August in Acajutla. 69

4.18 Yield Moisture Index (YMI) for Corn During the Period of May Through August in San Salvador. 70

4.19 Yield Moisture Index (YMI) for Corn During the Period of August Through November in San Salvador 71

4.20 Yield Moisture Index (YMI) for Corn During the Period of August Through November in Acajutla 72

4.21 Palmer Drought Index (PDI) for Acajutla, El Salvador. . . . 74

4.22 Palmer Drought Index (PDI) for Los Andes, El Salvador . . . 75

4.23 Palmer Drought Index (PDI) for San Salvador, El Salvador. . 76

4.24 Soil Moisture Index (SMI) for San Salvador During 1975. . . 77

4.25 R-Index for Acajutla During 1975. 78

CHAPTER I

INTRODUCTION

The economy of El Salvador has traditionally been characterized as agrarian. Agriculture is the largest segment of the national economy. The actual agricultural system is dualistic. Commercial farming produces crops chiefly for export such as coffee, cotton, beef, and sugarcane. Agricultural exports account for two-thirds of total export earnings. Subsistence cultivation of small hillside plots is commonly practiced by the bulk of the rural population which is made up of small land owners and land renters who produce mostly staple crops. Among the most popular staple crops are corn, beans, rice, sorghum, potatoes, bananas, and some other vegetables.

The agriculturally oriented economy of El Salvador is highly vulnerable to variations in the climate; increasing the level of agricultural production and reducing losses due to anomalous climate conditions can be both economically and socially beneficial. This report should be viewed as a preliminary report on a climatic impact assessment program. It is designed to serve as a working document for assigning procedures in El Salvador and implementing an assessment program in the future.

Despite its limitation, the main scope of this report is to provide information about climatic conditions and the effects that climate variability can have on agriculture. The results of this report may have important implications to decision makers and planners involved with agricultural development programs. Another goal of this report is to provide the basis for the implementation of an agroclimatic analysis program by using historic climatic data to develop models which might contribute to agricultural crop forecasting, land use programs, crop/weather advisories, and crop calendars for farmers.

CHAPTER II

AGROCLIMATIC BACKGROUND

A. Physical Environment

El Salvador is the smallest mainland country in Latin America with an estimated area of 20,935 square kilometers. It is bounded on the west by Guatemala, on the north and east by Honduras and on the south by the Pacific Ocean [Figure 2.1]. Thus, El Salvador is the only Central American country without a coastline on the Caribbean Sea. Its varied terrain ranges from tropical lowlands on the Pacific coastal plain to arid semi-desert in the mountainous region of the North [Blutstein, et al, 1971].

El Salvador lies entirely within the Central American volcanic axis. Two parallel chains of dormant and active volcanos extend east-west through the country [Figure 2.2]. The southern range (Cadena Costera) contains the highest peak while the northern range (the Sierra Madre) is generally lower and less continuous. Low, fairly flat alluvial basins (the central lowlands and the valley of the Rio Lempa) are found between the ranges of single peaks and extensive plains existing along the south coast.

The mountain ranges, running east and west, roughly divide the country into three distinct physical zones, characterized primarily by elevation but also by general climatic conditions. The southern coastal plain is called the torrid land (tierra caliente). It consists of a narrow, relatively flat belt which extends from the Guatemala border to the Gulf of Fonseca. The coastal range (Cadena Costera) forms the northern demarcation of the torrid zone, which is bounded by the Pacific Ocean on the south. The northernmost latitudinal zone is known as the cold land (tierra fria). It comprises the northern lowlands, formed by the wide valley of the Lempa River and the Sierra Madre, which extend to the Honduran border. Between

Figure 2.1. Administrative Divisions in El Salvador

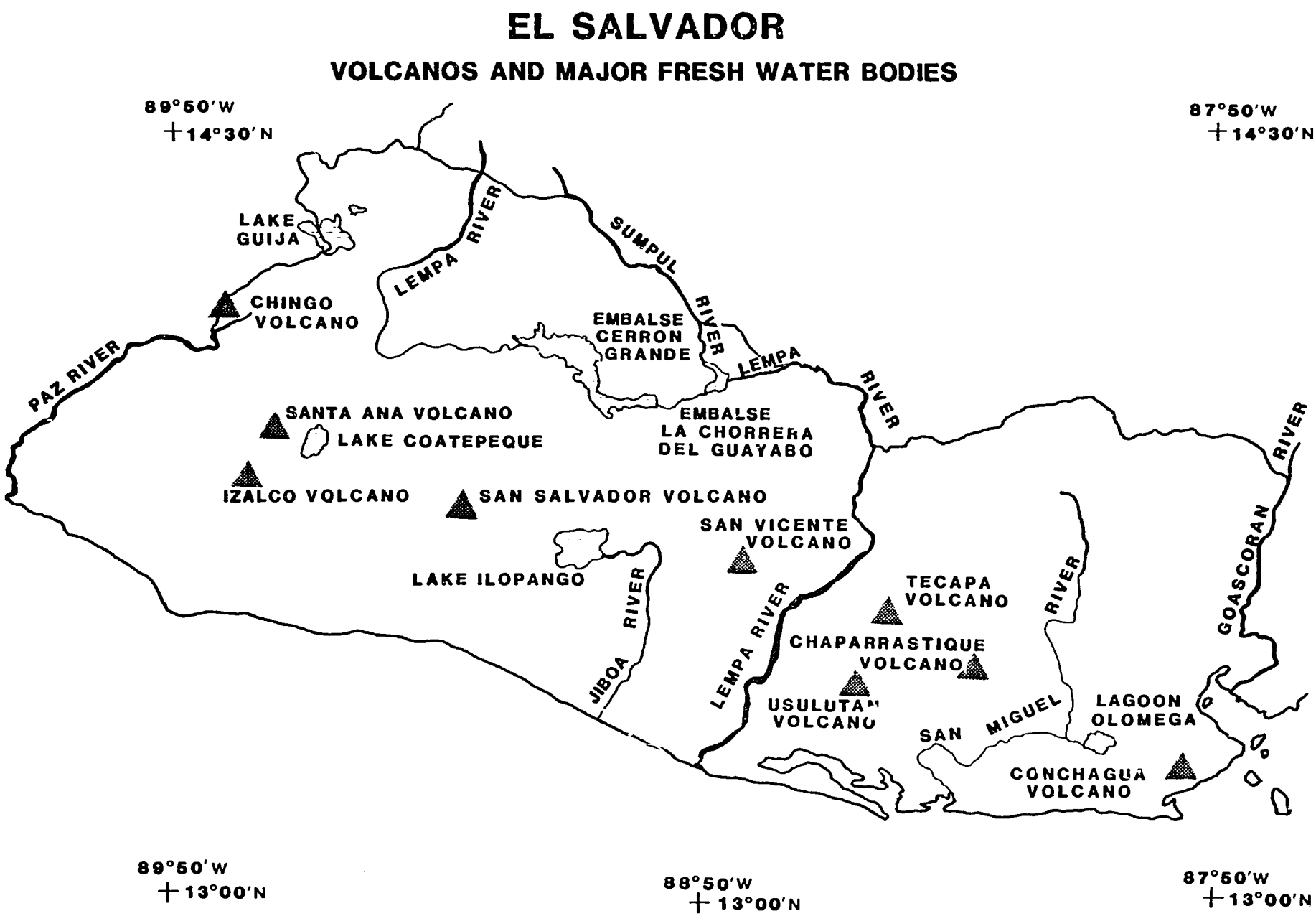


Figure 2.2. Volcanos and Major Fresh Water Bodies in El Salvador

the two mountain-demarcated zones lie the central highlands called the temperate land (tierra templada), which includes most of the national territory [Figure 2.3].

B. Climate

The climate is generally moderate, with warm days and cool nights. Because of the country's small size and compact physical structure, climate conditions are relatively uniform in its three regions with no pronounced extremes distinguishing one from another. Even though there are marked climatic contrasts between the central plateau and the mountain-fringed zones in the North and South, seasonal and diurnal variations are moderate. The climate is generally temperate and pleasant with only an occasional severe rainy season. There are two distinct and fairly well defined seasons, the dry, regionally called "verano", and the wet, called "invierno". The wet season generally lasts six months, May through October, and the dry season extends from November to April. During the dry season approximately 6 percent of the annual total rainfall is received [Menendez, 1970]. The mean annual rainfall for the whole country is approximately 182[illegible] mm, with occasional extremes of 1,450 to 2,310 mm [Evaluation Technologies, Inc., 1982]. In June, perhaps more often in September, heavy rains known locally as temporales bring persistent torrential downpours for several days or even weeks. Sometimes these torrential rains cause floods, damaging a large percentage of the crops. The heaviest rainfall activity occurs on the coast, while the central and northern regions experience moderate rainfall.

Temperatures vary generally with altitude, with maximum temperatures and humidity along the coastal lowlands. The central plateau has a temperate climate bordering on the semitropical. Coolest temperatures are found in the northern mountains. In general, the climate is warm rather

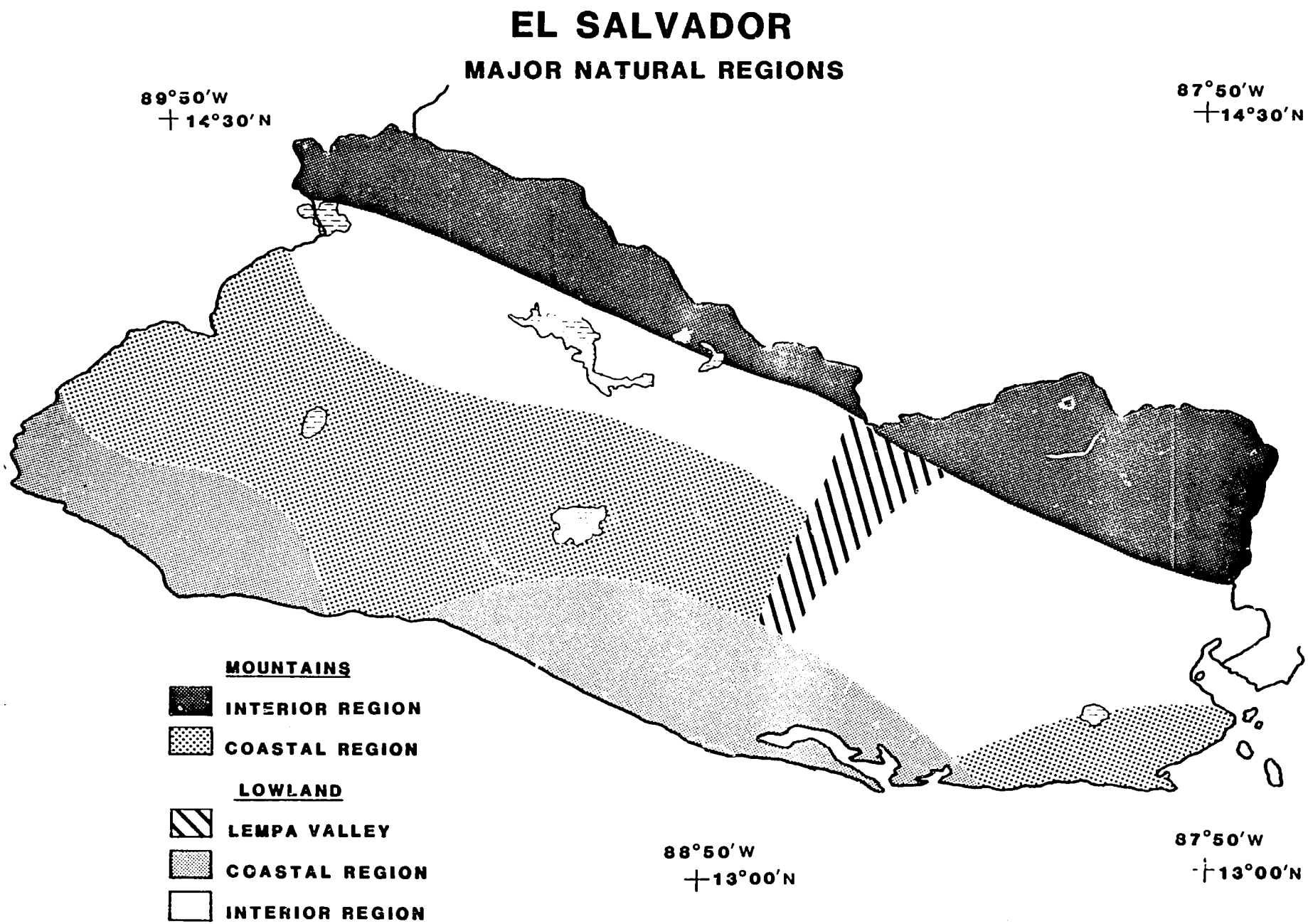


Figure 2.3. Major Natural Regions in El Salvador

than hot, with the average minimum annual temperature for the country as a whole 23°C and the maximum 32°C [Blutstein, et al, 1971].

El Salvador is rarely affected by weather hazards such as hurricanes, tornadoes, or cyclones. If large scale systems develop too far south of the Caribbean Sea, then the country can suffer from the fringe effects of tropical storms or torrential rainfall, as was the case with hurricane Fifi in 1974. El Salvador is occasionally subjected to gales of high pressure polar air that drives down from the north in strong, gusty storms, causing minor damage to crops. During the rainy season the rainfall regime is abruptly interrupted by a dry period known as the Canicula Interestival [for more details of this phenomenon see Arze]. According to Arze [1982] this dry period usually lasts up to 30 days, and usually begins by the middle of July and ends by the middle of August. This discontinuity of the rainfall regime presents serious limitations to agricultural crop production.

C. Agricultural Regions and Crops Distribution

The ecological conditions (climate and soil) of the above three natural regions determine the distribution of vegetation and land use [Figure 2.4 and Figure 2.5]. The principal crops are coffee, cotton, sugarcane, corn, rice, beans, and sorghum. Other crops are raised in minor proportions, such as vegetables (tomatoes, potatoes, cucumbers, etc.), henequen, citrus, melons, tobacco, bananas, and coconuts.

Despite the small size of the country, marked regional variations in cultivation are apparent. Coffee, for instance, is grown on the volcanic hills in the interior of the country and on the coastal range; most coffee plantations are located at altitudes between 600m and 900m. Cotton plantations are mainly located on the coastal lowlands. Sugarcane is grown in the central valleys and the western coastal zone. Corn and other staple crops are widely grown throughout the country [Figure 2.6].

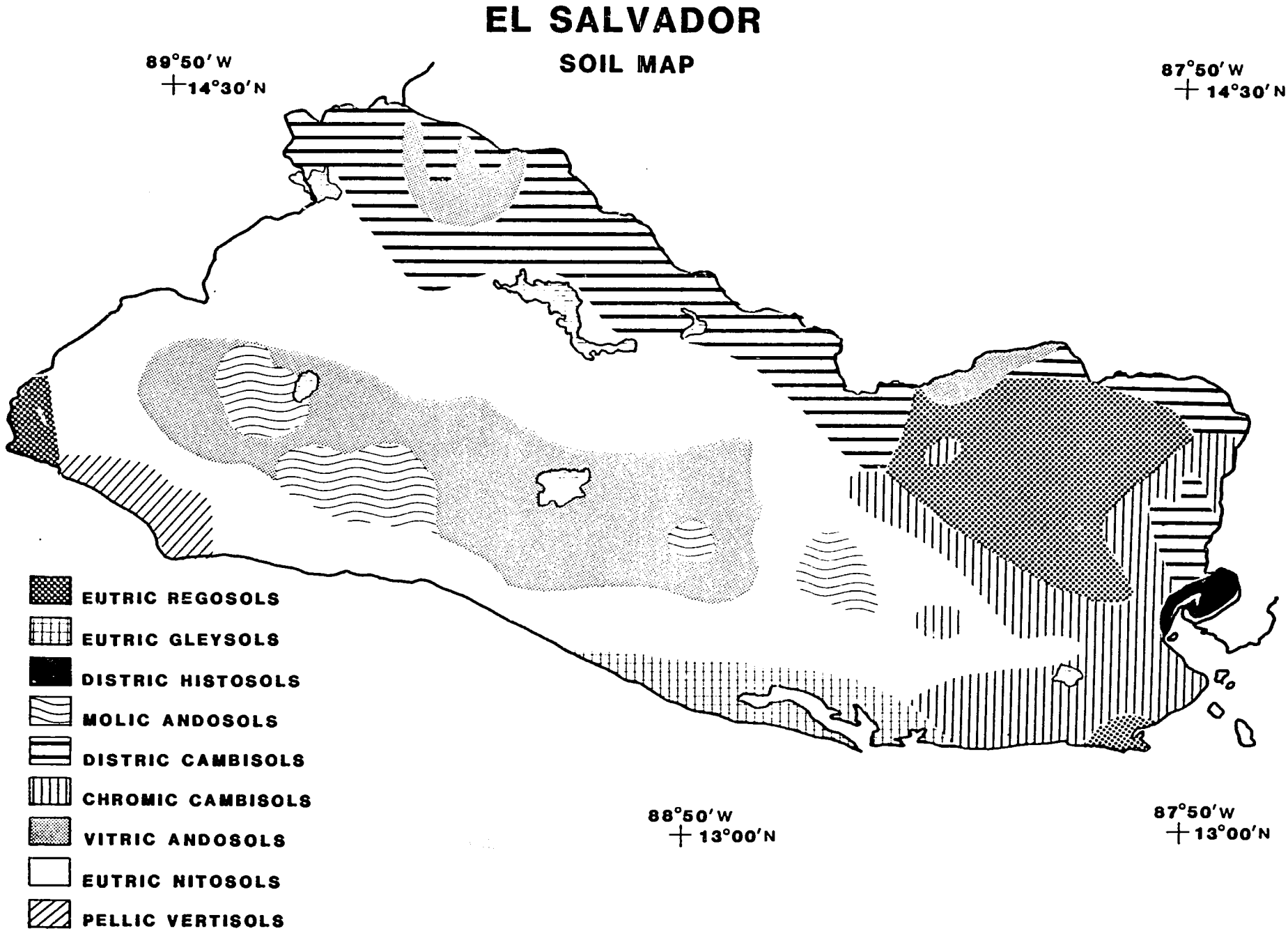


Figure 2.4. Soil Map of El Salvador (Adapted from FAO-UNESCO, 1972)

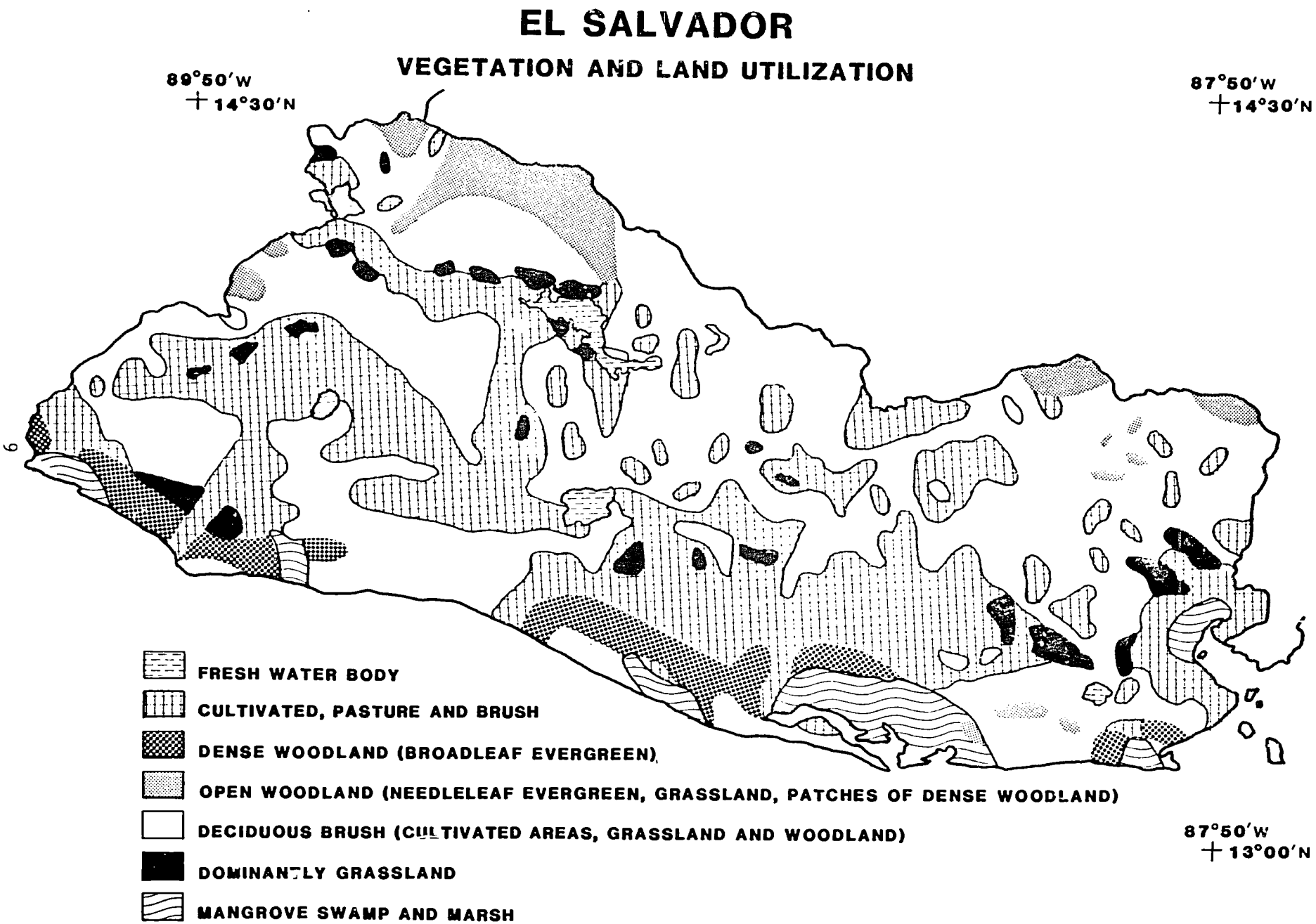


Figure 2.5. Vegetation and Land Utilization in El Salvador

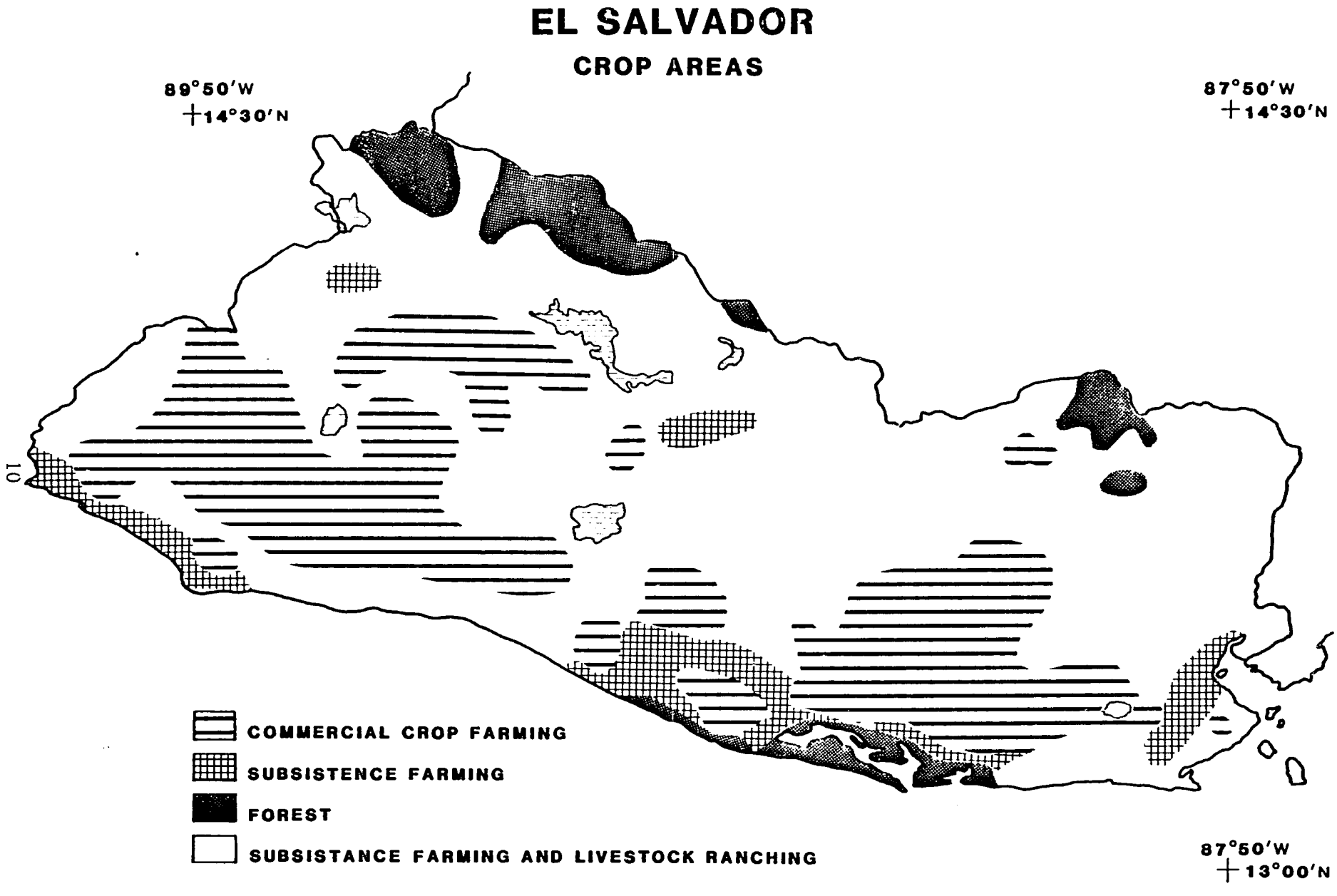


Figure 2.6. Distribution of Major Commercial and Subsistence Crops in El Salvador

D. Agricultural Practices for Main Crops

The agricultural practices employed in crop production are diversified, and they greatly depend upon the sort of crops, topography, and type of soil. Land preparation prior to planting, planting or sowing, the crop calendar, fertilizer use and harvesting season are dependent on the kind of crop. An attempt is made here to describe how each of the main crops is treated during their vegetative cycle; more detail is beyond the scope of this report.

1. Coffee

Coffee is a perennial plant; therefore cultivation is not practiced annually. Prior to cultivation, seedlings are carefully prepared. The seedling plants may be transplanted into the field when 9 to 12 months old. The soils where coffee is planted are fertile, with good retention of moisture, but the terrain presents many irregularities. Generally, plants begin to flower 3 to 4 years after planting, are in full bearing at 6 to 8 years, and continue to give an economic yield for about 30 years [McIlroy, 1963]. However, due to recent genetic improvements, plants reach the reproductive stage in a shorter time. Fruits mature 6 to 8 months after flowering, depending upon climatic conditions. The fruits are picked by hand when fully ripe. Coffee trees begin to flower between the last two weeks of April and the middle of May. The flowering process greatly depends on the availability of water; it usually occurs right after the first rainfall. Consequently, there is no fixed date when these plants begin their flowering period. Coffee plantations are generally fertilized either once or twice a year with ammonium sulphate or NPK 20-20-0 (nitrogen, potassium, calcium). The harvesting season begins by late October and ends by the middle of February. Once again, this season is subject to climatic conditions.

2. Cotton

Cotton is the second most important crop in El Salvador. The cotton plantations are generally large and highly mechanized. The land is plowed before the rainy season starts using machinery and oxen in hilly terrains. In some cases the land is not plowed due to rocky terrains; this is only true with small plantations. The planting season is generally between the end of May and the beginning of June. The soil must be wet enough to support germination which occurs in about 5 to 15 days. Four of five seeds per hole are planted, and after 3 weeks growth the seedlings are thinned to one to two per hole. Plants are fertilized at least twice before the harvesting season with either ammonium sulphate or NPK, depending upon the soil conditions. Aerial insecticide spraying is practiced several times during the season; the frequency depends on the pests. The first flowers are seen 8 to 10 weeks after planting provided that there are no severe interruptions in the rainfall regime. Harvesting begins six months after planting, between November and March [Table 2.1]. Harvesting is done by hand, and there are three to four pickings.

3. Sugarcane

Sugarcane is propagated vegetatively from short stem cuttings called sets, comprising nodes and internodes, which are taken from the upper parts of mature cane. The cane used for planting should be well grown plants, 10 to 12 months old. Sets should be 20 to 25 cm long with 2 or 3 nodes. Prior to planting, the soil should be plowed or thoroughly cultivated to a depth of at least 20 cm and then heavily manured. The soils of small plots, mainly for domestic consumption, are rarely plowed. Once the land is ready the sets may be planted on a slant, with one third of the set showing above the soil, or may be laid flat end to end in the furrows and lightly covered with soil. The sets sprout in about 10 to 14 days. It is

Table 2.1

Estimated Crop Calendar for Main Crops in El Salvador

Crop Name	MONTHS												COMMENTS
	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC	
Coffee	H H H H	H H			T T T T F F F	T				H	H H H H	H H H H	Fruits mature in 6 to 8 months after the flowering period.
Cotton	H H H H	H H H H	H		P P	P P	F	F F F F			H H	H H H H	Generally harvesting begins 6 months after planting.
Sugarcane	H H H H	H H H H	H H	P P P	P P				F	F F F F	F F	H H	The flowering periods vary according to the type of plantation (i.e. ratoon crop or new crop).
Corn	H H				P P P P	P P	F F F	H H H H P P P	H H P P	F F F	H H	H H H H	The vegetative cycle lasts from 75 to 120 days (criollo 75 days and the HS hybrid 120 days).
Beans					P P P	P	F F F H	H H H P P P		F F F	H H H H	H H	The bulk of this crop is planted during the latter part of the rainy season.
Rice						P P	P P	F	F F F	H H	H H H H	H H	There is little rice planted during the first part of the rainy season.
Sorghum	H H H H			P	P P P	P P P	F F F	H H H P P P	F F F F	H H H H F F	F F H H	H H H H	There are two well known varieties of sorghum: sapo and criollo. The vegetative cycle for sapo variety is shorter than criollo.*
Tomatoes					T T T		F F F	H H H H T T	H H H T	F F F	H H H	H H	Tomatoes are generally transplanted twice a year during the rainy season. Their vegetative cycle greatly depends on the variety being planted.

H: Harvesting
T: Transplanting
P: Planting
F: Flowering

*In fact, there can be two harvests of sorghum sapo during the rainy season.

important to note that this procedure is not performed every year in the same plot but usually every two or three seasons, known as ratooning. Most cane planting takes place during the month of April, just before the rainy season starts. Most sugarcane plantations are fertilized at least once every season with ammonium sulphate. There is little, if any, use of pesticides.

Unlike most crops, flowering indicates cessation of the vegetative growth and hence of sugar production. Flowering usually starts by the end of September to October. Harvesting is done by cutlass. Cutting is done as near the ground level as possible since the sugar content is highest in the lower part of the stem and high cutting adversely affects ratooning. The leaves are returned to the soil and the tops likewise unless used for planting materials. After cutting, the sugar content diminishes rapidly and cut cane should reach the mill as soon as possible.

4. Staple Crops

In El Salvador, staple crops are the most important crops simply because they represent the bulk of the diet of the population, There is no single agricultural practice employed in the production of the staple crops; they vary depending not only upon the regions where the crops are planted but from one farmer to another. In general, the agricultural practices for the staple crops (corn, beans, sorghum) begin in May. Farmers begin planting as soon as the soil contains enough moisture to permit germination. Most of the staple crops can be planted twice a year; one planting in May and the other by the middle of August [Table 2.1].

E. Importance of Agriculture to El Salvador

El Salvador is still fundamentally dependent upon agriculture for both its foreign exchange earnings and the production of domestic crops. Agriculture accounts for 25 percent of the Gross Domestic Product (GDP) and 77 percent of export earnings [Evaluation Technologies, Inc., 1982]. Furthermore, agriculture is not only the largest segment of the national economy, but also employs nearly half the population. Although labor is seasonally heavy in the agricultural sector, many farmworkers are unemployed part of the year.

Although the long-term trend has been towards an increase in crop exports, production of those crops has drastically dropped during the last three years due to the political turmoil that the country is experiencing [Evaluation Technologies, Inc., 1982].

Probably the most important aspect of Salvadorean agriculture is the subsistence cultivation which produces the bulk of the food crops for internal consumption. Approximately 70 percent of the staple crops come from subsistence farming [Arze, 1982].

F. Climatic Impact on Agriculture

As indicated before, agriculture in El Salvador has several limitations due to climatic conditions. Perhaps one of the most noticeable climate impacts on agriculture is the inability to practice agriculture the year-round due to the dry season. Not only is the land unoccupied in the dry season, but also the farmers. It is important to point out that the staple crops are affected most by the lack of rain during the dry periods thus reducing the production of commodities. However, it appears that a certain amount of irrigation has been practiced during the dry season in various areas, such as Zapotitan and Sonsonate, to increase food production [Lebaron and Percy, 1973]. Also, some farms can be found on the river

basins. Very often soils on the river basins are quite fertile and retain moisture for a long period of time. Some farmers practice agriculture on areas outside river basins during the dry season. These areas are selected sites with soils that preserve moisture. Generally, the land is plowed and planted with crops which have low water requirements for vegetative growth. This type of farming does not require irrigation and is regionally called "Cultivos de Humedad." However, these dry season cultural practices are conditioned by the traditional wet season.

The weather hazards of winds and hurricanes that beset surrounding areas in Central America do not occur as frequently in El Salvador. Generally speaking, pests and plant diseases do not present a real threat to agriculture, mainly because presently there are mechanisms to fight such diseases. However, agriculture is seriously affected by droughts which occur during the rainy season.

Droughts are basically observed every year with varying duration. Droughts seem to cause the most noticeable damage because they often occur at the same time that the crops are experiencing their most critical vegetative stages. During the last two decades, El Salvador has suffered severe agricultural losses due to the presence of droughts during the rainy season, primarily during the critical time in the middle of the rainy season. An attempt is made here to cite some of the most severe and recent droughts in El Salvador.

Precipitation was far below normal during June and July, 1972, and there were great losses to agriculture. No precipitation fell from July 15 to August 14, 1974, causing heavy agricultural losses in corn and bean production in the southern part of the country. Sugarcane yields were cut by drought in 1975. No rain for 25 days, from July 15 to August 10, 1976, in several parts of the country caused serious damage to corn, rice, and

beans; rainfall deficits were as high as 90 percent in August [WMO, Vol. 26, October, 1977]. In 1977, grain crops suffered from lack of soil moisture as weather was dry most of the year; severe drought occurred after mid-year.

Compared to droughts, floods are infrequently observed. The flood intensity and frequency greatly depend upon the nature of the rainy season. They are sometimes linked to tropical storms or disturbances that pass through the south of the Caribbean Sea, moving westward. One example is the floods caused by hurricane Fifi in 1974.

G. Technology Changes in the Past 15 Years

There has been a general trend toward modernization of agricultural practices. Automated machinery has gradually been introduced during the last decade. The use of fertilizers is virtually imperative in both commercial and subsistence farming. Aerial spraying has already been practiced for several years, mostly on cotton plantations. A certain amount of irrigation has been practiced in various areas of the country. For some time the Ministry of Agriculture, through the Centro Nacional de Tecnologia Agropecuaria (CENTA), has provided agricultural extension services to farmers. In spite of the fact that those services have not been fully extended to the entire country, knowledge of many up-to-date farming procedures are available.

CHAPTER III

DATA AND METHODOLOGY

A. Meteorological Data

The meteorological data used in this report includes available records of monthly air temperature, relative humidity, sunshine, evapotranspiration and wind speed for the years 1970 and 1975. The data were obtained from the Servicio Meteorologica de El Salvador [1975] and World Meteorological Organization Publication Number 71 [1972]. Twenty-three principal weather stations with almost complete records were selected, uniformly distributed throughout the country [Figure 3.1]. Not all the selected weather stations report pan evaporation; therefore piche evaporation data were used. The wind data were reported as the average speed in km/h and direction in percentage.

1. Selection of Data

In this report, the meteorological elements were carefully selected and the data were quality controlled. Some weather stations do not have all the records for the above weather elements. The selection of the weather stations was based upon the geographical location and completeness of data. The meteorological elements selected are those that have the most influence on soil moisture, potential evapotranspiration and evapotranspiration.

2. Capabilities and Limitations

Long periods of record, needed to observe the most common trends of the climate to see how they affect agriculture, were not available for the above meteorological elements. Agronomic data, such as area, production and yield of main crops in El Salvador, were also not available. It would be important to have such records to correlate them with the outputs of

Figure 3.1. Selected Weather Stations in El Salvador

this report. However, in spite of all these limitations, this report provides the basis to make a more extensive analysis of climate-agriculture.

3. Episodic Events

Episodic event data include documented reports on the historical occurrences of droughts, flooding and other anomalous weather events associated with crop failure.

Many different episodic events have been registered for El Salvador by various institutions, organizations and news media. Some episodic events have been gathered since 1957 [Ravelo and Steyaert, 1983]. The most severe and recent of them are discussed above. A great deal of that information was obtained from reports of the World Meteorological Organization, United States Department of Agriculture, FAO, and The New York Times.

B. Methodology

1. Climatic Analysis for El Salvador

In spite of the great geographic variety which characterizes the Central American region, and results in a profusion of regional and local climates, there still persists a relatively strong and clearly observable pattern of climate which reflects the great planetary controls. According to Trewartha [1961], the whole region is dominated by the seasonally shifting subtropical anticyclones of the North Atlantic and North Pacific, together with the tropical easterlies located on the equatorial margin.

In El Salvador, particularly, climate events are primarily reflected in the rainfall activity. There are many meteorological factors that contribute to either seasonal or unseasonal precipitation, starting from planetary scale to orographic and diurnal conditions. Only the most important factors are discussed in this report.

The phenomenon of precipitation in El Salvador is partially dependent upon the migration of the Intertropical Convergence Zone (ITCZ). The

ITCZ is a broad transitional zone where the trade winds converge; it swings north and south with the sun. Kendrew [1953] points out that in April the lowest pressures are over the equator, and as the sun enters the northern hemisphere the ITCZ follows. The ITCZ reaches its most northerly position in July, when it extends up to the middle of Central America [Figure 3.2]. By November the ITCZ begins to migrate equatorward and reaches its southernmost point in January [Figure 3.3]. The ITCZ migrates less on the ocean; on the Pacific coast it remains north of the equator even during the period of November through April. Formation of precipitation depends on the uprising movement of the air. There is convergence of air, which implies rising motion, along the ITCZ thus providing the necessary conditions for convection and precipitation.

The rainy season, not only in El Salvador but also in the entire Central American region, occurs when the ITCZ moves away from the equator. Consequently, it should be clear that the rainy season and precipitation are associated with the ITCZ. According to Kendrew [1953] the heaviest convectional downpours and frequent thunderstorms occur near the ITCZ. Also, Hastenrath [1975] suggests that the near disappearance of the temporales on the Pacific side of the Central American region, which basically occur during the latter part of the rainy season, can be related to the equatorward shift of the ITCZ over the eastern North Pacific.

The rainfall regime, as well as the rainy season, is associated with the trade wind inversion. The trade wind inversion takes place when the humid air, characteristic of the tropics, extends to only moderate heights. At a comparatively low level, the moisture content falls off very rapidly with height; the region of rapid change may be marked by an inversion of temperature. Above lies extremely dry air, the superior air. Berry et al [1945] admit that a sharp zone of demarcation between the humid lower layer

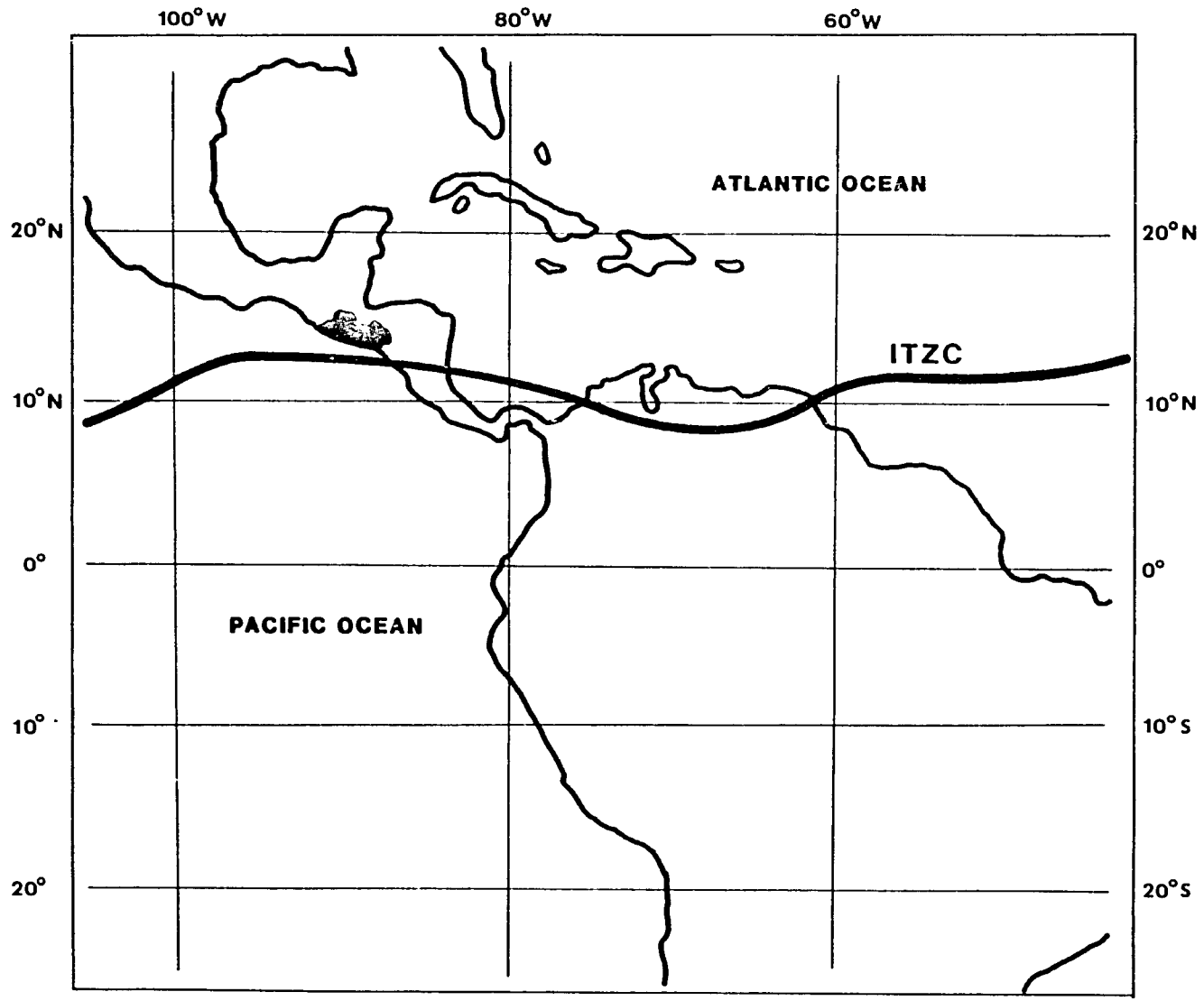


Figure 3.2. Mean Position of the ITCZ During June-August, 1958 (Adapted from Rudloff, 1981)

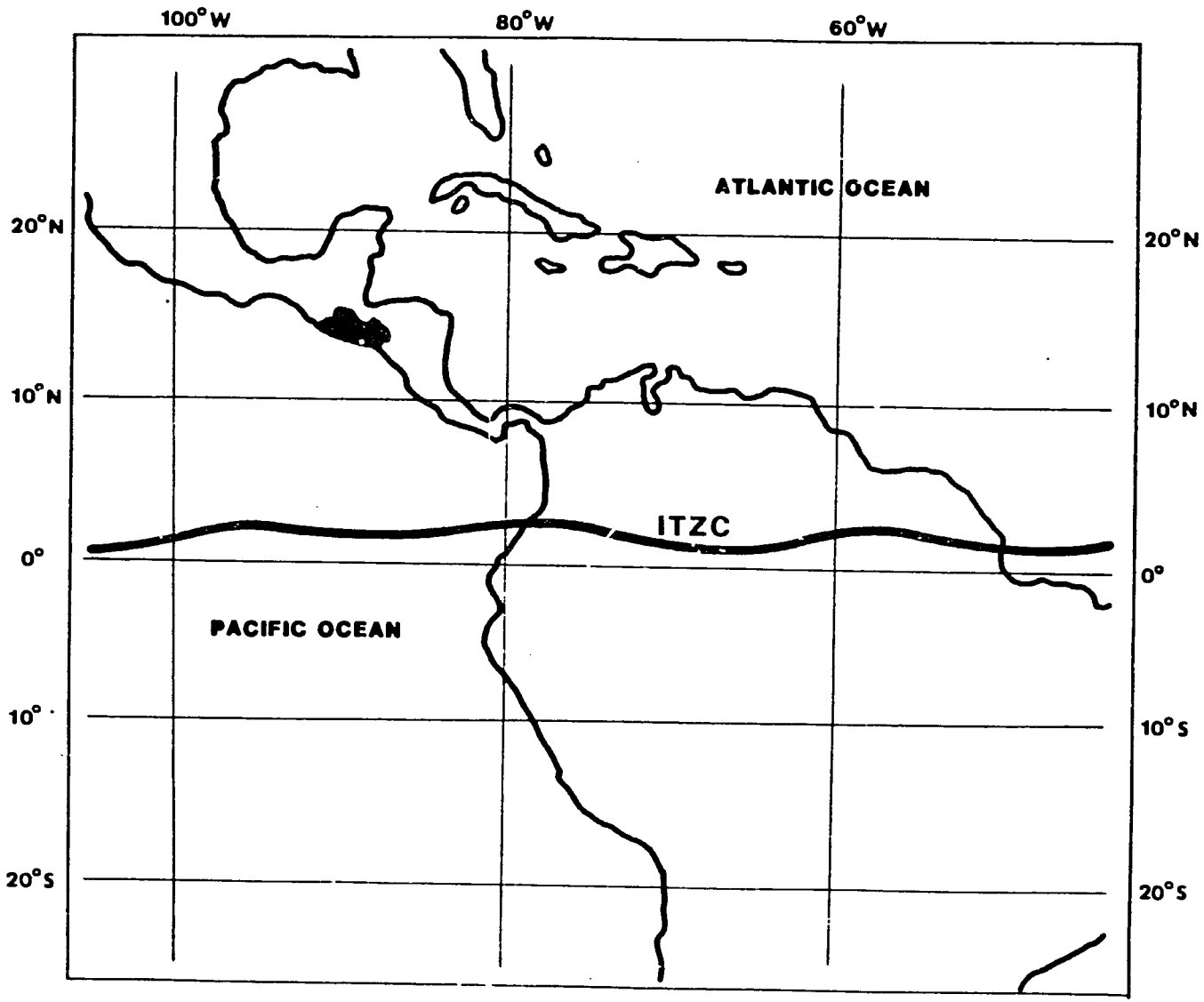


Figure 3.3. Mean Position of the ITCZ During December, 1957-February, 1958 (Adapted from Rudloff, 1981)

and the dry upper air almost always exists, even in the absence of any temperature inversion. Trewartha [1961] indicates that during the period of June through September the inversion is either absent or confined to high levels. During the dry season, by contrast, the inversion is lower and more frequent except in the highlands where altitude offsets latitude to produce mesothermal conditions. It can be inferred that there is a strong correlation between frequency, strength and height of the trade wind inversion and seasonal rainfall amounts. Dry periods, unlike wet periods, are characterized by high frequency of inversion occurrence, low trade wind inversion and strong trade wind inversion.

Another meteorological factor that affects the rainfall regime in El Salvador is the western Atlantic polar trough. This feature is important because it has some effect on the continuity of the rainy season. As described and explained earlier, the wet season in El Salvador is abruptly interrupted by the so called Canicula Interestival. The early peaks of rainfall seen at the beginning of the rainy season are correlated with the positions of the trough, which at those times are more nearly centered over the area. Trewartha [1961] claims that the proximity of the trough means more perturbations and hence more rainfall. These remarks well agree with Rudloff [1981] who says that tropical disturbances very often have a decisive influence on the shower activity.

2. Agroclimatic Tools

Several agroclimatic tools are investigated which include various methods for estimating potential evapotranspiration (PET), soil moisture, evapotranspiration (ET), Palmer Drought Index (PDI) and crop water requirements. These tools are used in crop yield modeling and as input for land use studies involving climate impact.

Potential Evapotranspiration

The concept of potential evapotranspiration is not new. Penman [1948] and Thornthwaite [1948] put forth this concept which has had a major influence on attempts to predict water needs in agriculture. Rosenberg [1974] defines potential evapotranspiration as

> ...the evaporation from an extended surface of a short green crop which fully shades the ground, exerts little or negligible resistance to the flow of water, and is always well supplied with water. Potential evapotranspiration cannot exceed free water evaporation under the same weather conditions.

PET estimates are essential to establish moisture demand on crops and land use studies.

Various methods are used to estimate potential evapotranspiration. Each method requires as input a different set of meteorological elements. Three methods examined in this report are described below.

Penman Method

A simplified version of Penman's equation [1948] is presented by Rosenberg [1974] in the following form:

$$PET = \frac{aR_n + bc(e_s - e_a)(1 + U_2 \times 10^{-2})}{a + b}$$

where

PET = potential evapotranspiration in mm/day,

a = slope of the saturation vapor pressure for pure water at mean temperature in mm Hg/°F,

R_n = net solar radiation in mm/day,

b = constant in the hygrometric equation (0.27 mm Hg/°F),

c = constant (0.35),

e_s = saturation vapor pressure (mm Hg),

e_a = actual vapor pressure (mm Hg), and

U_2 = mean wind speed at 2m (km/day).

This method uses solar radiation or sunshine, vapor pressure, wind speed and temperature to estimate potential evapotranspiration. Vapor pressure is not included in the data set, but is calculated from the values of relative humidity and air temperature. This method has the advantage that it considers both the solar radiation and water vapor fluxes within the crop canopy evapotranspiration surface and the atmosphere near the ground. However, it does not account for advective fluxes such as sensible and latent energy.

Hargreaves Method

Hargreaves [1977] developed an equation to compute PET based on air temperature and solar radiation. Sunshine hours can be used instead of solar radiation when the latter is not available. Hargreaves' formula is

$$PET = 0.0075(RSM)TMF$$

where

PET = potential evapotranspiration (mm/day),

RSM = solar radiation (mm/day), and

TMF = monthly mean temperature (°F).

This method requires solar radiation data which is are not always available. If only air temperature and sunshine information are available, it is possible to estimate solar radiation. Thus, Hargreaves has developed several empirical equations to estimate solar radiation from a variety of commonly observed meteorological parameters.

When not measured directly, solar radiation (RSM) can be calculated from tabular values of extraterrestrial radiation, RMM, in equivalent mm

of water evaporation per month and from the percentage of possible sunshine (S) occurring at a given location. The conversion equation from RSM to RMM, allowing for the difference in sunshine percentage, can be written as

$$RSM = 0.075\ RMM \times S^{1/2}$$

where S is the possible sunshine which can be determined from the actual duration of sunshine in hours (SH) from day length (DL) and from the number of days in the month (DM). The equation for S is

$$S = 100\ \frac{SH}{DL} \times DM.$$

Thornthwaite Method

Thornthwaite [1948] describes the biological and physical importance of evapotranspiration in climatic determination. As a consequence of his efforts in studies of climatic classification systems, he developed an equation for estimating potential evapotranspiration. The general formula is expressed as

$$PET = 1.6(10\ \frac{T}{I})^a$$

where

PET = estimated potential evapotranspiration in cm/day,

T = monthly mean air temperature in °C,

I = annual heat index which is a function of the normal mean temperature of each month or

$$(I = \sum_{i=1}^{12} \frac{(\text{monthly normal mean temperature})}{5}^{1.514}),\ \text{and}$$

a = polynomial function of I ($a = 6.75 \times 10^{-3} I^3 - 7.71 \times 10^5 I^2 + 1.79 \times 10^{-2} I + 0.49$).

The formula must be adjusted for daylength at each location because not all the months of the year have an equal number of days and the numbers

of the sunshine hours (daylength) change with seasons of the year and latitude. This method has the great advantage of using only one meteorological parameter and the local latitude as input. Nevertheless, one must be aware that mean temperatures do not necessarily correspond to the surface energy balance which is closely related to the evapotranspiration process.

Soil Moisture

Soil water content is an important parameter for numerous applications in agriculture. Soil moisture plays an important role not only for plant growth, development and yields but also for farm operations and practices such as planting, cultivation, harvesting and irrigation. Direct measurements of soil moisture involve several problems related to instrumentations and the variations in soil characteristics and moisture content. In recent years, direct soil moisture measurements have been feasible mostly in experimental work. However, estimates of soil moisture can be determined from agroclimatic techniques. Numerous methods have been proposed. Baier and Robertson [1966] proposed a computerized mathematical model for estimating changes in daily soil moisture content in various zones of the soil profile from daily totals of precipitation and potential evapotranspiration. Baier et al [1979] provided the most recent version of this model.

The required accuracy and frequency of soil water measurements depend upon the purpose of application, but one aspect common to all users might be that they require a rapid, reliable, nondestructive method for measuring soil water content. As far as this report is concerned, such a method has not yet been fully developed. Available soil moisture for this report was estimated by using Palmer's technique [1965] which is based on soil moisture balance.

Palmer [1965] divides the plant-soil system into two arbitrary layers. The upper layer, which is equivalent to the plow layer, is assumed to hold 25.4 mm of available moisture at field capacity lost at a potential rate. Furthermore, it is assumed that the underlying layer loses water at that potential rate when the profile is saturated. The plant available water in the underlying layer depends on the depth of the root system and the soil characteristics in the area under investigation.

The water loss due to actual evapotranspiration for the surface and also the underlying layer is expressed by the following equations:

1. $L_s = S_s$ or PET_c, whichever is smaller
2. $L_u = (PET_c - L_s) \dfrac{S_u}{(PAW_{max} - 25.4)}$
3. $AET = L_s + L_u$

where

PET = potential evaportranspiration,

L_s = loss from the soil surface layer,

L_u = loss from the underlying layer,

S_s = actual available soil moisture in the surface layer from the previous month's budget,

S_u = actual available soil moisture in the underlying layer from the previous month's budget,

AET = actual evapotranspiration, and

PAW_{max} = maximum plant available water or the difference between the field capacity and the permanent wilting point of the soil.

The budget is initiated at some previous time when the soil moisture is at field capacity. Precipitation exceeding storage capacity of the soil

is accounted for as runoff (RO).

Ravelo and Steyaert [1983] define the plant available water (PAW) as follows:

$$PAW_i = PAW_{i-1} + P_i - AET_i - RO_i$$

where

PAW_i = plant available water for the current ith month,

PAW_{i-1} = plant available water for the previous month's budget,

P_i = rainfall for the ith month,

AET_i = actual evapotranspiration for the ith month, and

RO_i = runoff for the ith month

The major inputs to this soil moisture model are monthly rainfall data and PET estimates.

Evapotranspiration and Runoff

Most water evaporated at plant surfaces is water that has passed through the plant, entering at the root hair and passing through the vascular tissue to the leaves or other organs. The process of evaporation of water that has passed through the plant is called transpiration. Soil evapotranspiration and plant transpiration occur simultaneously in nature and there is no easy way to distinguish between the two processes. Hence, the term evapotranspiration (ET) is used to describe the total process of water transfer to the atmosphere from vegetation land surfaces.

Terms associated with the water balance in the soil include precipitation, irrigation, percolation, runoff, evapotranspiration and the change in volume of water stored in the soil during some specified time period (Rainfall + Irrigation = Percolation + Runoff + ET + change in volume of water stored [from Rosenberg, 1974]).

Runoff is defined as the portion of precipitation on the land which does not infiltrate the ground and flows over the surface, ultimately reaching the streams and then the sea. The runoff magnitude greatly depends on slope and drainage of soils.

Crop Coefficients

To account for the effect of crop characteristics on crop water requirements, crop coefficients (KC) are studied to relate PET to crop evapotranspiration PET. The KC values represent evapotranspiration of crops under optimum conditions producing optimum yield.

Doorenbos [1975] defines the crop coefficient as

$$KC = \frac{PET\ (crop)}{PET\ (ref)}$$

$$PET\ (crop) = KC \times PET\ (ref)$$

where PET (ref) can be obtained from any of the three PET methods discussed above.

Crop coefficients are helpful to determine the crop water requirements for different crops at various stages of development. Factors affecting the values of the crop coefficient (KC) are mainly the crop characteristics, crop planting or sowing date, rate of crop development and length of growing season. General climatic conditions, especially wind and humidity, need to be considered. It is well known that it is the wind conditions which will affect the rate of transpiration due to the degree of air turbulence above the rough crop canopy. The rate of transpiration is higher under dry air wind conditions compared to humid air wind conditions.

Doorenbos [1975] divided the crop growing season into four stages. For each stage, he found crop coefficients (KC) for different climatic conditions; they are presented in Table 3.1. He defines the four

Table 3.1

Crop Coefficients (kc)

CROP	Crop Development stages					Total growing period
	Initial	Crop development	Mid-season	Late season	At harvest	
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
subtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75-0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soybean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Watermelon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 -0.25	0.8 -0.9
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.05
Citrus						
clean weeding						0.65-0.75
no weed control						0.85-0.9
Olive						0.4 -0.6

First figure : Under high humidity (RHmin >70%) and low wind (U <5 m/sec).
Second figure: Under low humidity (RHmin <20%) and strong wind (>5 m/sec).
Source: Doorenbos and Pruitt (1977).

stages in crop development as follows:

1. Initial stage

Germination and early growth when the soil surface is not or hardly covered by the crop.

2. Crop development stage

From end of initial stage to attainment of effective full ground cover.

3. Mid-season stage

From attainment of effective full ground cover to time of start of maturing as indicated by discoloring of leaves (beans) or leaves falling off (cotton).

4. Late season stage

From end of mid-season stage until full maturity or harvest.

Crop Water Requirement

The crop water requirement (CWR) varies widely between climates having similar air temperatures for example, between very dry and very humid climates or between generally calm and very windy conditions. The effect of climate on crop water requirements is thus not fully defined by the temperature and day length alone. Consequently, crop water requirements vary not only with the kind of crops but also with climatic conditions.

The sources of water supply are primarily rainfall and soil available water. Moisture deficiences may result from below normal water supply, above normal crop water requirements or both. The crop water requirement is a function of the atmospheric demand, the kind of crop, and crop growth stages. It is possible that by monitoring the water supply and crop water demands, assessments on crop conditions can be made.

The CWR is defined as the depth of water needed to meet the water loss

through evapotranspiration (PET crop) of a crop free of diseases growing in large fields under nonrestricted soil conditions. Soil water content and fertility most be included to achieve full production potential under a given growing environment.

As indicated earlier, crop water requirements are calculated by considering the effects of climate, crop characteristics, local conditions and agricultural practices, including the local climate, altitude, size of fields, advection, soil water availability, soil salinity, cultivation methods, and practices for which local field data are required.

As described by Doorenbos and Pruitt [1977], the CWR may be estimated as:

$$CWR_{ij} = PET_i * KC_{ij}$$

where

CWR_{ij} = crop water requirement for the jth crop and the ith crop growth stage,

PET_i = average potential evapotranspiration for the ith crop growth stage (PET for the reference crop), and

KC_{ij} = appropriate crop coefficient for the jth crop and the ith crop growth stage.

The CWR plays an extremely important role in agriculture, mainly as a tool for conducting land use studies. Climatic and soil information, such as maximum plant available water moisture, can help to determine which crops are appropriate and when they should be planted to minimize drought vulnerability. For instance, plant available soil moisture, estimated from the soil moisture budget, and the water requirements for a specific crop can be computed for a 15 or 30 year period. Probabilistic values for a crop requirement being satisfied can be determined for some desired level such as 3 of 4 years or 9 of 10 years.

3. Agroclimatic Indices

The main objective of agroclimatic indices is to provide reliable information on the impact of weather on crop yield. The indices discussed here, related to crop water requirements and based on monthly precipitation data, provide monthly crop condition assessments. For instance, the nature of drought impact on agriculture may be examined by analyzing various agroclimatic indices. They can be expressed in meteorological units or in nondimensional form.

These indices include the following.

a. Yield Moisture Index

The Yield Moisture Index (YMI) was developed by CEAS [1979] and is defined for a particular crop as:

$$YMI_j = \sum_{i=i}^{N} P_i \, KC_{ij}$$

where

YMI_j = Yield Moisture Index for jth crop (corn, beans, etc.)

P_i = precipitation during the ith crop growth stage (planting, vegetative, flowering, etc.), and

KC_{ij} = appropriate crop coefficient for the ith crop stage and jth crop (KC developed by Doorenbos and Pruitt, 1977).

The YMI is a drought index and represents an improvement over cumulative rainfall because it weights each crop stage of the individual crops. For example, the water requirement at the reproductive stage is much higher than at earlier crop stages.

b. R-Index

The R-Index, developed by Yao [1966], is a measure of plant water supply in relation to plant water requirements. The R-Index is

defined as:

$$R = \frac{AET}{PET}$$

where R is a nondimensional variable with values between 0.0 and 1.0. The R-Index is mainly a function of the atmospheric energy which contributes to evaporation from the soil and plant surface and precipitation which replenishes the soil moisture.

According to Yao [1966], this index can be used as a tool to help solve the problems of agricultural land use capabilities, long term agricultural planning, irrigation project design, and agricultural drought. The R-Index can also be used to analyze the effect of water stress on crop response and to estimate optimum crop planting dates to ensure adequate moisture during critical growth stages. For instance, optimum crop planting dates can be determined by first obtaining those periods when the R-Index approaches the value of one, which would be ideal for the flowering stage of the crop.

c. Soil Moisture Index

The Soil Moisture Index (SMI), developed by Ravelo and Decker [1977], is based on the assumption that the seasonal distribution of soil moisture characterizes the effects of climate and weather variability on plant growth better than any single climate parameter. The index is defined as the ratio between the plant available water (PAW) and the maximum plant available water (PAW_{max}). The plant available water is the difference between actual soil moisture (SW) and permanent wilting point (PWP), while the maximum plant available water (PAW_{max}) is the difference between the field capacity (FC) and the permanent wilting point (PWP). The SMI normalizes the soil moisture according to variations in the type of plant

and soil. Thus, the Soil Moisture Index is defined as:

$$SMI = PAW/PAW_{max}$$

where

$$PAW = SW-PWP$$

$$PAW_{max} = FC-PWP.$$

Field capacity (FC) is defined as the maximum moisture that can be retained by the soil after excess gravitational water has drained away.

The values of the SMI range from 0.0 through 1.0. A SMI of zero indicates extreme moisture stress while a value of one indicates no moisture stress on the crop. The computation of this index requires some methods to estimate both PET and soil moisture.

d. Palmer Drought Index [Palmer, 1965]

The Palmer Drought Index (PDI) is a potentially useful method for assessing the impact of drought on agriculture and providing information on the duration and intensity of drought. The PDI is based on monthly fluctuations of soil moisture conditions which are estimated from a hydrological accounting system. The required input data include the water holding capacity of the soil, monthly precipitation, and monthly potential evapotranspiration.

Ravelo [1983] clearly summarizes the method for calculating the PDI which allows computation of a Climatologically Appropriate for Existing Conditions (CAFEC) Index for precipitation, evapotranspiration, soil moisture recharge, loss and runoff. For an individual month the CAFEC quantities (denoted by a circumflex) for precipitation (P), loss (L), and runoff (RO) are computed as follows:

1. $P = ET + R + L + RO$

2. $ET = PET \dfrac{\overline{ET}}{\overline{PET}}$

where PET and $\overline{PET}$ are the current and average potential evapotranspiration, and $\overline{ET}$ is the average actual evapotranspiration.

3. $L = PL \dfrac{\overline{L}}{\overline{PL}}$

where PL and $\overline{PL}$ are current and average potential loss of soil moisture, and $\overline{L}$ is the average soil moisture loss. PL is defined as

$$PL = PL_s + PL_u$$

where PL_s = PE or S_s, whichever is smaller, and $PL_u = (PET - PL_s) \dfrac{S_u}{PAW}$.

4. $R = PR \dfrac{\overline{R}}{\overline{PR}}$

where PR and $\overline{PR}$ are the current and average potential recharge, and $\overline{R}$ is the average recharge.

Potential recharge is defined as the amount of moisture required to bring the soil to field capacity. Thus,

$$PR = PAW - S$$

where S is the amount of available moisture in both layers of the soil at the beginning of the month ($S = S_s + S_u$).

5. $RO = PRO \dfrac{\overline{RO}}{\overline{PRO}}$

where PRO and $\overline{PRO}$ are the current and average potential runoff, and $\overline{RO}$ is the average runoff.

Potential Runoff is defined as

PRO = PAW - PR or

PRO = S.

The difference between the actual precipitation and the CAFEC

precipitation for each month represents a fairly direct measure of moisture departure from normal:

$$d = P - P.$$

These departures are weighted and the resulting index is reasonably comparable both in space and time.

The appropriate weight (K) for the term (d) is a ratio of average moisture demand and supply, and can be estimated for each month as follows:

$$K = \frac{(PET + R)}{(\overline{P} + \overline{L})} .$$

The monthly "moisture index, Z," is therefore defined as:

$$Z = dK.$$

Successive monthly indices for past dry periods are combined to yield drought classes: mild, moderate, severe, and extreme.

Finally, the drought severity index can be calculated using the following equation:

$$X_i = X_{i-1} + \frac{Zi}{3} - 0.103\ X_{i-1}$$

where X_i = severity index for the ith month and

X_{i-1} = severity index for the previous months.

The PDI treats wet and dry periods as a function of accumulated differences between supply (precipitation) and demand (evapotranspiration). Conditions of near normal rainfall should provide an average moisture supply to the surface layer of the soil. Moreover, above normal precipitation is usually necessary after a drought to restore the soil moisture to normal conditions. The PDI is designed to allow comparison of any month or region to average conditions. The index is potentially capable of providing

useful assessment information on both flooding and drought situations. Also, the index has been used as an indicator of general crop conditions and the availability of soil moisture to meet the needs of crops.

The PDI is designed to monitor both dry and wet periods. The index values are scaled such that negative values indicate drought and positive values indicate wet conditions. An index of zero indicates normal conditions. Table 3.2 provides the index categories for the dry and wet periods.

Palmer [1965] points out that a drought index of -4.0 spells economic disaster in any region in which the established economy is significantly dependent on the weather for its moisture supply. He suggests that the last four drought classes present problems in the vegetative development of plants. He describes those classes as follows:

1. Mild drought: Some of the native vegetation almost ceases to grow.
2. Moderate drought: The least drought-resistant members of the native plant community begin to die and the more xerophytic varieties start to take their place.
3. Severe drought: Only the most xerophytic varieties of native vegetation continue to grow and vegetal cover decreases.
4. Extreme drought: Drought-resistant varieties gradually give way to open cover. More and more bare soil is exposed.

e. Crop Condition Index

The Crop Condition Index (CCI) is a potentially useful method for indicating the normalities or abnormalities of crops. In order to compute the crop condition index it is necessary to consider the effect of the previous month's rainfall on the present month's water supply. Thus the

Table 3.2

Palmer Drought Index (PDI)
Classes for Wet and Dry Periods

PDI			CLASS
	≥	4.00	Extremely wet
3.00	to	3.99	Very wet
2.00	to	2.99	Moderately wet
1.00	to	1.99	Slightly wet
0.50	to	0.99	Incipient wet spell
0.49	to	-0.49	Near normal
-0.50	to	-0.99	Incipient drought
-1.00	to	-1.99	Mild drought
-2.00	to	-2.99	Moderate drought
-3.00	to	-3.99	Severe drought
	≥	-4.00	Extreme drought

Antecedent Precipitation Condition (APC) is defined as:

$$APC_i = P_{i-1} - CWR_{ij-1}$$

for $P_{i-1} > CWR_{ij-1}$, otherwise $APC_i = 0$

where

APC_i = antecedent precipitation condition for the ith month,

P_{i-1} = precipitation during the previous crop growth stage, and

CWR_{ij-1} = crop water requirements for the previous crop growth stage.

During the planting period, APC is estimated as

$$APC_i = P_{i-1} - PET_{i-1}$$

for $P_{i-1} > PET_{i-1}$, otherwise $APC_i = 0$

where

PET_{i-1} = potential evapotranspiration during the month prior to planting, and

P_{i-1} = precipitation during the month prior to planting.

Therefore, the CCI is defined as:

$$CCI_{ij} = \sum_{i=1}^{n} \frac{(APC_i + P_i)}{CWR_{ij}}$$

where

CCI_{ij} = Crop Condition Index for the jth crop and the ith crop growth stage, and

P_i = rainfall during the ith crop growth stage.

It must be pointed out that rainfall is censored to 200 mm which is approximately the field capacity for medium texture soils.

The CCI should be meticulously tested and evaluated before operational use. The CCI, alike most indices, can be used for crop assessments.

4. Application of Indices

The agroclimatic indices, discussed above, provide an objective method

for assessing drought impact on agricultural crops. They are not designed to assess the impact of flooding or other anomalous weather factors which may determine variations in crop yield from one year to another. Similarly, the indices are not intended to assess crop conditions in areas under effective irrigation.

Furthermore, agroclimatic indices can provide useful information on drought impact in terms of relative crop yield or production by the end of the reproductive crop stage. For instance, an assessment about crop yield can be given before the harvesting season, sometimes as much as several weeks before harvest.

The indices can be expressed in various forms: raw values, percent normal, and percentiles. The analyst or the user can precisely decide the manner in which to present the outputs.

There are some indices that are suitable for certain areas more than others. Therefore, the analyst must decide which index or combination of indices is appropriate for the region under investigation. It is strongly recommended to have long periods of record for meteorological data to compute the indices. Moreover, it has been shown that long periods of record provide better index results. It is suggested that a period of 20 to 30 years of climatic data is adequate enough to obtain meaningful index results.

Combination of indices can be accomplished by using episodic data. For example, the indices can be computed from 20 to 30 years of historic climatic data and plotted as a time series. Episodic reports on the failure of crops due to drought may suggest that historically crop failure is associated with index values which are below a specific value.

Probably the most important application of the indices is the contribution to land use studies. They can contribute to the agricultural

crop forecast problem and crop/weather advisories to farmers. Similarly, farmers can also be advised on recommended planting date, scheduling of irrigation, and application of pesticides.

In El Salvador, particularly, the indices can be valuable tools to assess the impact of the canicula on agriculture, primarily on subsistence farming. These indices can be helpful to delineating the areas drastically affected by the canicula. Moreover, through the knowledge of the indices, farmers can be advised on when crops should be planted in order to avoid crop damages due to the canicula effects. Arze [1982] has clearly pointed out that Salvadorean farmers have recently adopted poli-agricultural practices and introduced new crops due to the canicula occurrence in many areas of the country. Thus, the indices could provide adequate information on agricultural potential, potential of the new crops being adapted to drought resistence (for example sorghum, regionally called "Sapo"), classification of climate-land interactions, and agricultural land use alternatives.

In general, agroclimatic indices could help to determine the regionally appropriate crop, optimum planting date, crop water requirements, crop calendars, and the risks involved with the crop vulnerability to climatic changes. Consequently, the indices are tools which help to reduce climatic vulnerability and lower the risk of crop failure.

5. Meteorological Satellites

The National Oceanic and Atmospheric Administration, (NOAA), United States Department of Commerce, is the agency that administrates the civilian meteorological satellites in the United States. Currently there are two kinds of civilian meteorological satellites: 1) Polar orbiting satellites, descending (North to South) and ascending (South to North) from pole

to pole, and 2) Geostationary Operational Environmental Satellites (GOES) stationed over the equator.

Information from both kinds of satellites has been used extensively to conduct land use studies and monitor many atmospheric phenomena. In meteorology, for instance, satellite data (imageries, pictures, etc.) have been used to estimate wind speed, wind direction, cloud tops, cloud bases, temperature profiles, and precipitation estimates. Most recently, meteorologists have been able to monitor tropical storms and predict, with certain accuarcy, where such storms might land. Moreover, meteorologists in middle latitudes find satellite data as an important tool to locate frontal systems and squall lines, mainly those which may bring severe weather. In agriculture, meteorological satellites now provide data that can be used for vegetation monitoring on a routine basis. Vegetation monitoring implies that assessments on agricultural crops can be provided with reliable accuracy.

An attempt is made here to briefly describe some of the characteristics of the polar orbiting satellites operated by NOAA. Currently NOAA has three spacecrafts in orbit. NOAA-6, a descending satellite, was launched on June 27, 1979. NOAA-7, an ascending satellite, was launched on June 23, 1981. NOAA-6 is at an altitude of approximately 815 km, and NOAA-7 at an approximate altitude of 860 km. The NOAA-8 satellite launched March 28, 1983 is in an orbit similar to NOAA-6 [Crosiar, 1984].

One of the primary instruments on board the NOAA polar orbiting satellites is the Advanced Very High Resolution Radiometer, (AVHRR). The AVHRR is a five channel instrument sensitive to radiation in five spectral regions:

Channel 1	0.58	-	0.68	microns (visible)
Channel 2	0.73	-	1.10	microns (near infrared)
Channel 3	3.55	-	3.93	microns (infrared)

Channel 4 10.30 - 11.30 microns (thermal infrared)
Channel 5 11.50 - 12.50 microns (thermal infrared).

NOAA-6 does not have Channel 5 on board.

The orbital period of the NOAA satellite is about 102 minutes which produces 14 orbits per day [Tarpley et al, 1984]. The acquisition of data is nearly real time, and satellites are operational in a manner that regular and continued coverage is assured; global coverage is provided every day.

According to van Dyk et al, [1984], the data from AVHRR are available from the satellite in three forms, each representing a different resolution.

Local Area Coverage (LAC) is the data recorded from selected portions of each orbit of all spectral channels for central processing. The LAC pixel (pixel is the picture element) represents an area of 1.1 x 1.1 km^2. Global Area Resolution (GAC) data are recorded with low resolution. GAC data are generated through computer processing from LAC data. One GAC pixel represents an area of about 16 km^2. Polar Stereographic Data (PSD) are generated from GAC data. One PSD pixel represents an area from 225 km^2 at the equator up to 900 km^2 at the poles.

The satellite data are processed according to user applications. For instance, daily data are used to generate weekly composites. Through this process, cloud, haze and look angle are reduced to provide a better indication of vegetation. Other processes of manipulating satellite data help to keep clouds or other meteorological features in the area under investigation. One of those features that can be analyzed is the migration of the ITCZ.

Various mathematical combinations of channel 1 and channel 2 data have been found to be sensitive indicators of the presence of green vegetation

and are referred to as vegetation indices. Two vegetation indices calculated from AVHRR channels 1 and 2 have been used routinely at CEAS. The Vegetation Index (VI) is defined by Tarpley [1984] as

$$VI = Ch_2 - Ch_1$$

and the Normalized Vegetation Index (NVI) is defined as

$$NVI = \frac{Ch_2 - Ch_1}{Ch_2 + Ch_1} .$$

The Normalized Vegetation Index is preferred for global vegetation monitoring because it partially compensates for changing illumination conditions, surface slope, and viewing aspects. Rock and soils have vegetation indices near zero. In scenes with vegetation, NVI ranges from 0.1 to 0.6; the higher values are associated with greater density and greenness of the plant canopy.

The VI emphasizes variations of healthy vegetation and provides responses for clouds and water. The VI values most commonly found are: 1) $VI < 0$ for clouds and water, 2) $VI < 8$ for healthy vegetation, 3) $0 < VI < 4$ for soils and rocks.

Some values of the VI were calculated for El Salvador during 1982, 1983 and 1984 (Figure 3.4). Pixel values over pure vegetation are given the highest return in the VI. As long as a given pixel includes soils, water, clouds, and any other features in addition to vegetation, its VI values will automatically be lower.

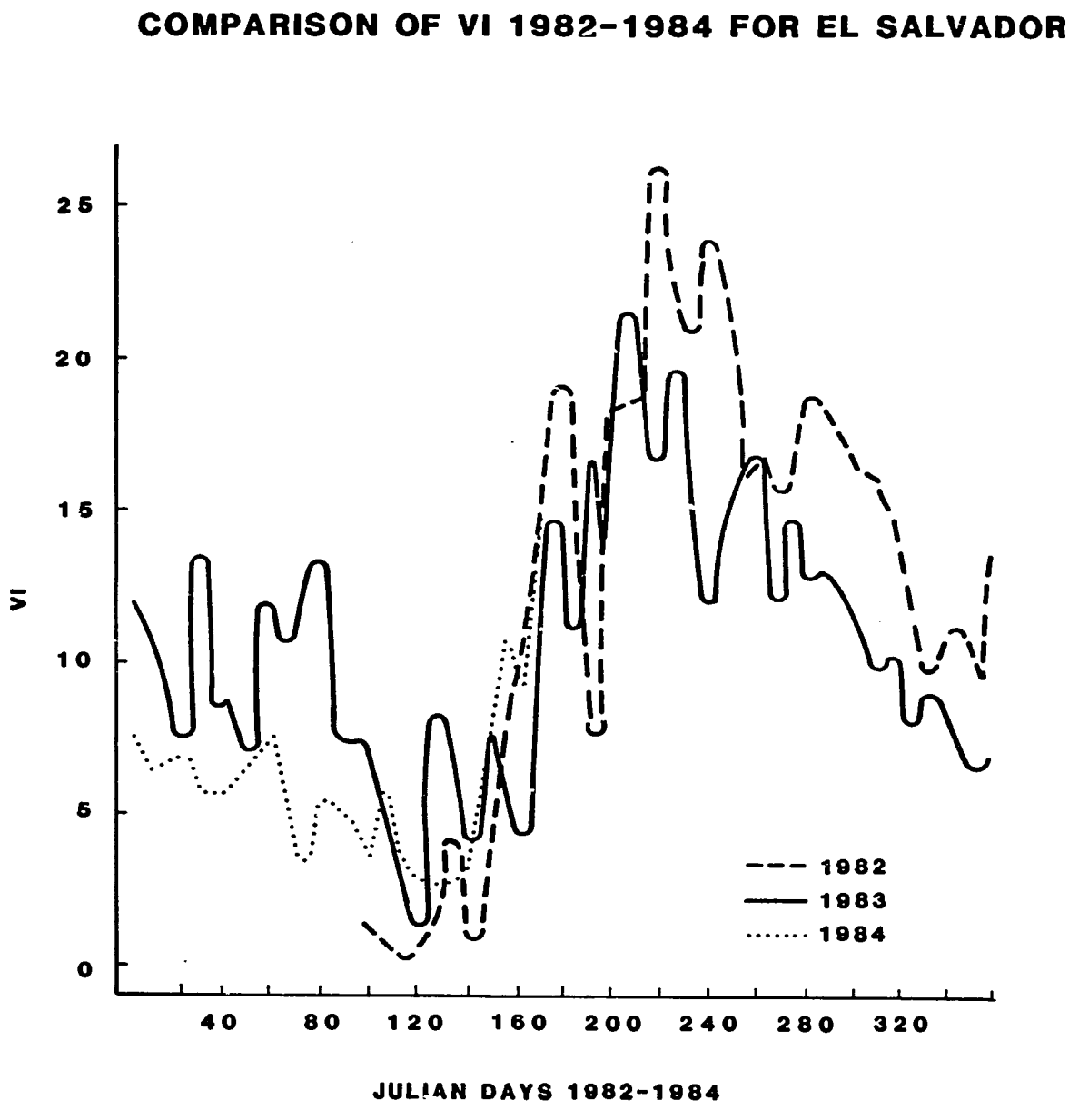


Figure 3.4. Comparison of VI 1982-1984 for El Salvador

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter some results of different methods to estimate potential evapotranspiration are compared and evaluated. Also, the results of a two-layer model to compute the soil moisture balance for three selected sites in El Salvador during 1975 are analyzed. Moreover, agroclimatic condition indices at various locations in El Salvador were developed in order to verify the impact of climate on agriculture. Finally, some satellite information for the entire Central American region was analyzed to investigate some of the capabilities that satellite data can provide to decision makers and land use planners.

A. Potential Evapotranspiration

The investigation and evaluation of three methods to estimate potential evapotranspiration was one goal of this report. PET values were calculated for the weather stations shown in Figure 3.1 during 1970 and 1975. However, only three weather stations were chosen for this report to make some analysis and comparisons of the different PET methods during 1975 (see Figures 4.1, 4.2, and 4.3). The year 1975 was selected due to data completeness and because a canicula or veranillo was observed by late June and early July. Figures 4.4, 4.5, 4.6, and 4.7 clearly show a tremendous drop of the rainfall regime compared with the normal pattern of some of the selected weather stations. Moreover, Figures 4.8, 4.9, 4.10, 4.11, 4.12, and 4.13 show the regions of El Salvador where the canicula was severe.

Monthly PET values were estimated using Penman, Hargreaves and Thornthwaite methods. Figures 4.1, 4.2, and 4.3 provide the results for Nueva Conception, La Galera, and Beneficio la Carrera, respectively. The units for the PET values are in millimeters. There is a remarkably good

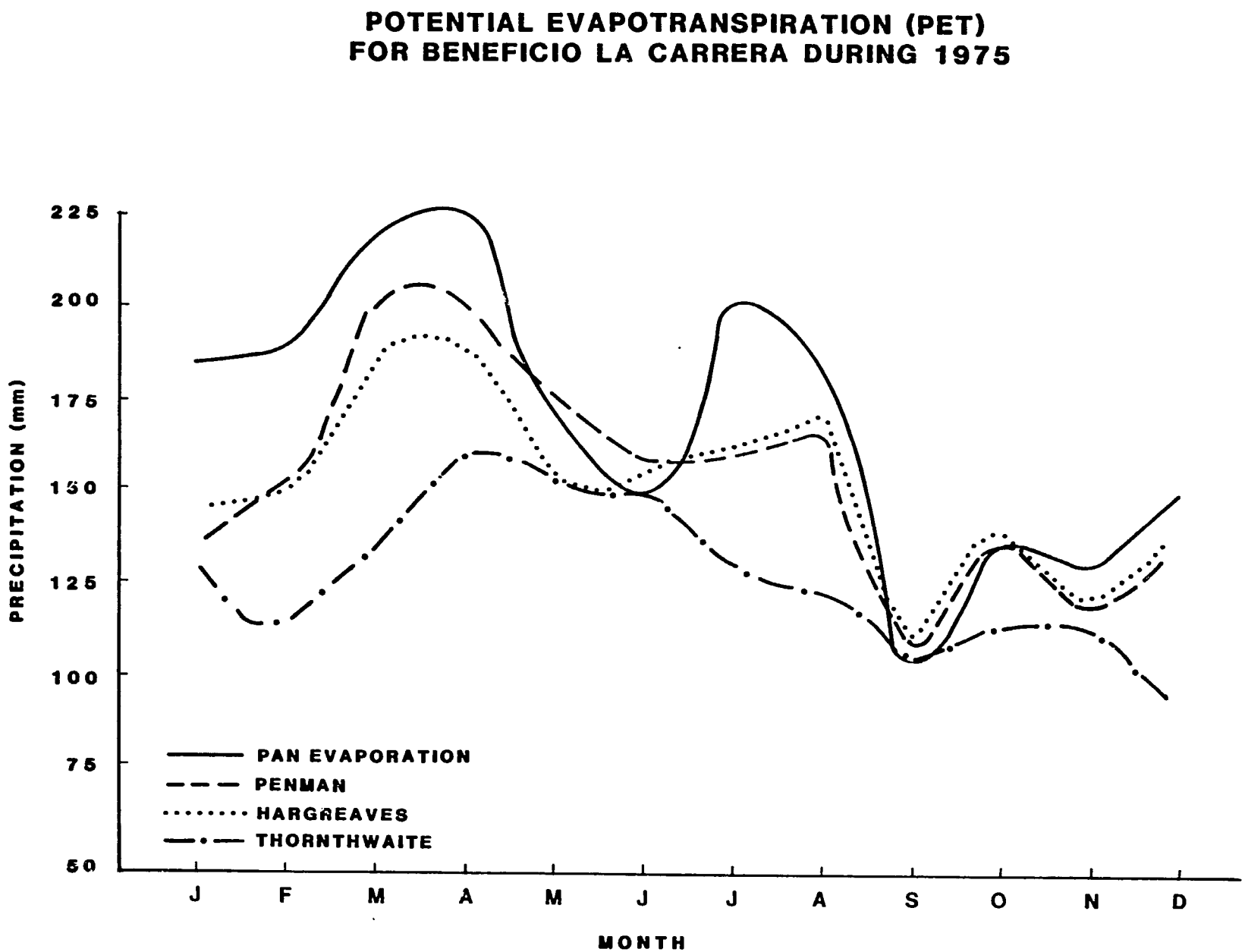


Figure 4.1. Potential Evapotranspiration (PET) for Beneficio La Carrera During 1975

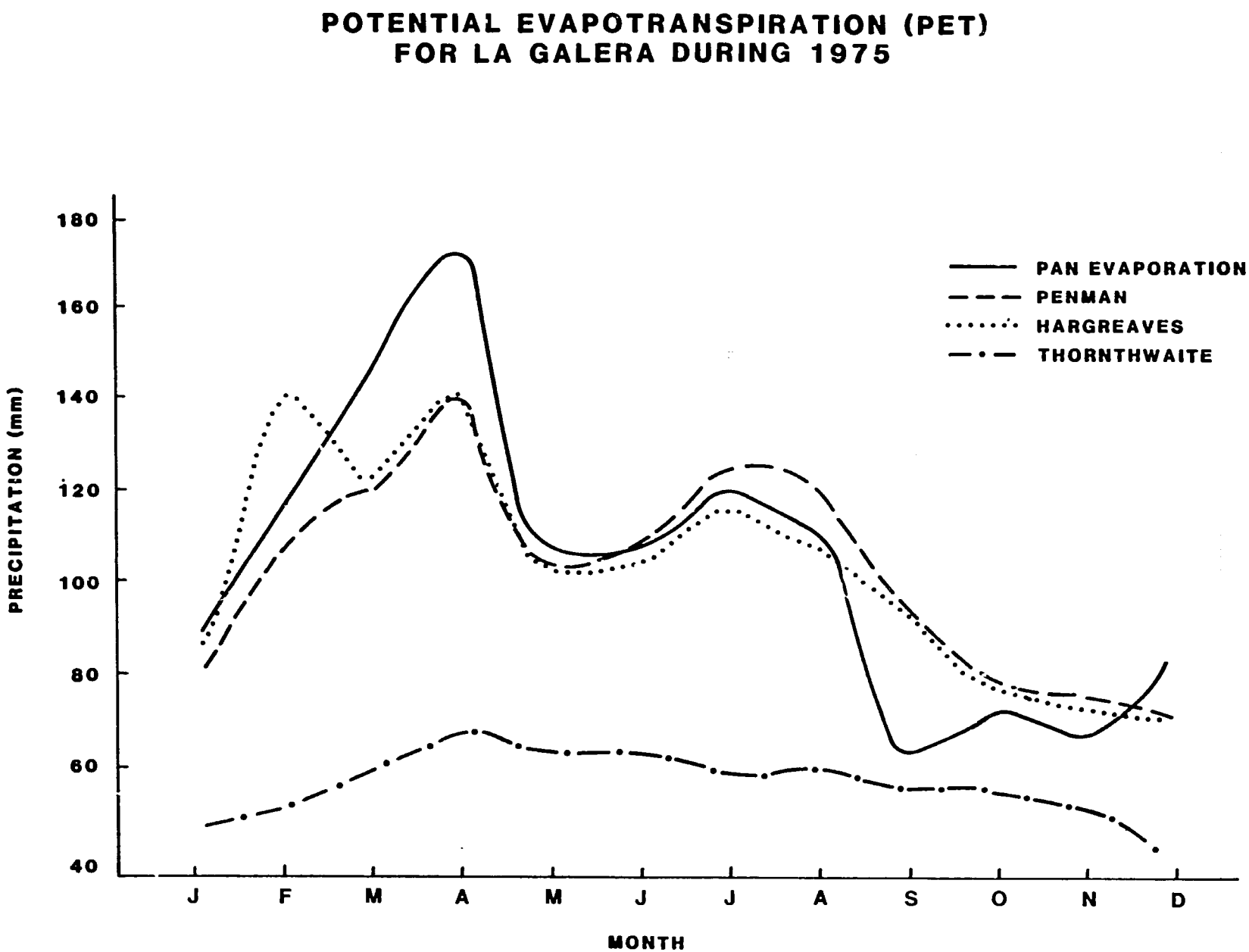


Figure 4.2. Potential Evapotranspiration (PET) for La Galera During 1975

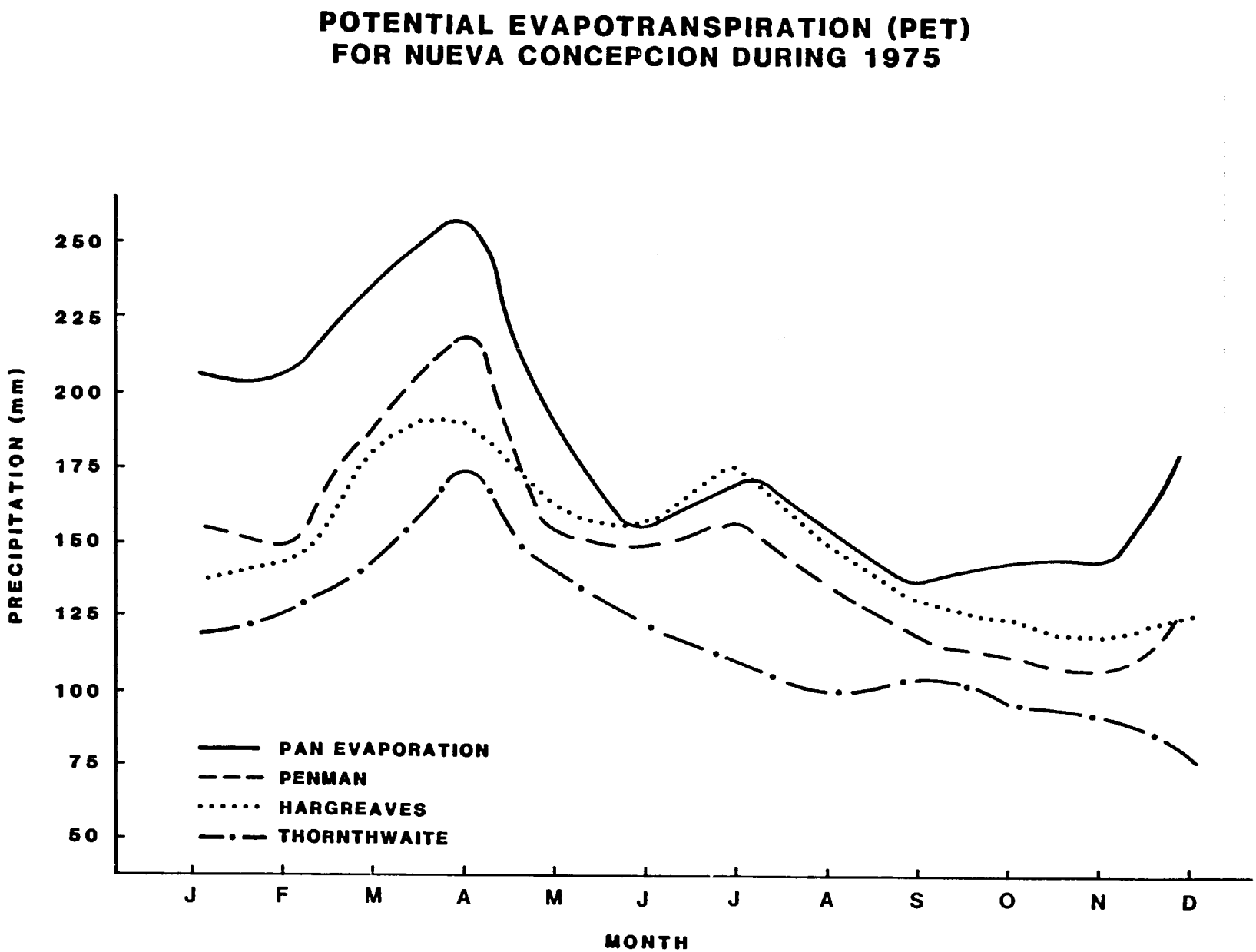


Figure 4.3. Potential Evapotranspiration (PET) for Nueva Concepcion During 1975

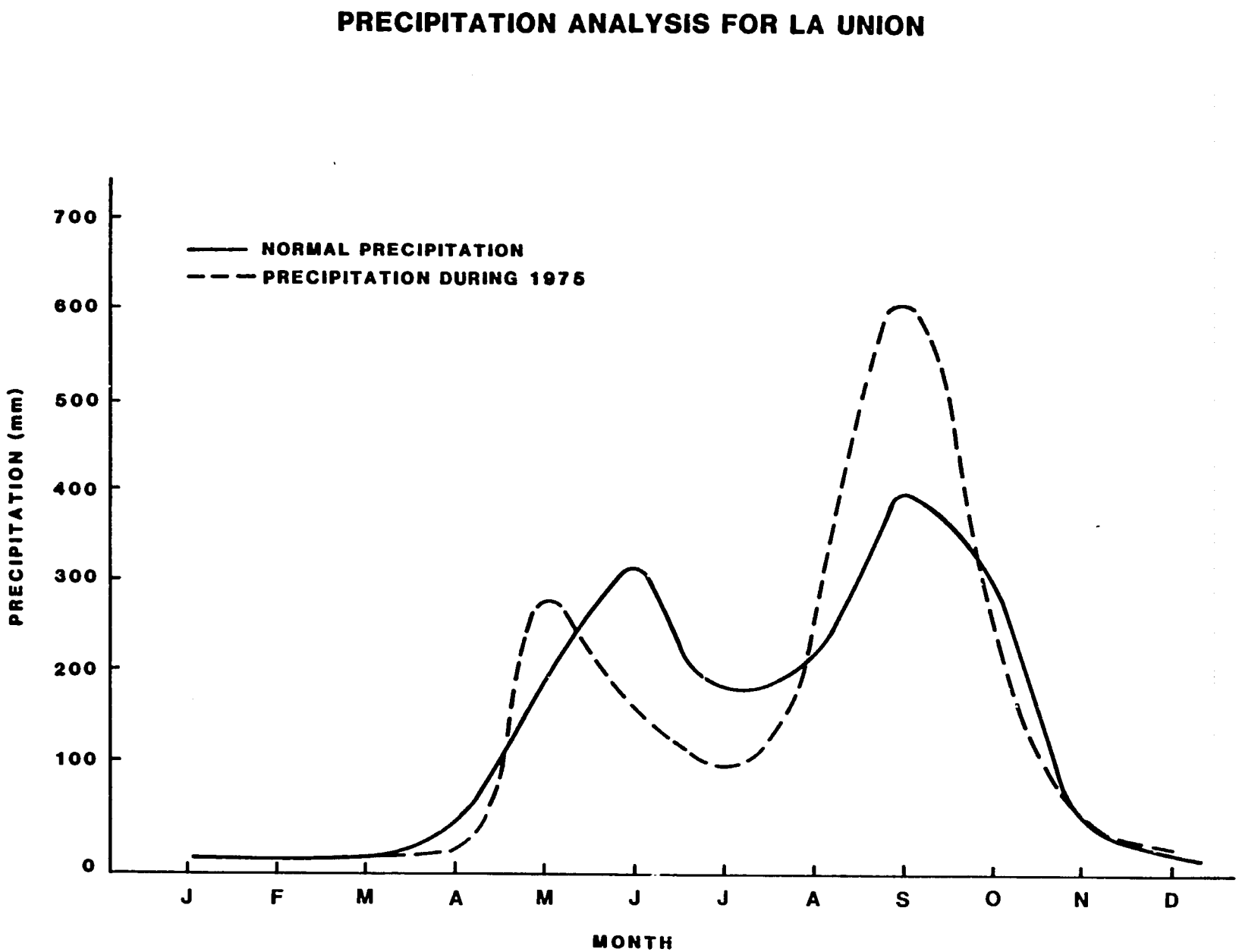


Figure 4.4. Precipitation Analysis for La Union

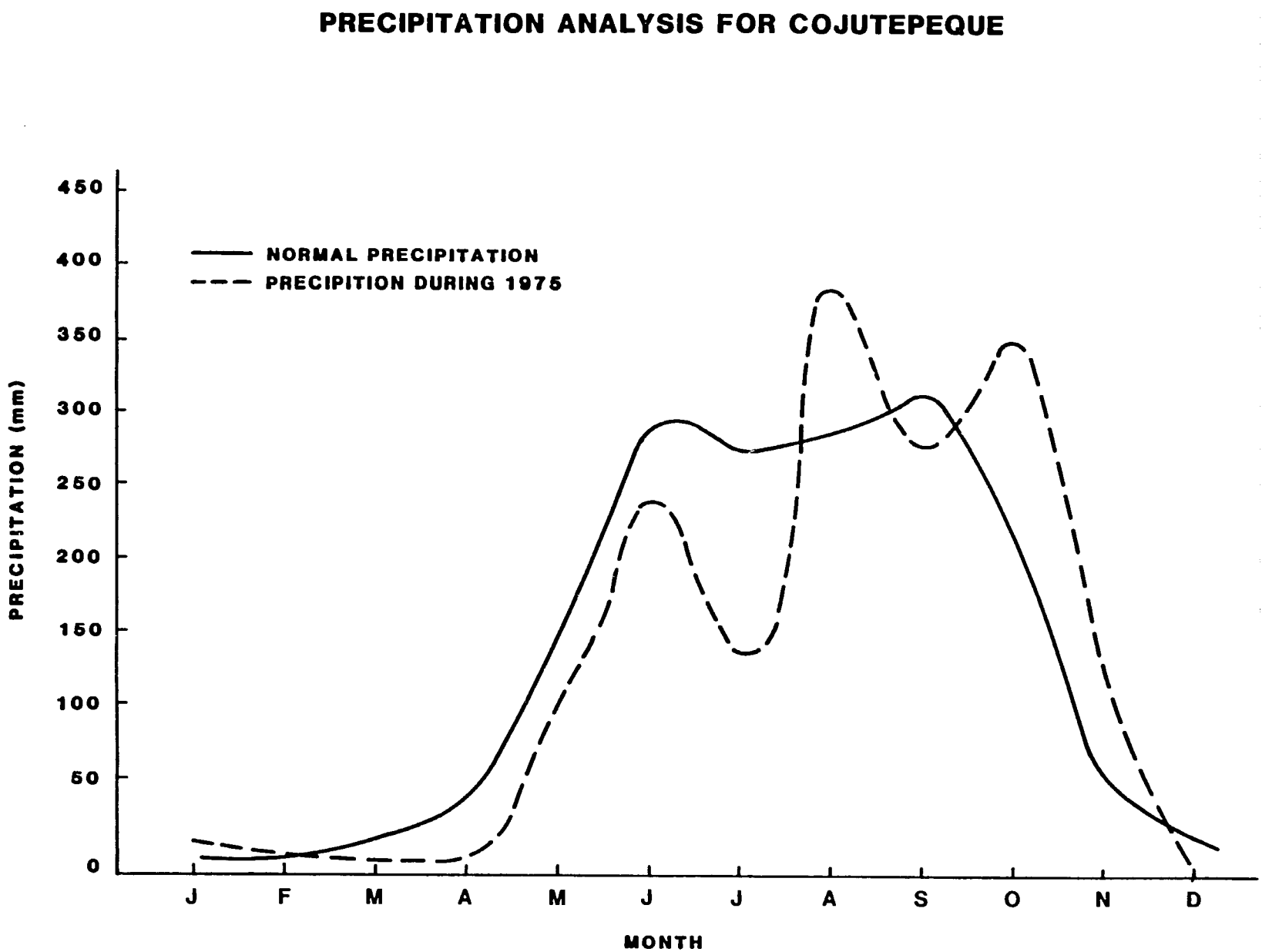


Figure 4.5. Precipitation Analysis for Cojutepeque

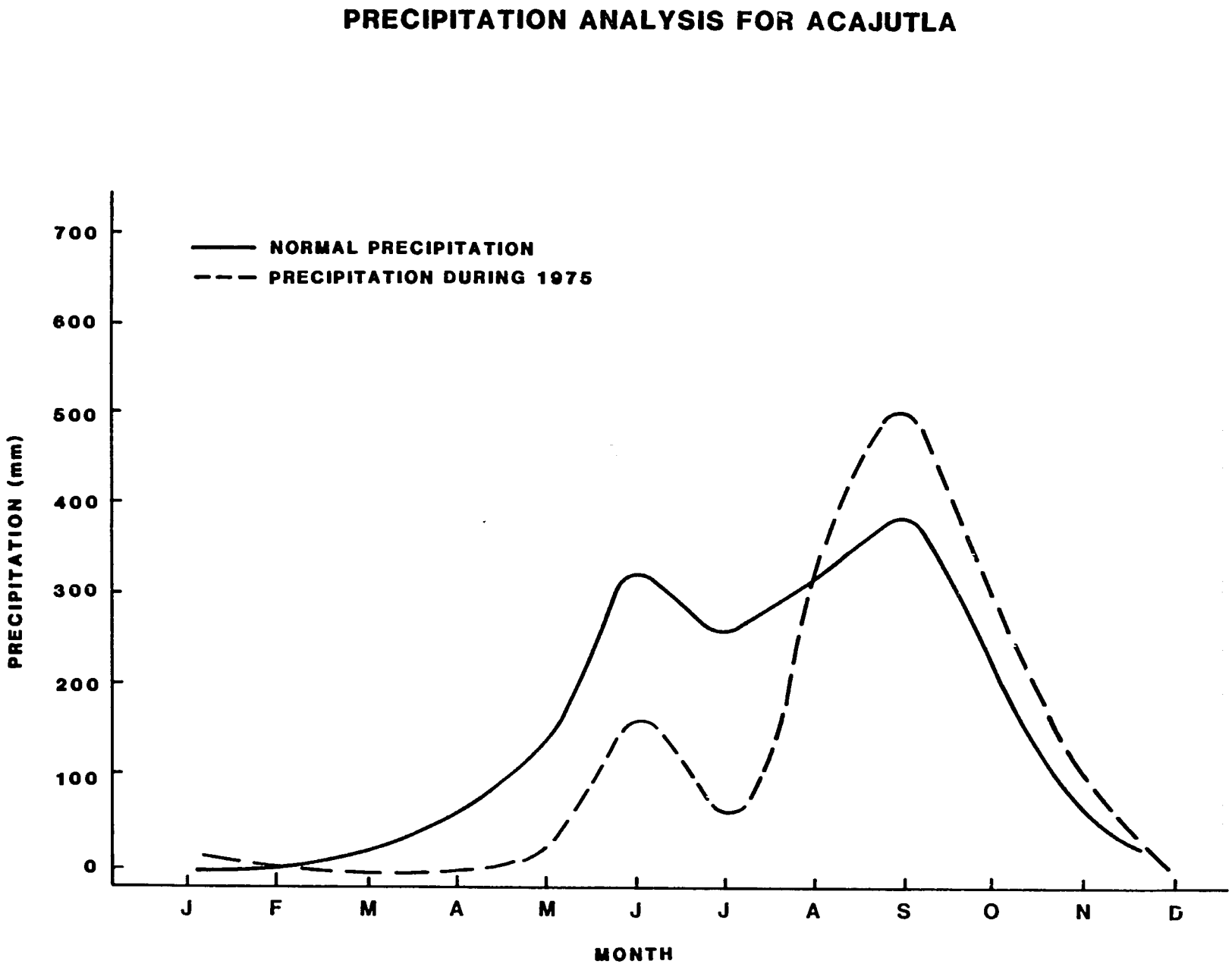


Figure 4.6. Precipitation Analysis for Acajutla

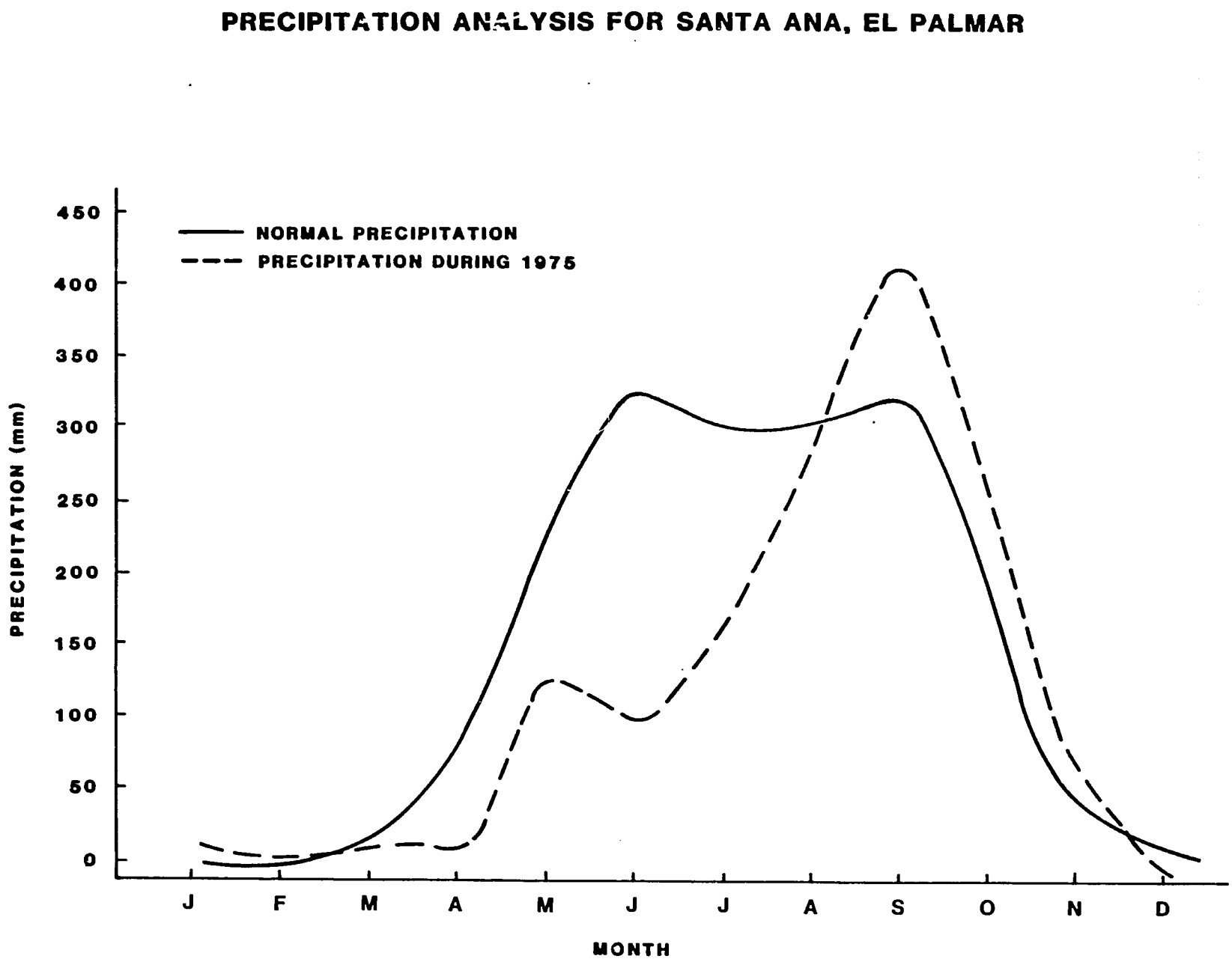


Figure 4.7. Precipitation Analysis for Santa Ana, El Palmar

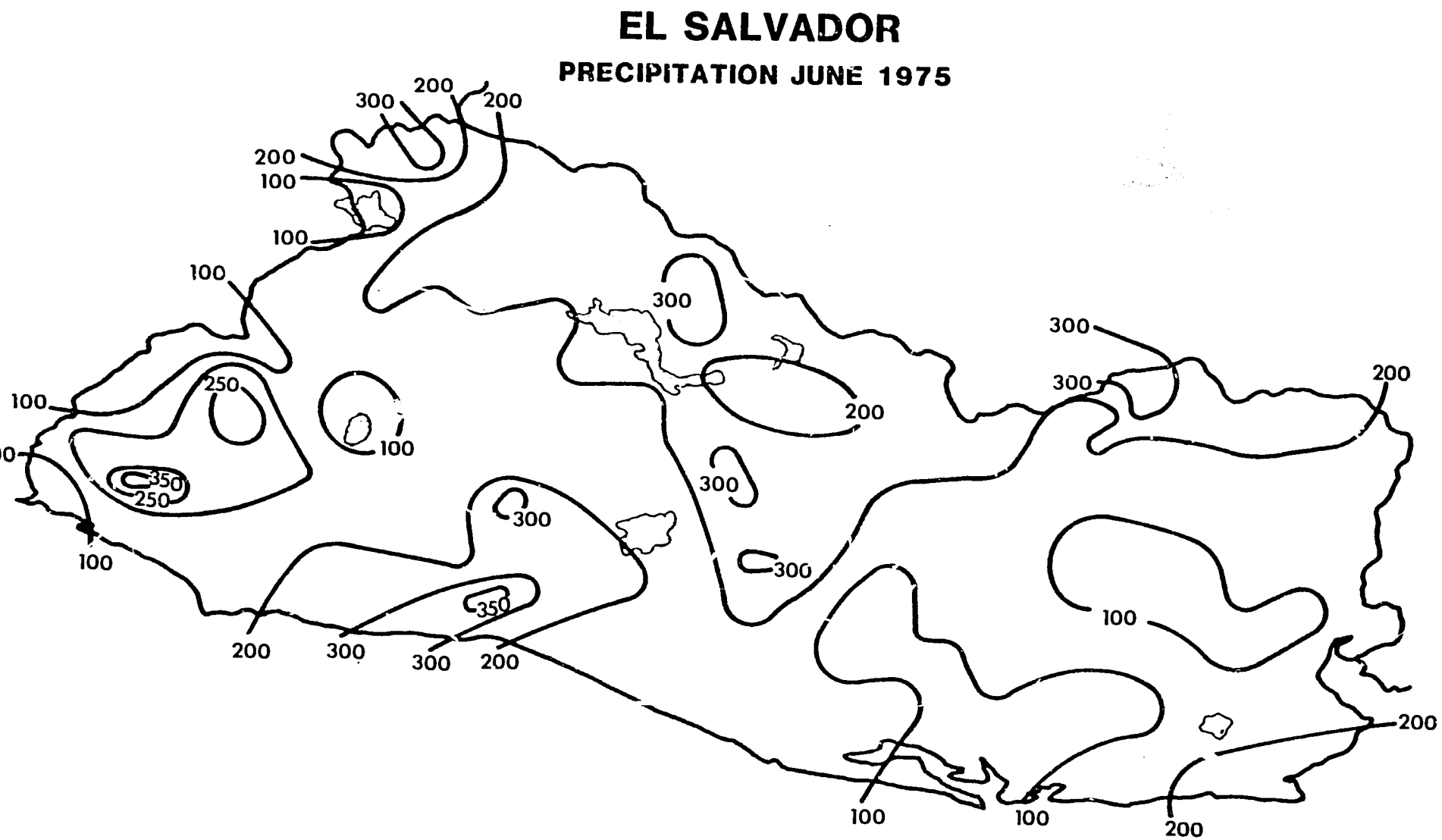


Figure 4.8. Total Precipitation (in mm) During the Month of June, 1975

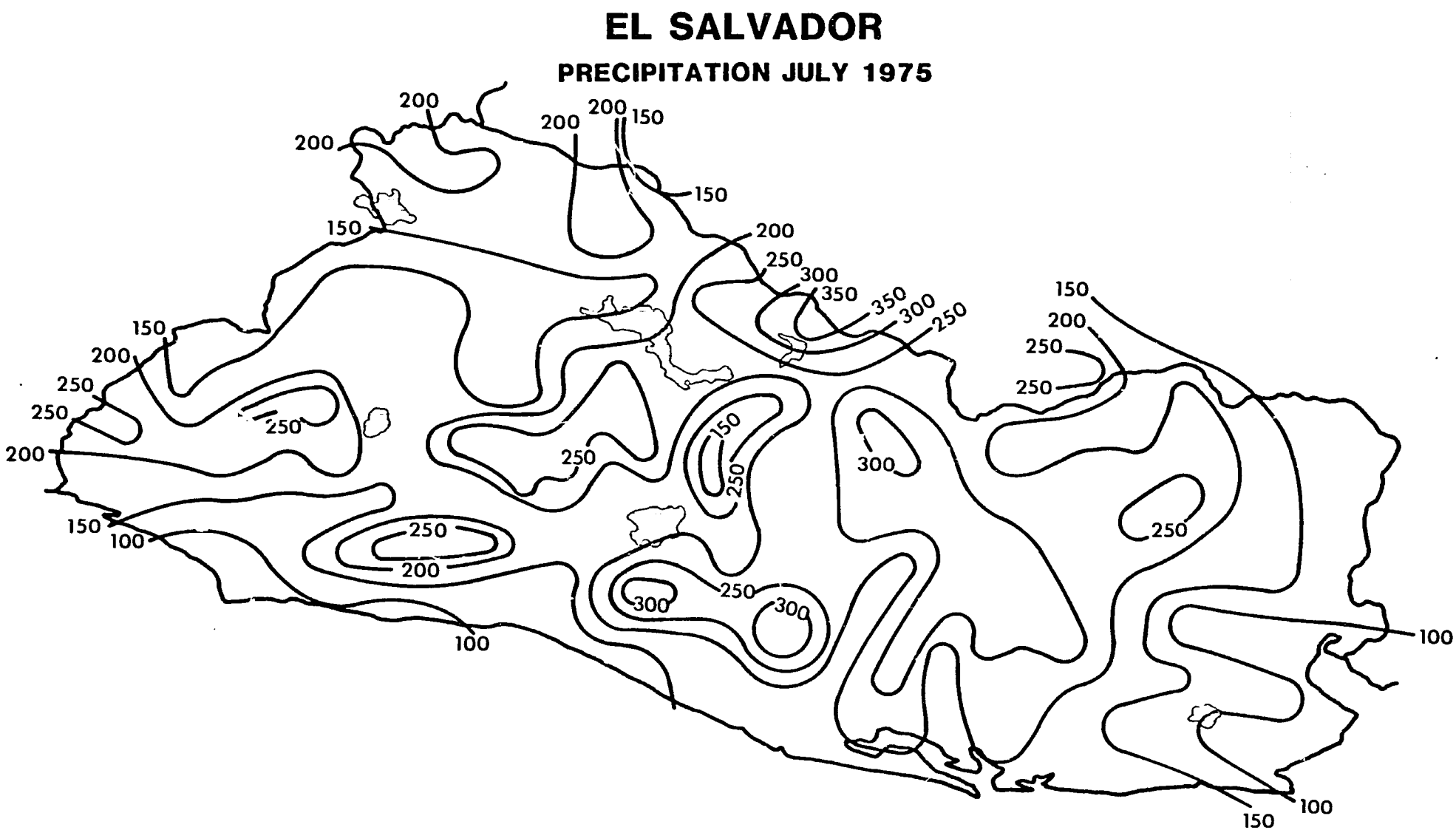


Figure 4.9. Total Precipitation (in mm) During the Month of July, 1975

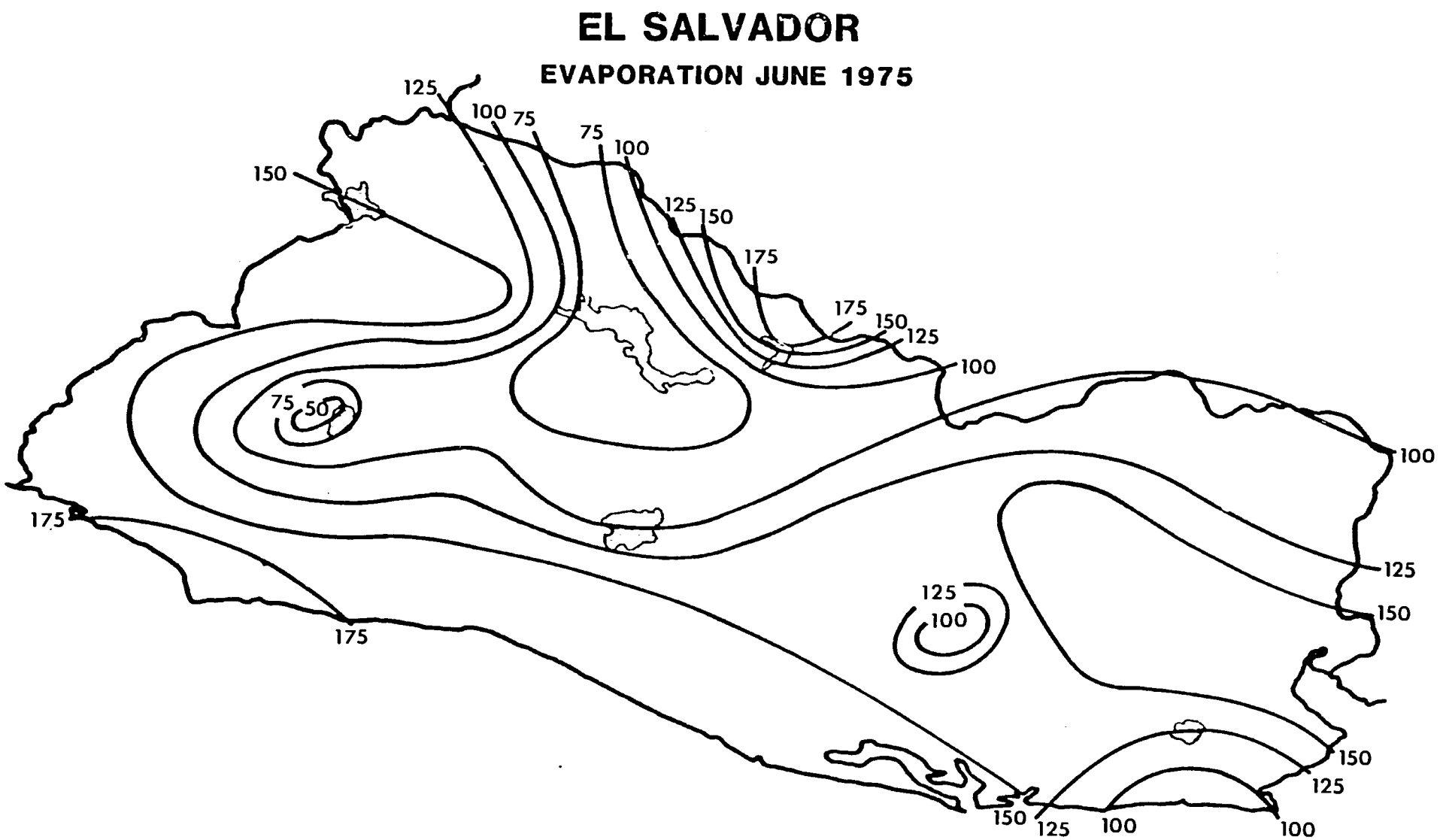


Figure 4.10. Total Evaporation (in mm) During the Month of June, 1975

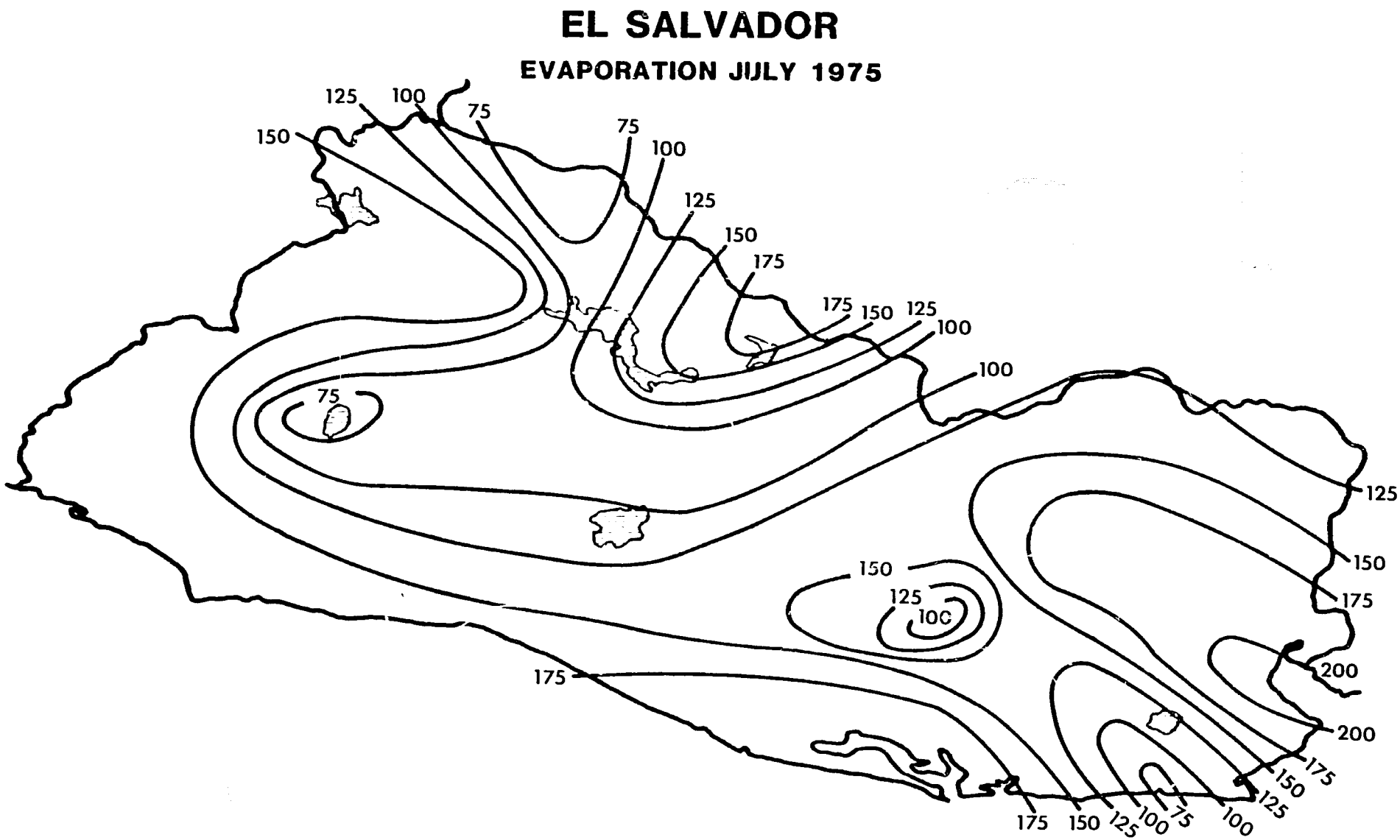


Figure 4.11. Total Evaporation (in mm) During the Month of July, 1975

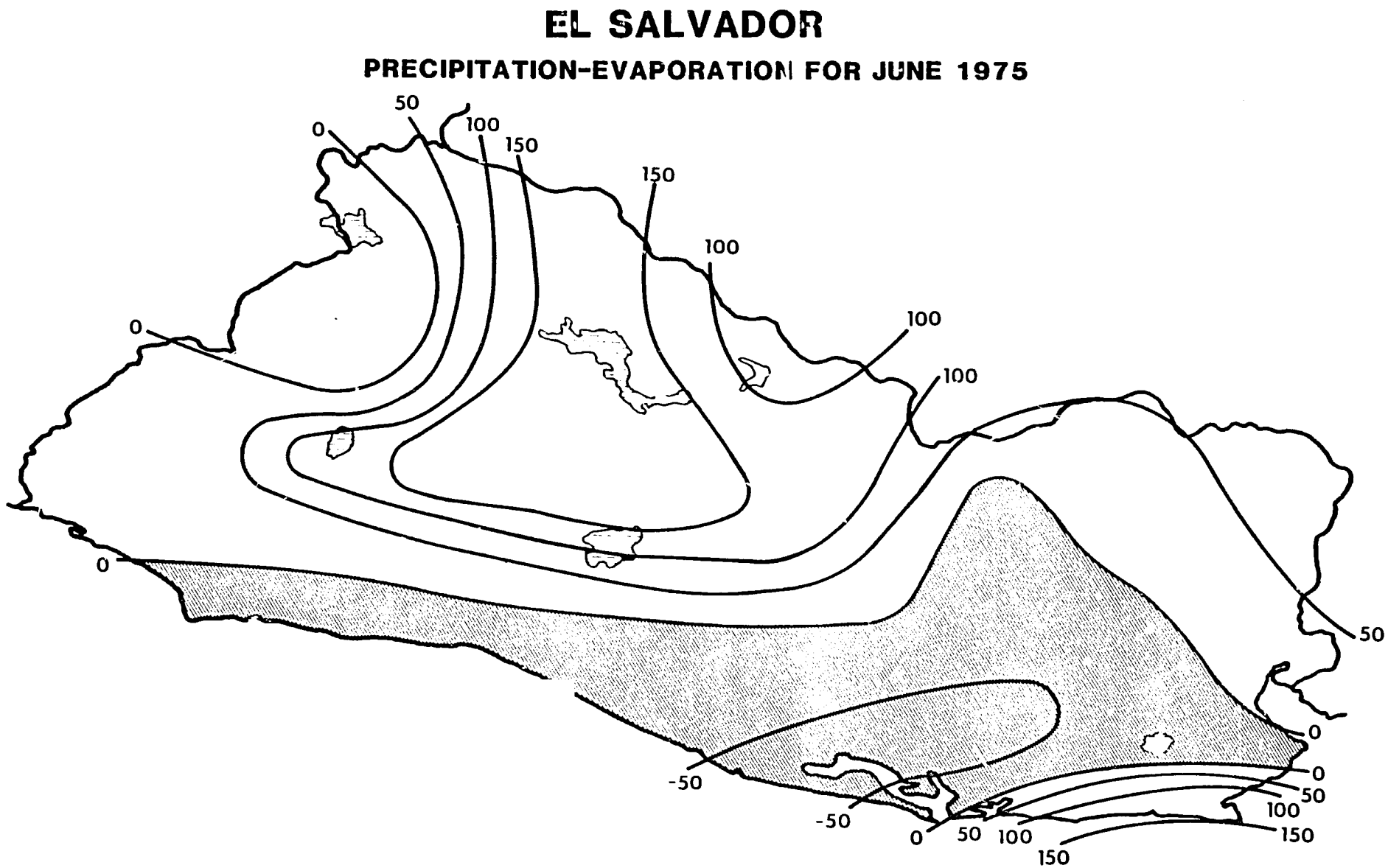


Figure 4.12. Difference Between Precipitation and Evaporation (in mm) During the Month of June, 1975

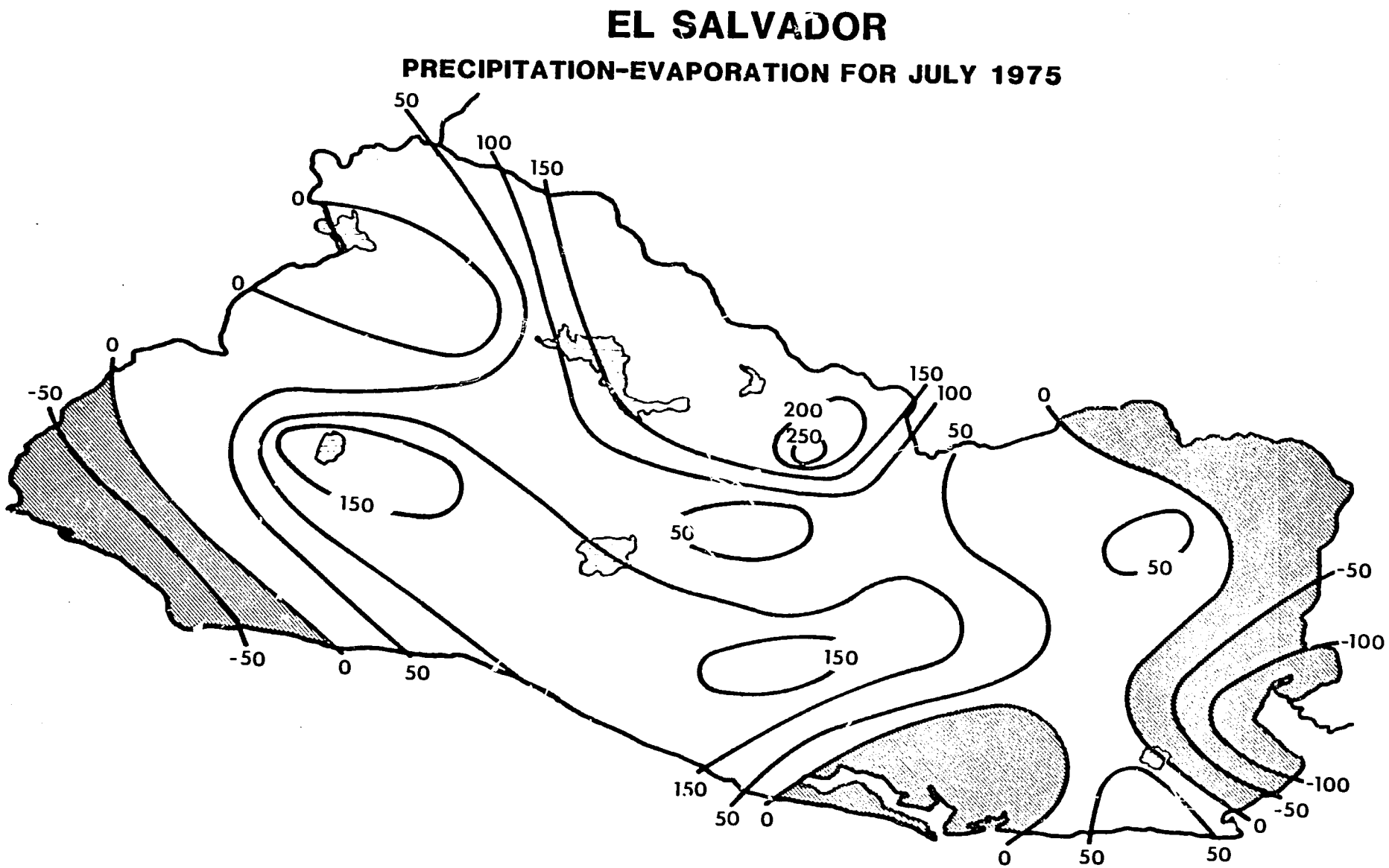


Figure 4.13. Difference Between Precipitation and Evaporation (in mm) During the Month of July, 1975

agreement between Penman, Hargreaves and pan evaporation. It must be pointed out that the Penman method for calculating PET is found to be close to the real values of pan evaporation. Indeed the Penman method must be in close agreement to the reality because it takes into consideration the meteorological elements that largely contribute to the physical process of evaporation. Also, it can be noticed from Figures 4.1, 4.2, and 4.3 that the PET curve, using Penman, behaves in a parallel manner compared to the evaporation curve. Therefore, some calibration may need to be done so that this approach to compute PET can simulate the process of evaporation.

Despite the few meteorological elements being considered to compute PET, the Hargreaves method appears to have a close agreement to evaporation. Even in some places with low altitudes, such as Nueva Concepcion and Beneficio La Carrera, the Hargreaves method appears to give more reliable results than the Penman method.

Alike the Penman method, the Hargreaves method to compute PET underestimates the values of evaporation but it generally follows the evaporation pattern.

In all the cases analyzed, the Thornthwaite method underestimated the PET values. Obviously one must expect this kind of result because the method uses only one meteorological parameter, temperature. As described and explained earlier, evaporation not only depends on temperature but also on a variety of atmospheric phenomena. However, one must say that the method has some applications with limitations. Moreover, the PET values obtained using Thornthwaite at high altitude are, for all practical purposes, useless; they are too far from reality, as is the case with La Galera (Figure 4.2).

B. Agroclimatic Indices

Agroclimatic indices were calculated for Acajutla, San Salvador, and Los Andes using long records of precipitation. These places may not be the most important agricultural sites in El Salvador, but they were selected simply because they have available data to calculate the indices. Much attention was spent to see how the index results are correlated with the canicula observed in 1975. For all practical purposes the index values were ranked in percentiles rather than their absolute values.

1. Crop Condition Index

As indicated below, the Crop Condition Index provides valuable information on the early vegetative (planting), late vegetative, and reproductive stages of crops. Figures 4.14, 4.15, and 4.16 present the results for three selected stations. As indicated before, in El Salvador farmers enjoy two planting seasons for the main crops such as corn, beans, and sorghum. Meteorological data for the second season was used to compute the Crop Condition Index. Index values are provided each year for planting, vegetative growth, and flowering. The index values are expressed in percentiles which are shown on Figures 4.14, 4.15, and 4.16. Absolute values of CCI are provided in the Appendix.

Meticulous analysis suggests that CCI values in the 20 to 40 percentile ranking indicate that crops are under extreme stress, while CCI below the 20th percentile tends to suggest that crop failure is likely to occur. However, if CCI is above the 40th percentile, crops have the necessary moisture to produce desirable yields. By closely studying Figures 4.14 through 4.16 one can easily draw a conclusion that crops were under extreme stress conditions at all the stages.

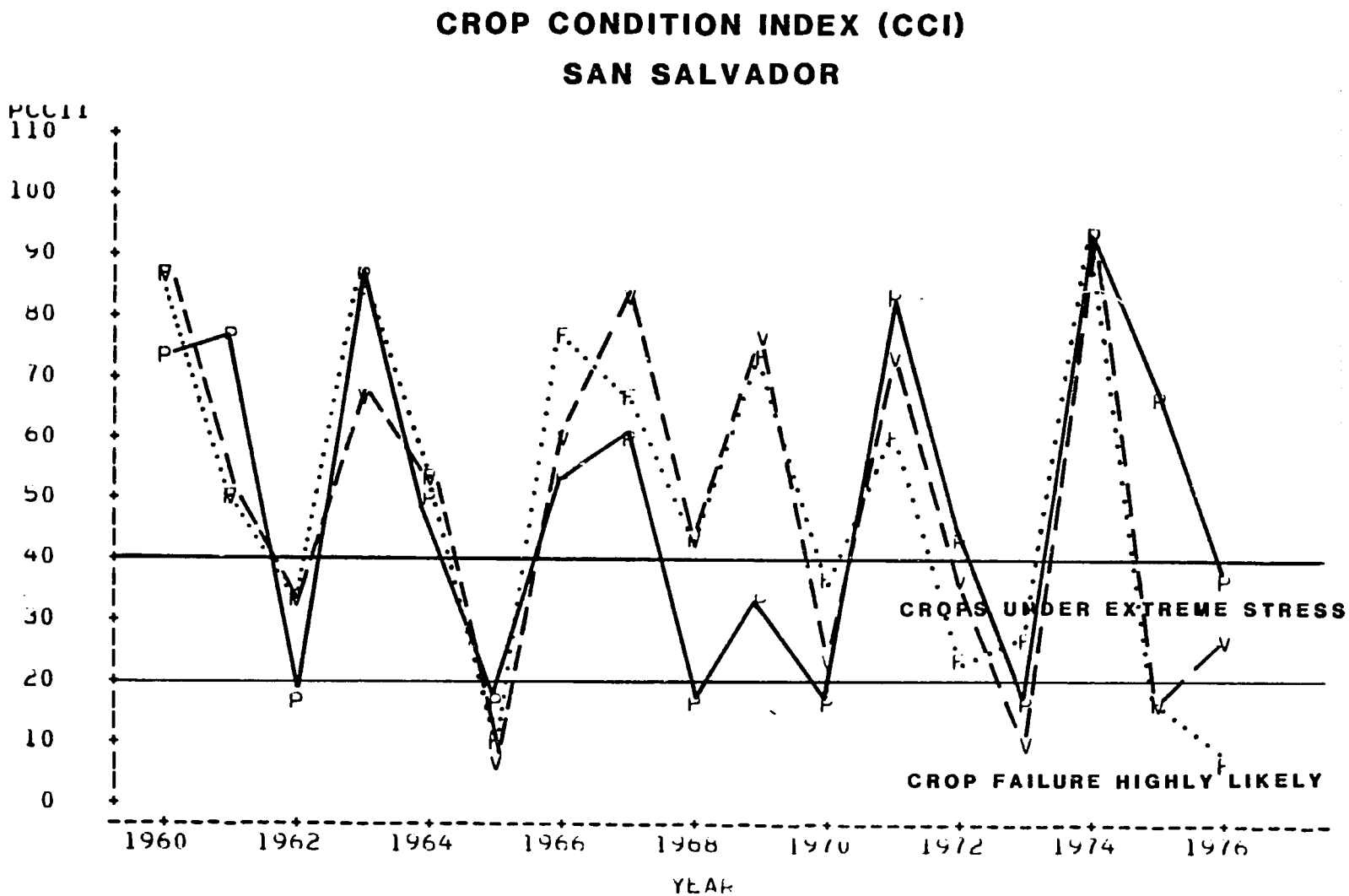


Figure 4.14. Crop Condition Index (CCI) for San Salvador

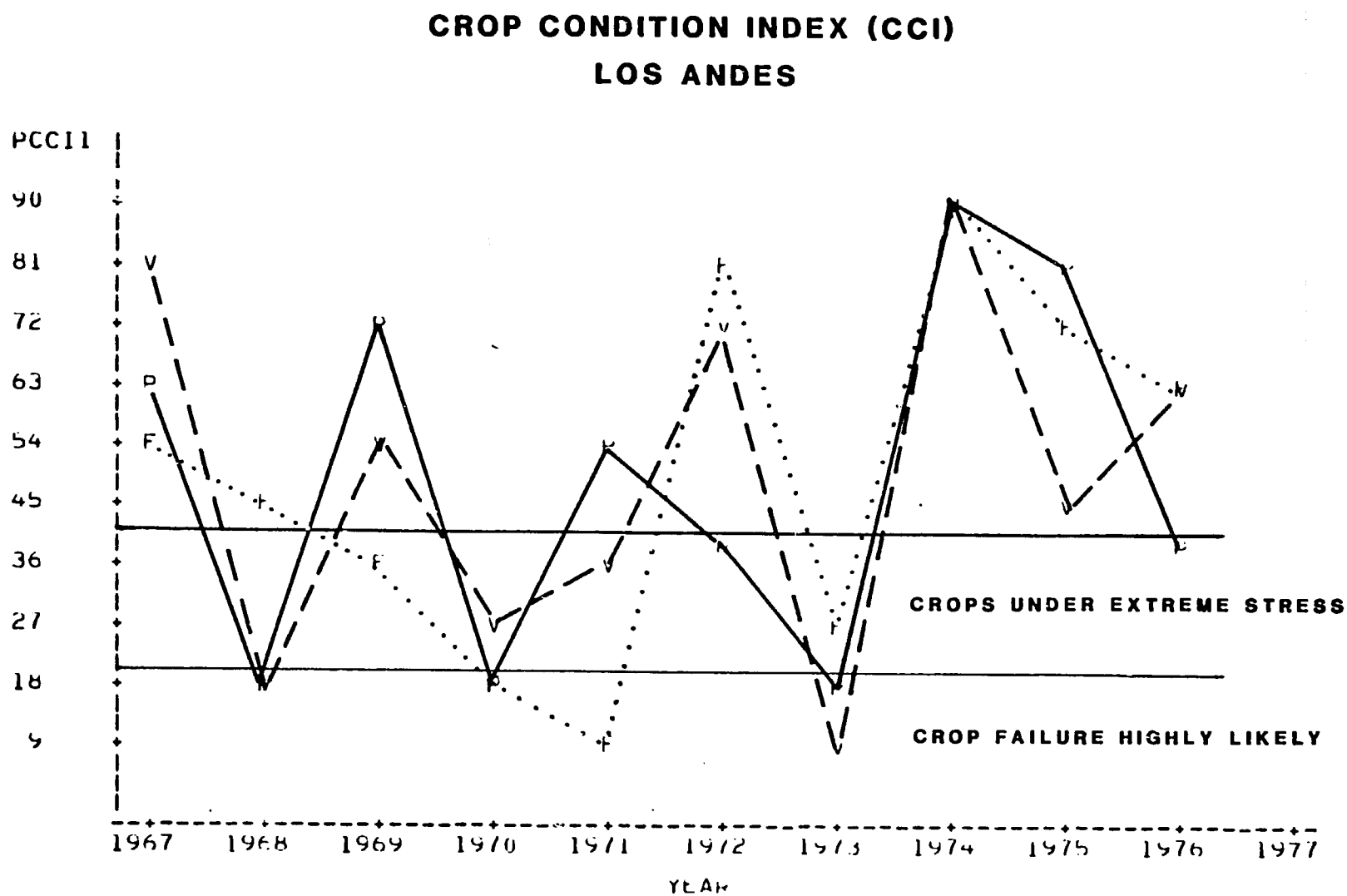


Figure 4.15. Crop Condition Index (CCI) for Los Andes

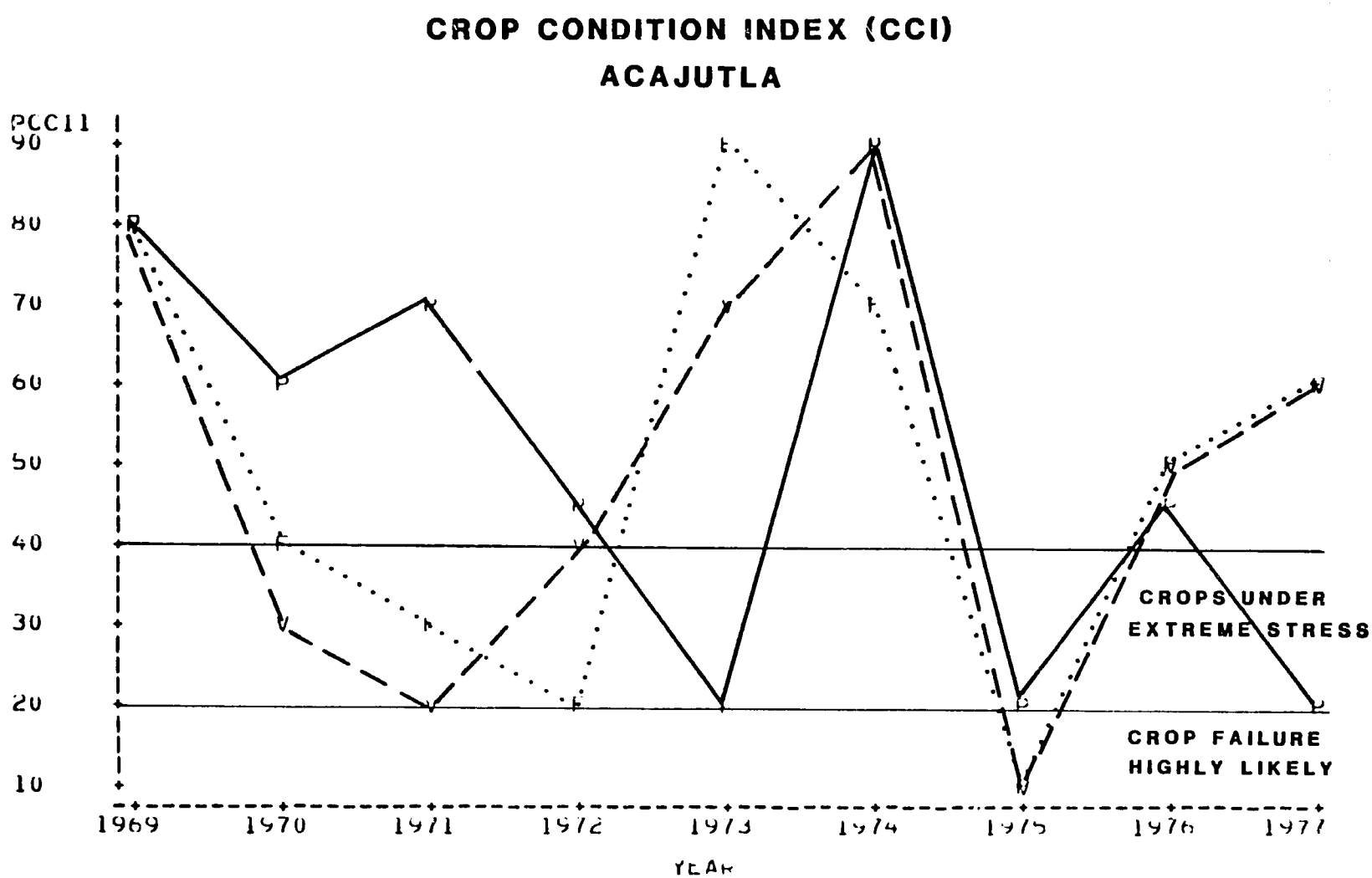


Figure 4.16. Crop Condition Index (CCI) for Acajutla

2. Yield Moisture Index

The Yield Moisture Index (YMI) was computed for corn and beans (dry) at Acajutla, Los Andes, and San Salvador. Available monthly precipitation data (1960-1977), crop coefficients adapted for those locations, and crop calendars were used to compute the YMI as previously discussed (Chapter III). The YMI was calculated for two seasons within the same year, one from May through August and the second from the middle of August to November. Those are the two main seasons in which maize and beans are planted in El Salvador.

Index values are provided each year for the planting, vegetative growth, flowering and ripening crop stages. The graphical plot for the YMI for corn and beans for the above locations, are shown on Figures 4.17, 4.18, 4.19, and 4.20. Each index is expressed in percentiles. Absolute values of the YMI are provided in the Appendix for the above stations. It must be pointed out that the index is most reliable as an indicator of crop conditions at the end of the critical flowering crop stage. Obviously that is the stage in which crops experience their maximum and critical growth and hence water availability must be adequate to obtain desirable crop yields.

Analysis tends to suggest that YMI values in the 20 to 40 percentile ranking indicate moderate drought while YMI values below the 20th percentile suggest drought impact on the crop. This was clearly the case during 1975 in which a severe drought was observed during the first crop season, see Figures 4.4, 4.5, and 4.6.

3. Palmer Drought Index

The Palmer Drought Index (PDI) was calculated as discussed in Chapter IV. To compute the PDI, the Thornthwaite PET method was used except for 1975

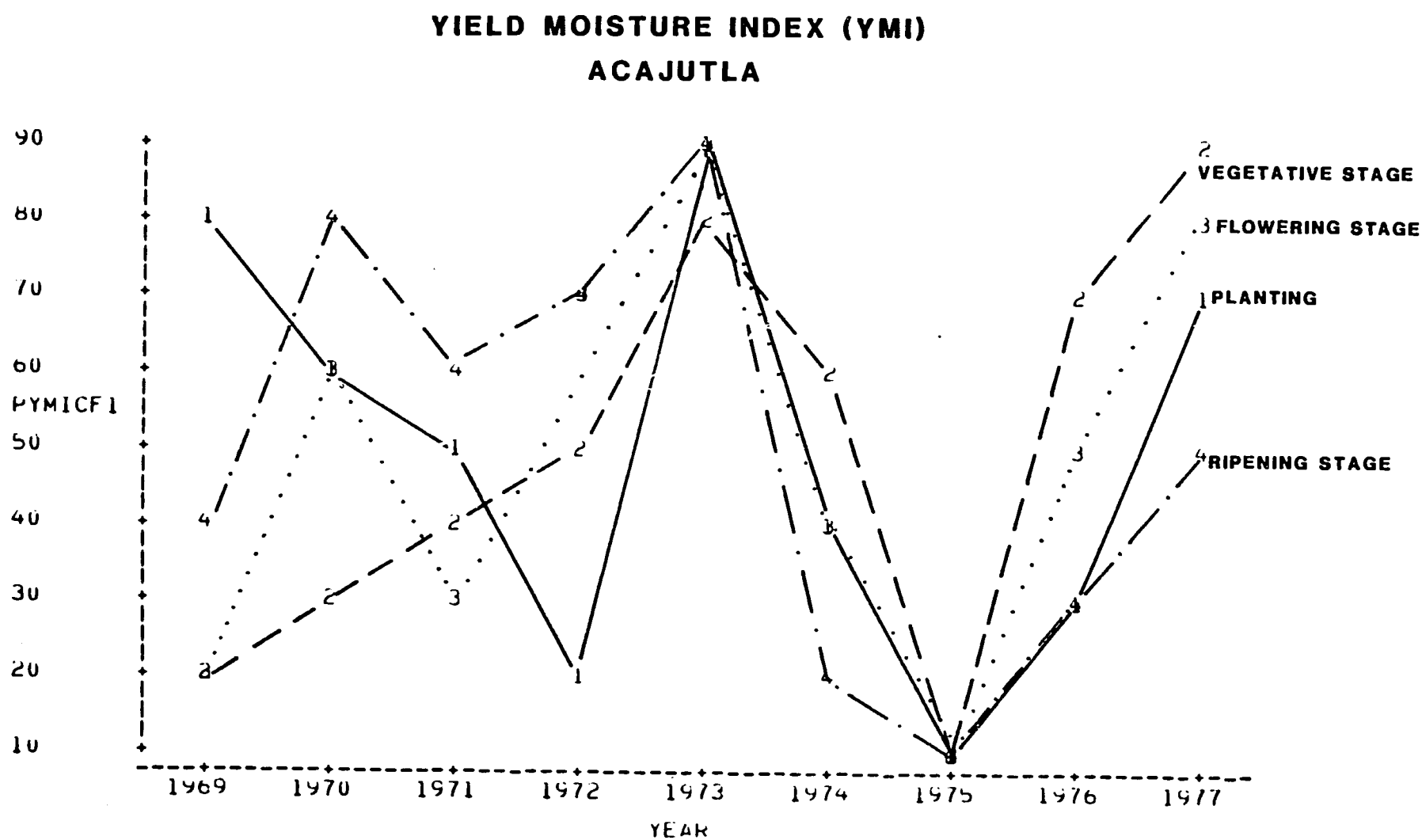


Figure 4.17. Yield Moisture Index (YMI) for Corn During the Period of May Through August in Acajutla

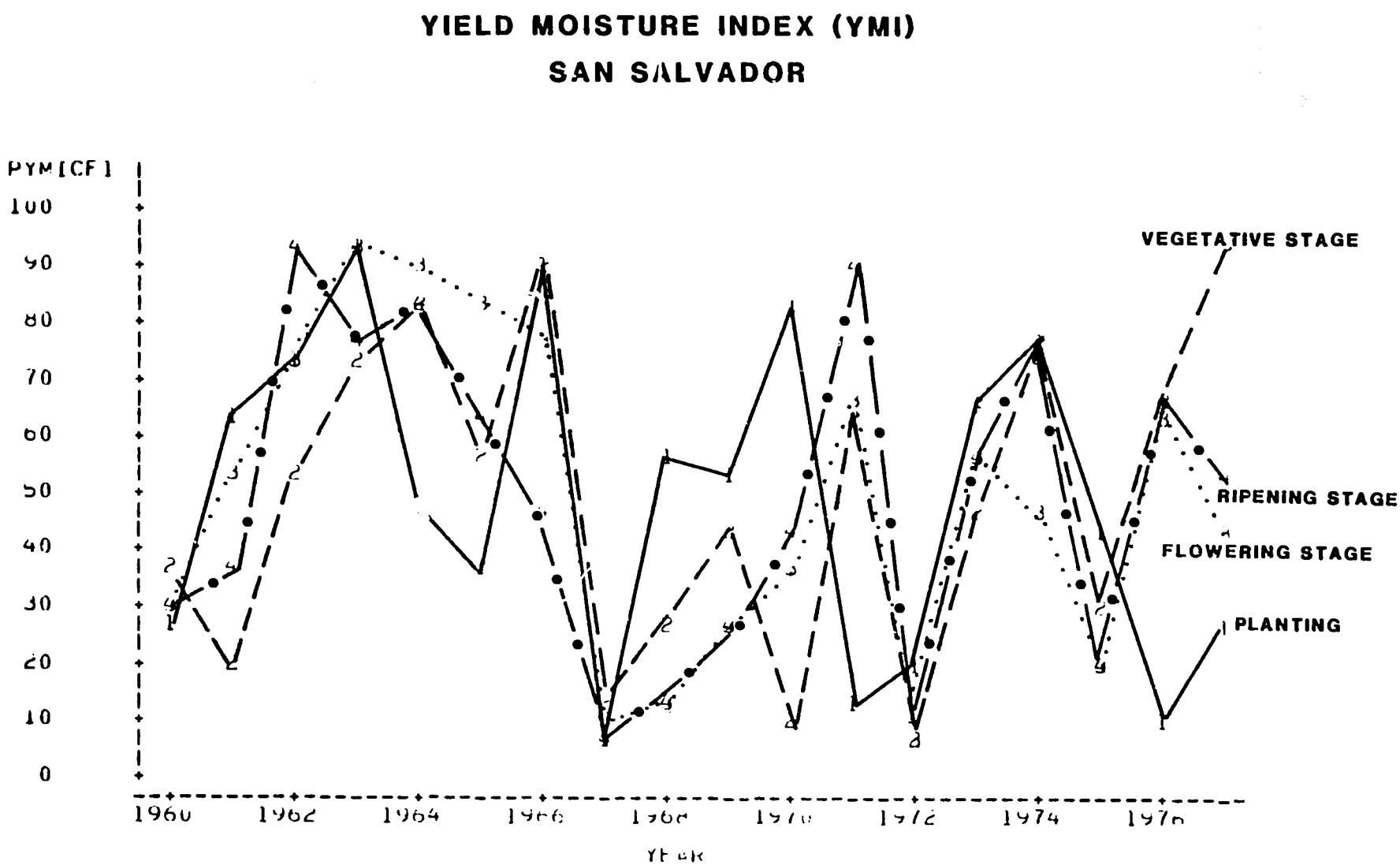


Figure 4.18. Yield Moisture Index (YMI) for Corn During the Period of May Through August in San Salvador

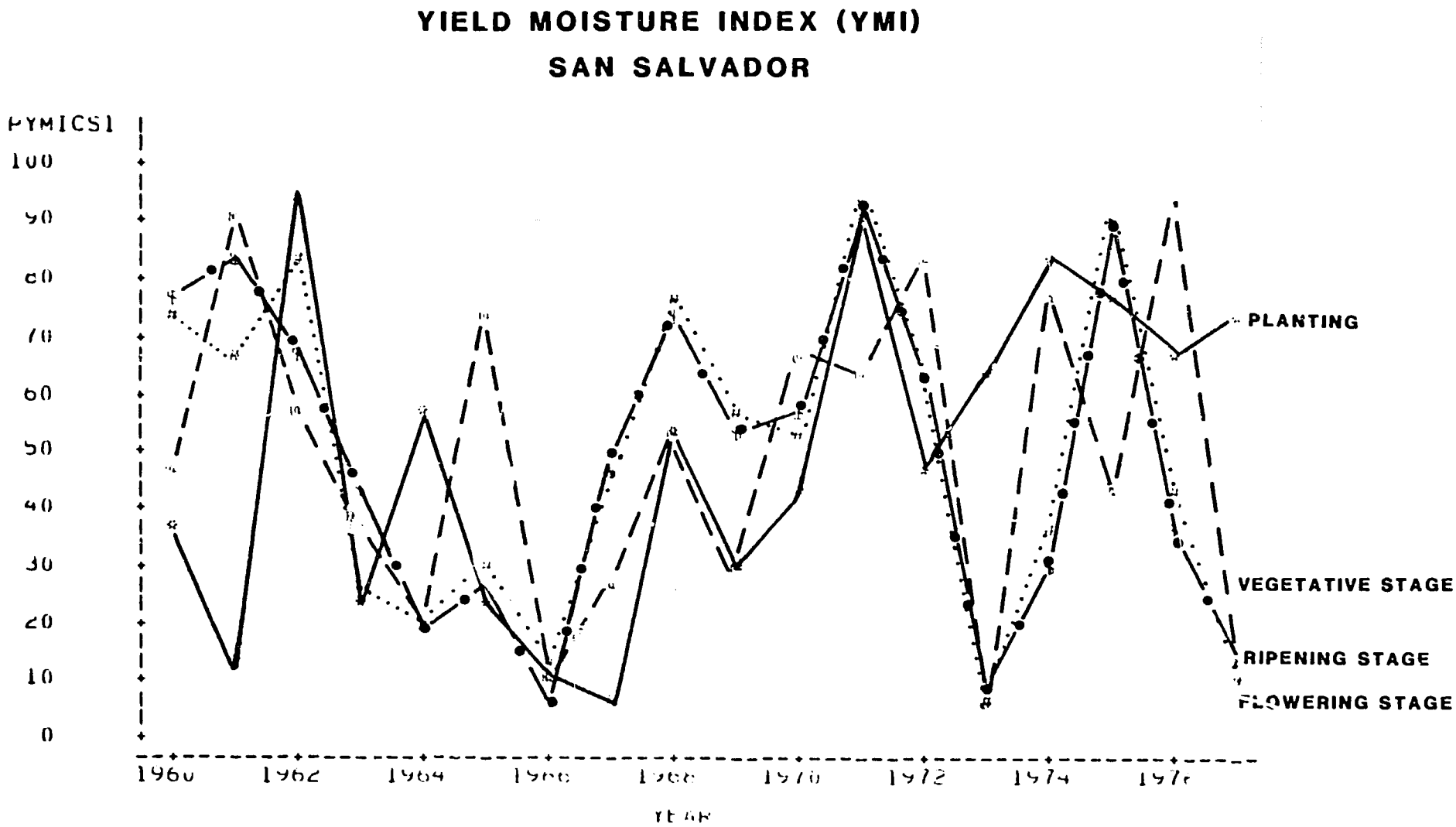


Figure 4.19. Yield Moisture Index (YMI) for Corn During the Period of August Through November in San Salvador

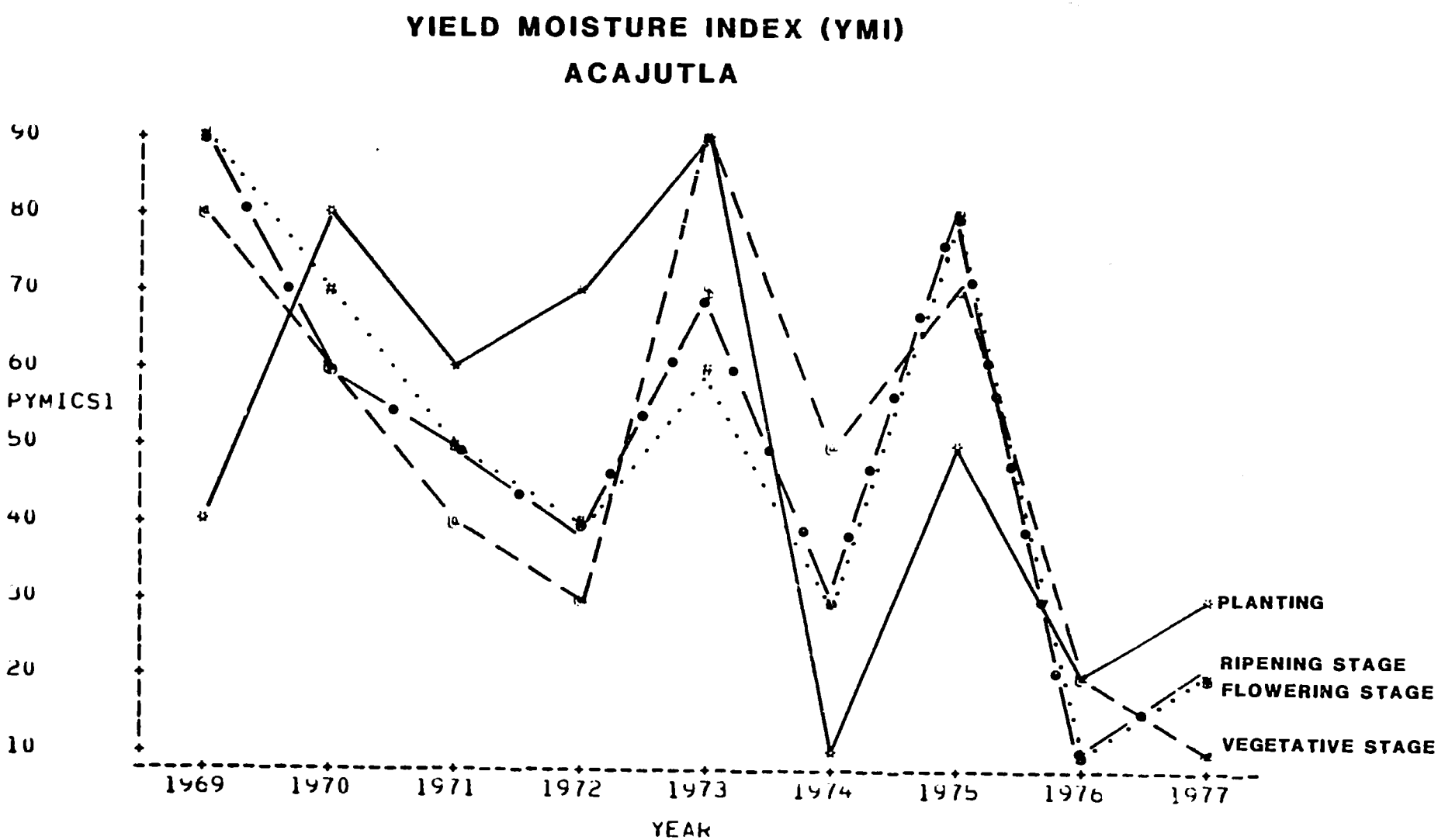


Figure 4.20. Yield Moisture Index (YMI) for Corn During the Period of August Through November in Acajutla

where the Hargreaves PET method was utilized in Los Andes and San Salvador. It must be said that the PET used to compute PDI should be the method that best approximates the process of evaporation. Ideally the Penman Method should have been used to compute PDI, but there was insufficient data to do so.

The PDI diagrams for Acajutla, Los Andes, and San Salvador are presented in Figures 4.21, 4.22, and 4.23. Extreme drought is indicated by the index during 1975, well agreeing with the actual situation. Moreover, periods of severe drought occurred during 1976 and 1977. As indicated earlier, both severe and extreme drought conditions pose a threat to the agriculture industry. Also, moderate drought conditions occurred during 1972.

4. Soil Moisture Index

As explained earlier, the Soil Moisture Index normalizes the soil moisture according to variations in the type of soil and plant. SMI values for San Salvador were computed; they are presented on Figure 4.24. The index provides meaningful results during the two well defined seasons observed in El Salvador, wet and dry. Obviously in this case study for San Salvador minor weather fluctuations cannot be observed. Even the canicula effects are extremely hard to observe, mainly because the index deals with historic climatic data. However, weather phenomena effects which occur periodically can readily be seen from the index outputs. For instances, one can easily see that San Salvador has extreme moisture stress between December and May, and no moisture stress between June and November.

5. R-Index

The R-Index was calculated for Acajutla, as discussed in Chapter III; the results are presented in Figure 4.25. As said before, the R-Index is a nondimensional variable and indicates plant water supply in relation

PALMER DROUGHT INDEX (PDI)

ACAJUTLA

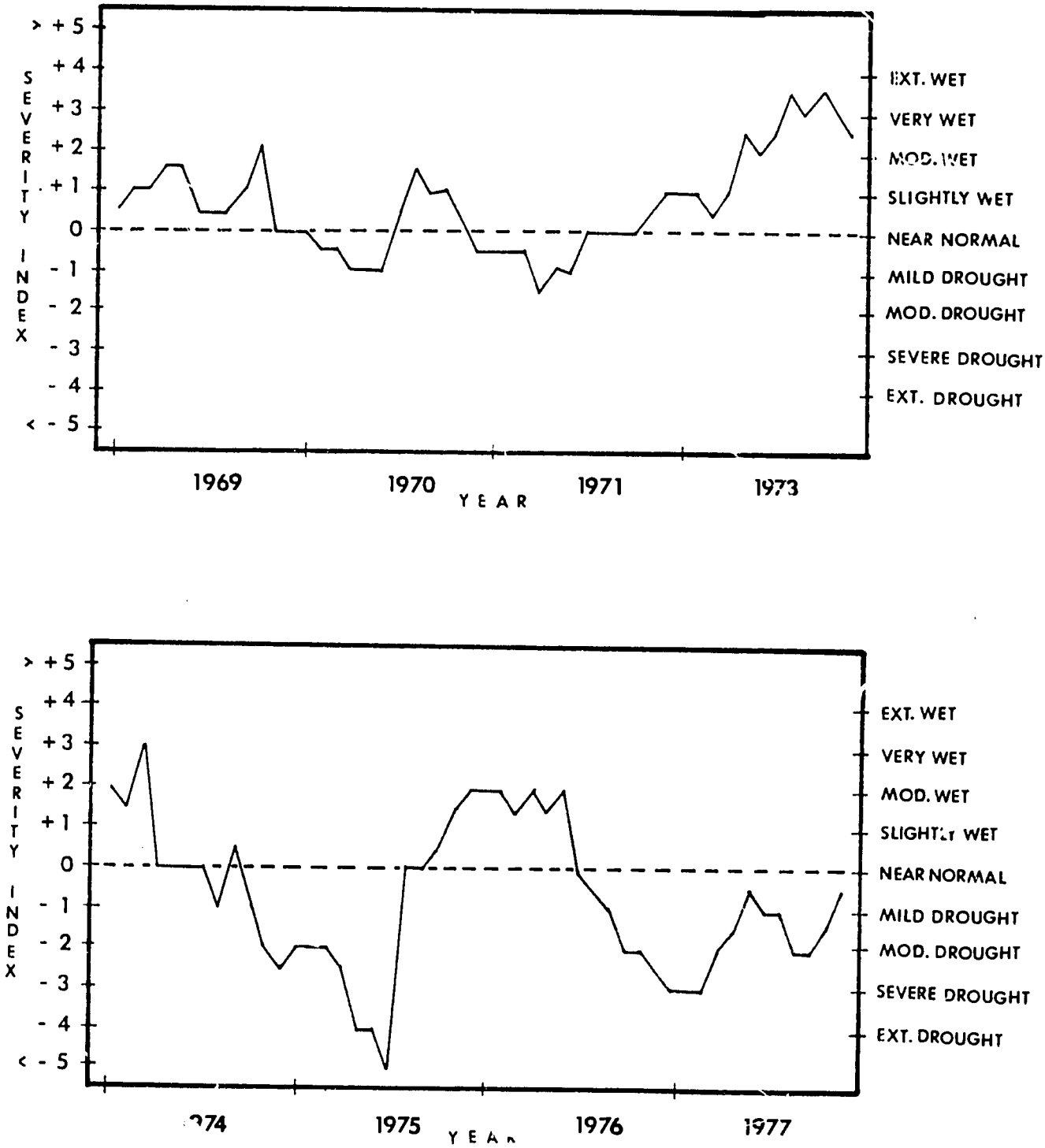
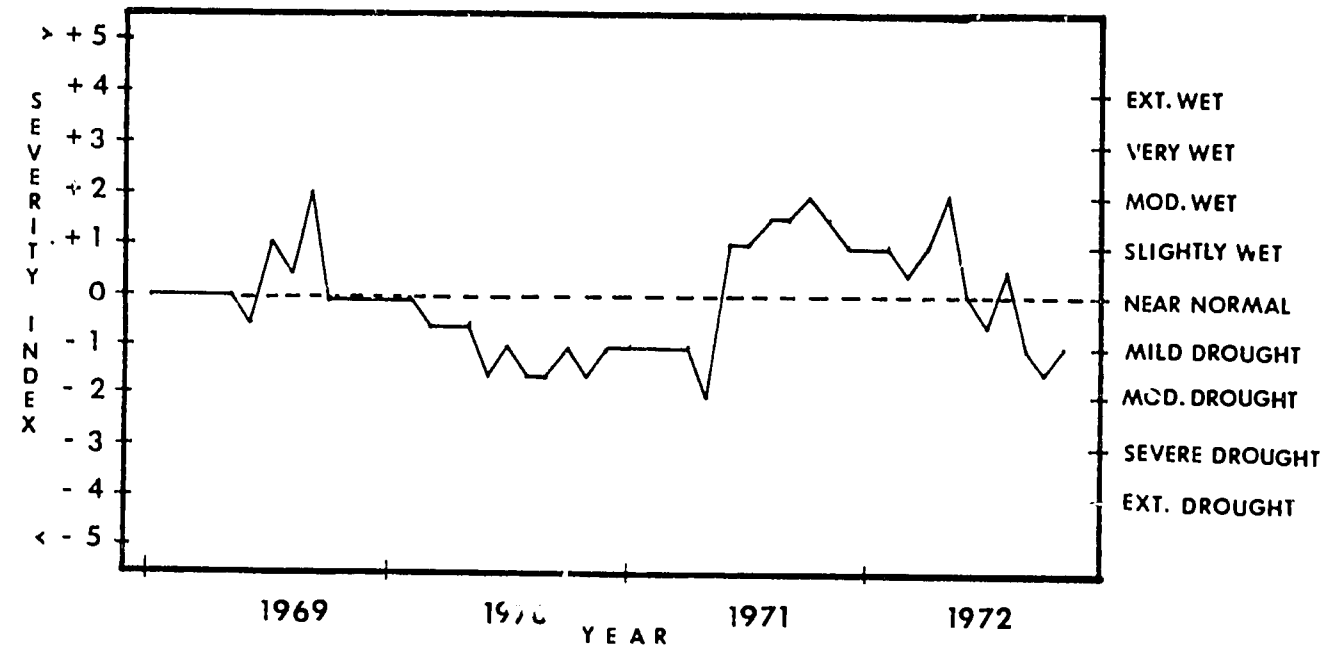


Figure 4.21. Palmer Drought Index (PDI) for Acajutla, El Salvador

PALMER DROUGHT INDEX (PDI)

LOS ANDES



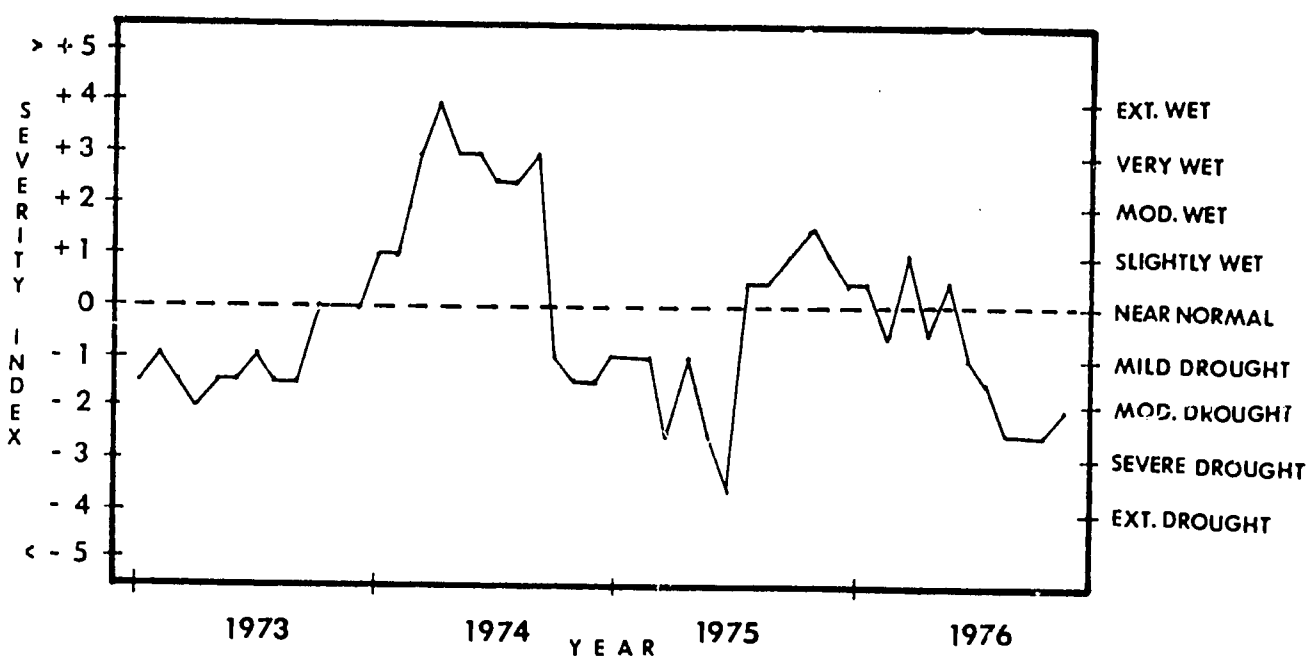
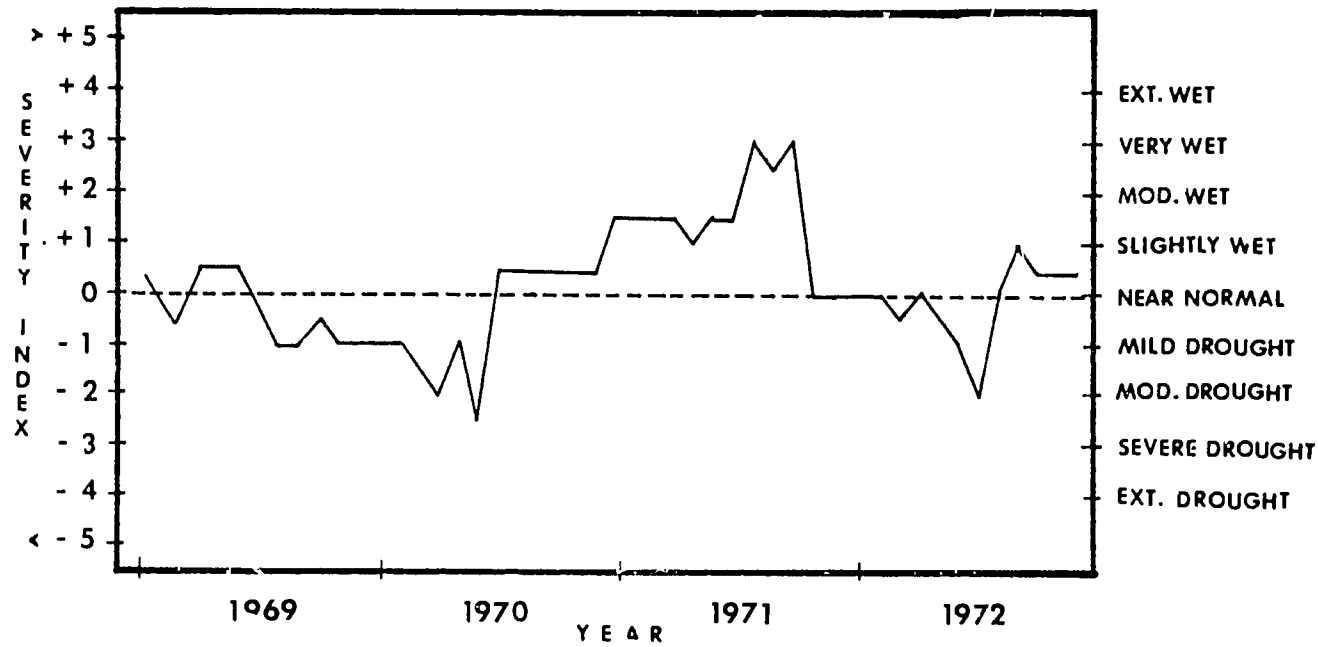


Figure 4.22. Palmer Drought Index (PDI) for Los Andes, El Salvador

PALMER DROUGHT INDEX (PDI)

SAN SALVADOR



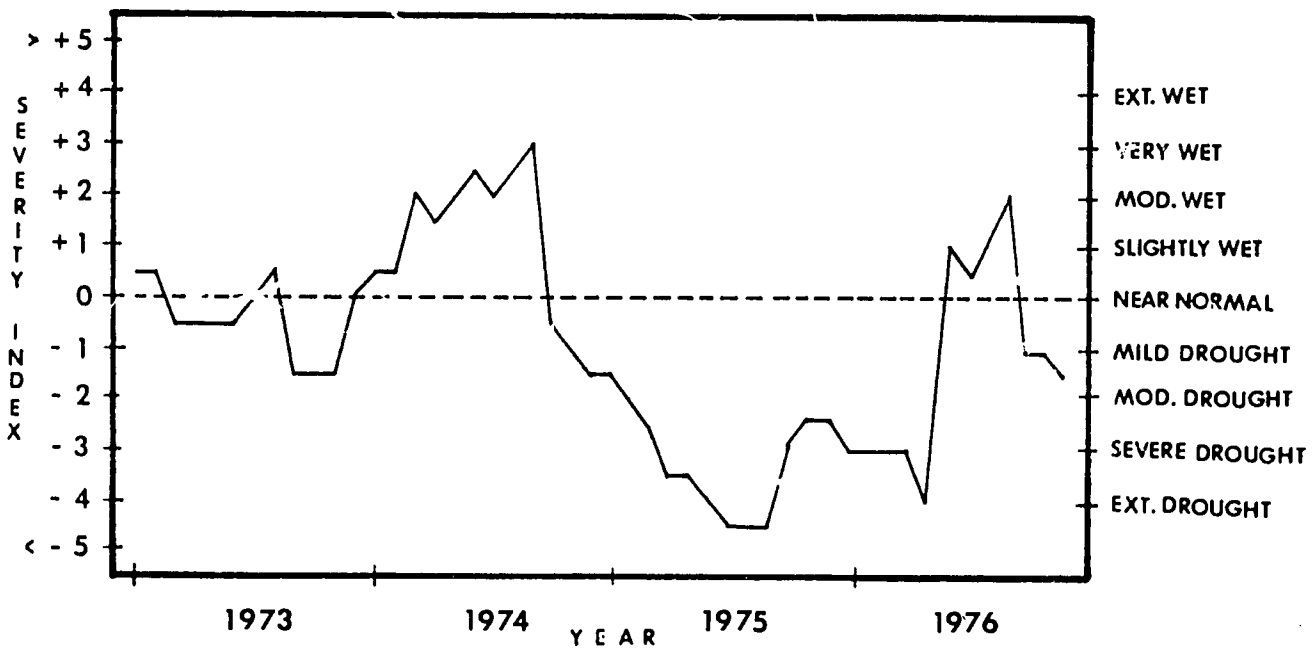


Figure 4.23. Palmer Drought Index (PDI) for San Salvador, El Salvador

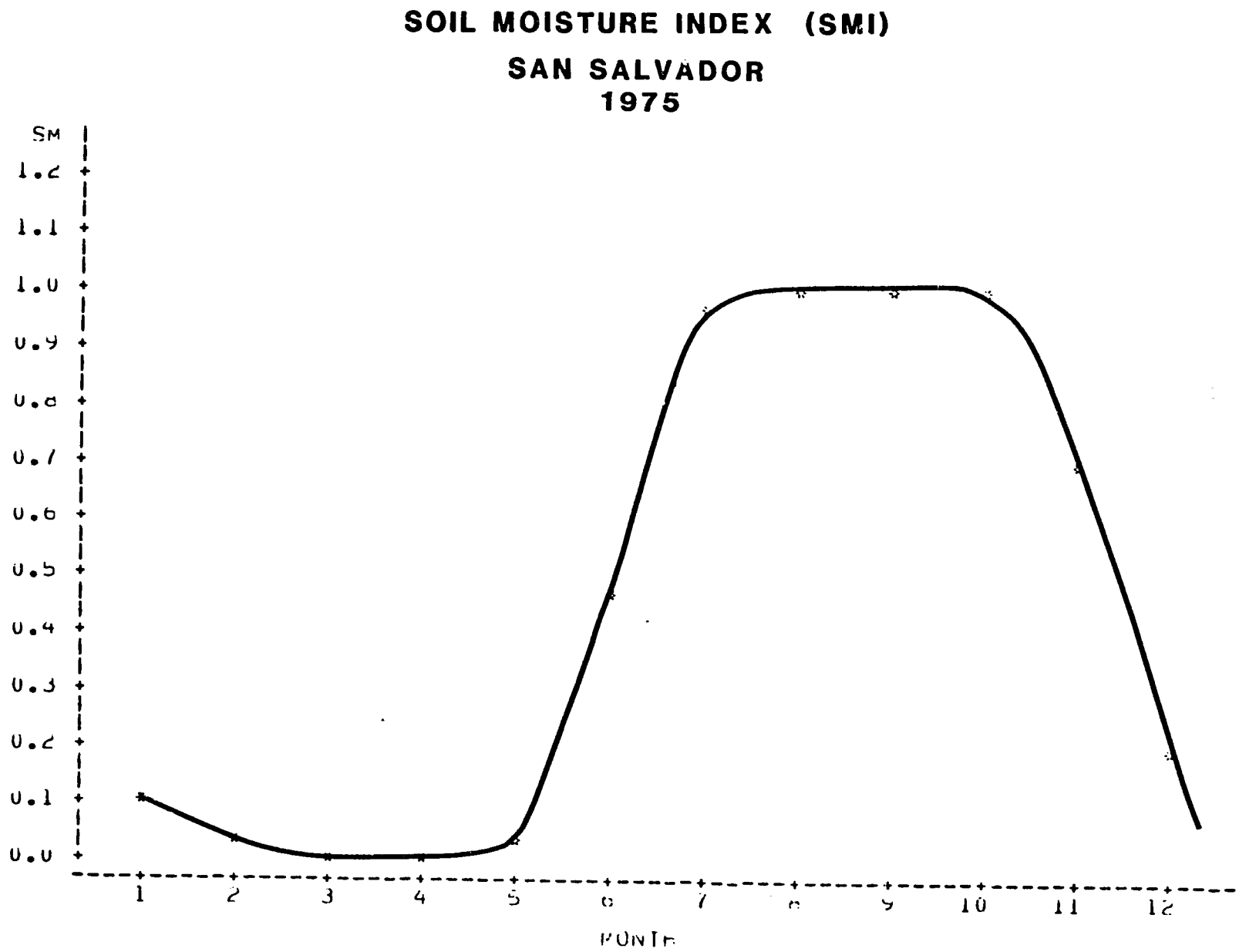


Figure 4.24. Soil Moisture Index (SMI) for San Salvador During 1975

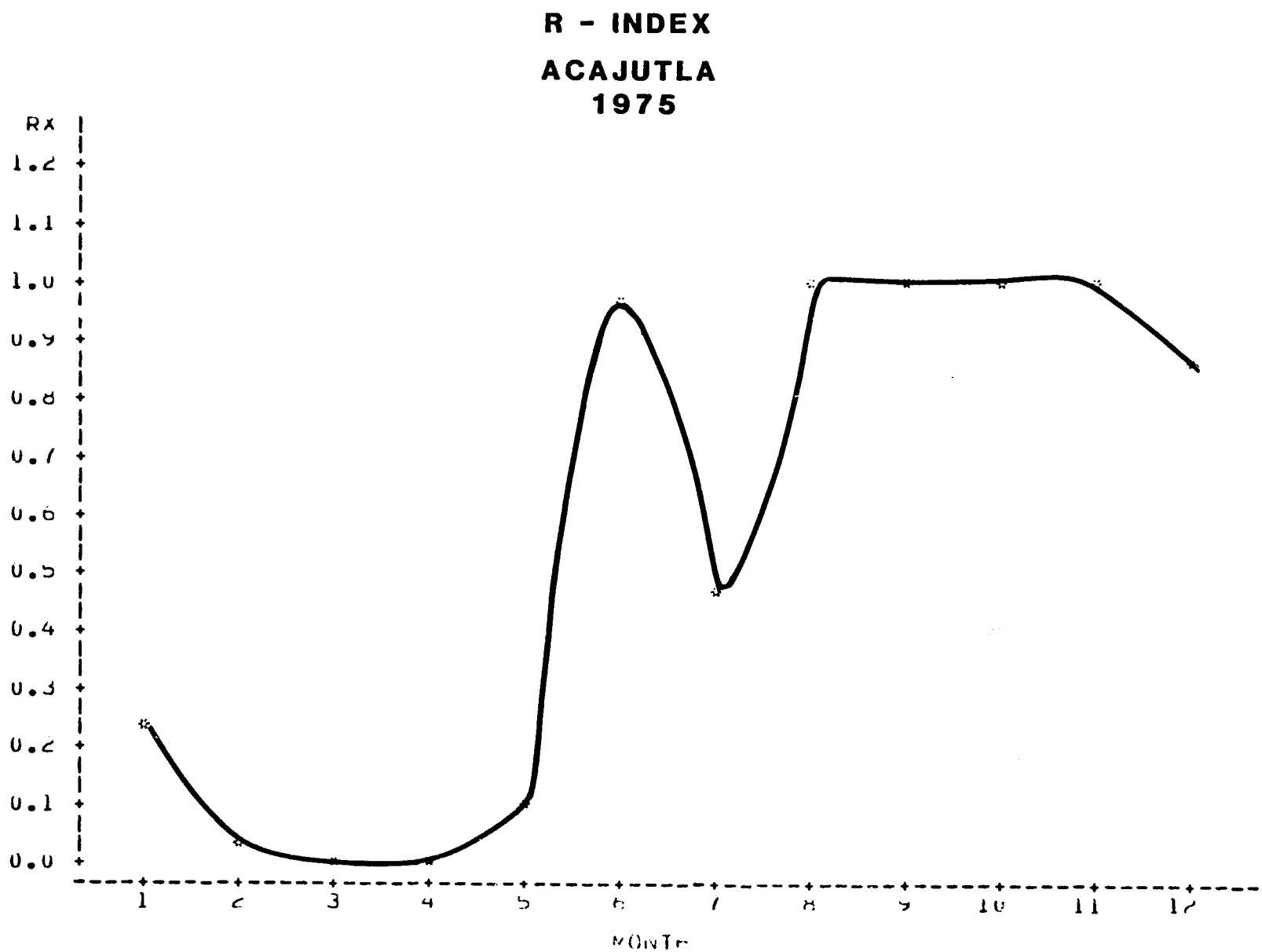


Figure 4.25. R-Index for Acajutla During 1975

to plant water requirements. From Figure 4.25 one can easily infer that during the month of July plants that are planted in May, such as corn, might be under severe stress. This fact confirms what was previously said about the uses of the R-Index, particularly regarding the help on solving the problems of agricultural land use capabilities and long-term agricultural planning. In this case study, Acajutla, optimum crop planting dates can be given to farmers. However, one must thoroughly test and evaluate this index before operational use.

6. Vegetation Index

Vegetation index values were calculated for El Salvador, as described in Chapter III, during 1982, 1983 and several months of 1984. By analyzing Figure 3.4 it can readily be seen that vegetative conditions during the period of March through April are extremely poor. Moreover, the index indicates that there was a lot of cloudiness during the month of May, a situation congruent with the reality. Similarly, it can be observed that vegetation reaches its healthiest condition by August and September. However, it seems that during the 200th Julian day, vegetation conditions were very abnormal thus giving an extremely low value for the Vegetation Index.

CHAPTER V

CONCLUDING REMARKS

This report is a result of a two-month training period at NOAA/CEAS, sponsored by the World Meteorological Organization through NOAA. Several potential evapotranspiration methods were studied in detail with extremely valuable outputs for crop condition assessments. Several agroclimatic indices were also discussed and evaluated. These indices provide reliable information on crop conditions at different stages. Most of the indices discussed in this report were analyzed and evaluated at several locations in El Salvador.

The main objective of this report is to increase awareness of the usefulness of agrometeorological information in order to increase Salvadorean agricultural production. The agroclimatic resources of El Salvador should be studied thoroughly to establish the impact of weather and climate on crops. This involves the development of programs that can provide early warning assessments to the main users, the farmers. In order to develop such a program a meteorological data base containing the main meteorological elements that affect agriculture need to be created. This data base must be extremely easy to access and data retrieval must be simple. Also, meteorological data need to be quality controlled. As suggested in the Executive Summary, to create this data base on a microcomputer is relatively inexpensive.

It is suggested that satellite information represents a variety of applications related to both meteorology and agriculture. The principal applications of satellite information were clearly described. Due to the size of El Salvador, it is pragmatically irrelevant to introduce agroclimatic procedures to monitor agriculture and meteorological phenomena

using satellite information; the resolution is not adequate to study meteorological features.

Nonetheless, a regional agroclimatic program can be introduced for the entire Central American region in which all the countries of the area would actively work. This kind of program would enhance the knowledge on our environment.

REFERENCES

Arze, J.B. 1982. Alternatives Para La Produccion de Cultivos en El Salvador Basados en la Incidencia de la Canicula. CATIE, Turrialba, Costa Rica.

Baier, W. and G.W. Robertson. 1966. A New Versatile Soil Moisture Budget. Can. J. Plant Science, 46:299-315.

Baier, W., J.A. Dyer, and W.R. Sharp. 1979. The Versatile Soil Moisture Budget. Technical Bulletin No. 87, Agrometeorology Section, Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario.

Berry, F.A., Jr., E. Bollay, and N.R. Beers. 1945. Handbook of Meteorology, First Edition, New York: McGraw-Hill Book Company, Inc.

Blutstein, H.I., et al. 1971. Area Handbook for El Salvador. American University, Washington, D.C.

Crosiar, C.L. 1984. Survey of Landsat, TIROS-N, DMSP, and Selected International Satellites. Unknown publisher.

Doorenbos, J. 1975. Crop Water Requirements. FAO Paper Number 24, Rome, 180 pp.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for Predicting Crop Water Requirements, FAO. Paper Number 24, Rome, 144 pp.

Evaluation Technologies, Inc. 1982. El Salvador: A Country Profile. Report Prepared for the Office of U.S. Foreign Disaster Assistance Agency for International Development, Department of State, Washington, D.C., 69 pp.

FAO-UNESCO. 1975. Soil Map of the World, Vol. III. Mexico and Central America, FAO-UNESCO, Paris.

Hargreaves, G.H. 1977. World Water for Agriculture. Utah State University, U.S.A.

Hastenrath, S. 1975. Large-Scale Circulation and Weather Anomalies in the Carribean and Central America. From Proceedings of the WMO/IAMAP Symposium on Long-Term Climatic Fluctuations, Norwich. pp. 18-23.

Kendrew, W.G. 1953. The Climates of the Continents. Fourth Edition, Oxford at the Clarendon Press.

Lebaron, A. and A. Percy. 1973. Preliminary Analysis of Economic Benefits of Improved Irrigation Practices in Zapotitan and Atiocoyo Projects El Salvador, Central America. Utah State University.

Menendez, M.E. 1970. El Salvador. In World Atlas of Agriculture, Vol 3, Instituto Geografico Agostini, Novara, Italy.

McIlroy, R.J. 1963. An Introduction to Tropical Cash Crops. Ibadan University Press, Ibadan, Nigeria.

Palmer, W.C. 1965. Meteorological Drought. Research Paper No. 45, U.S. Weather Bureau, Washington, D.C.

Penman, H.L. 1948. Natural Evaporation from Open Water, Bare Soil and Grass. Royal Soc. London Proc. Ser. A. Vol. 193. 193 pp.

Ravelo, A.C. 1983. Workshop in Climate Assessment for Agriculture, Methods, and Applications. Unpublished manuscript.

Ravelo, A.C. and L.T. Steyaert. 1983. Climate Assessment Methods for Drought/Food Shortages in Central and South America: Final Report. Assessment and Information Services Center, Climate Impact Assessment Division, Models Branch, Columbia, Missouri, U.S.A.

Rosenberg, N.J. 1974. Microclimate: The Biological Environment. New York: John Wiley and Sons.

Rudloff, W. 1981. World-Climate. Wissen-Schaftliche Verlagsgesellschaft mbH Stuttgart, West Germany.

Servicio Meteorologico de El Salvador. 1975. Anuario Meteorologico, Direccion General de Recursos Naturales Renovables, Ministerio de Agricultura y Ganaderia, San Salvador, El Salvador.

Tarpley, J.D., S.R. Schneider, and R.L. Money. 1984. Global Vegetation Indices from the NOAA-7 Meteorological Satellite. Journal of Climate and Applied Meteorology, 23: 491-494.

Thornthwaite, C.W. 1948. An approach toward a Rational Classification of Climate. Geographical Review, 38: 55-94.

Trewartha, G.T. 1961. The Earth's Problem Climates. University of Wisconsin Press, Madison, Wisconsin, U.S.A.

van Dyk, A., D. McCrary, S. LeDuc, and M. Lyon. 1983. AVHRR Training Set. Assessment and Information Services Center, Columbia, Missouri, U.S.A.

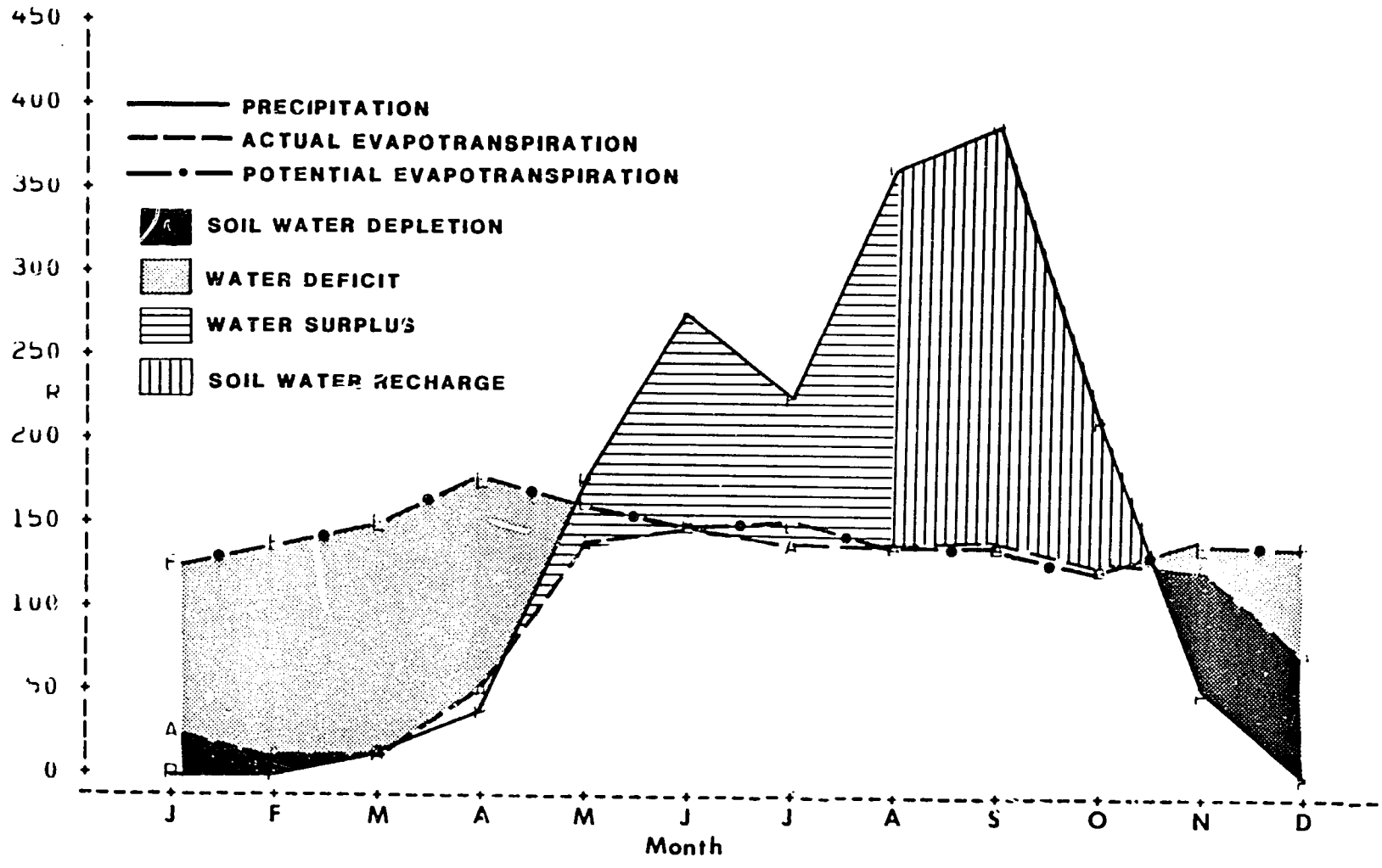
World Meteorlogical Organization. 1972. Anuario Meteorologico del Istmo Centroamericano Resumen 1970. San Jose, Costa Rica.

Yao, A.Y.M. 1969. The R Index for Plant Water Requirement. Agricultural Meteorology, 6: 259-273.

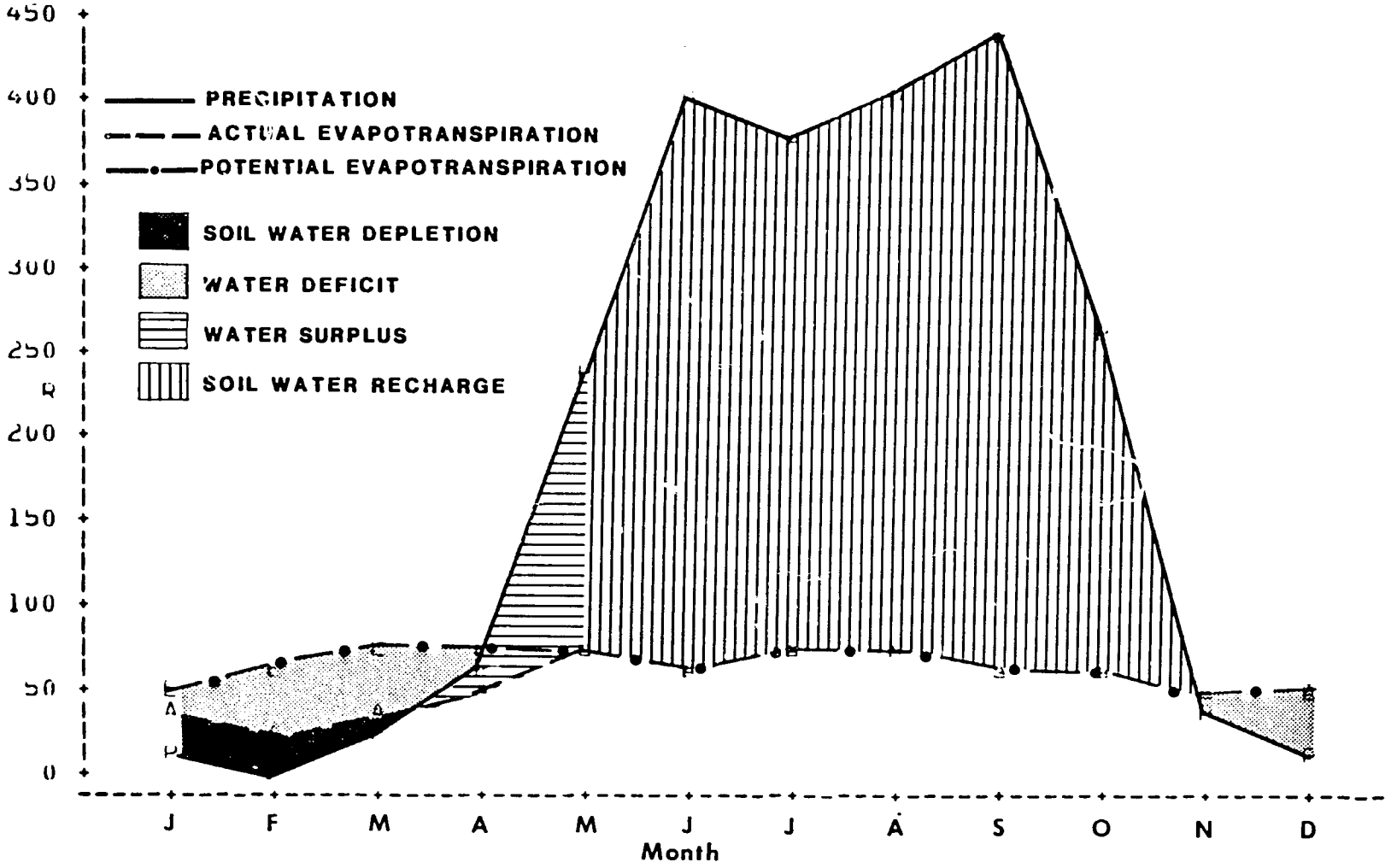
APPENDIX

This appendix contains climatic diagrams for Acajutla, Los Andes, and San Salvador. Soil moisture budgets, for the above places, are presented for the year 1975. Some meteorological data are also presented, mainly data which were utilized to compute PET. Absolute values of PET for the different methods discussed in this report are presented.

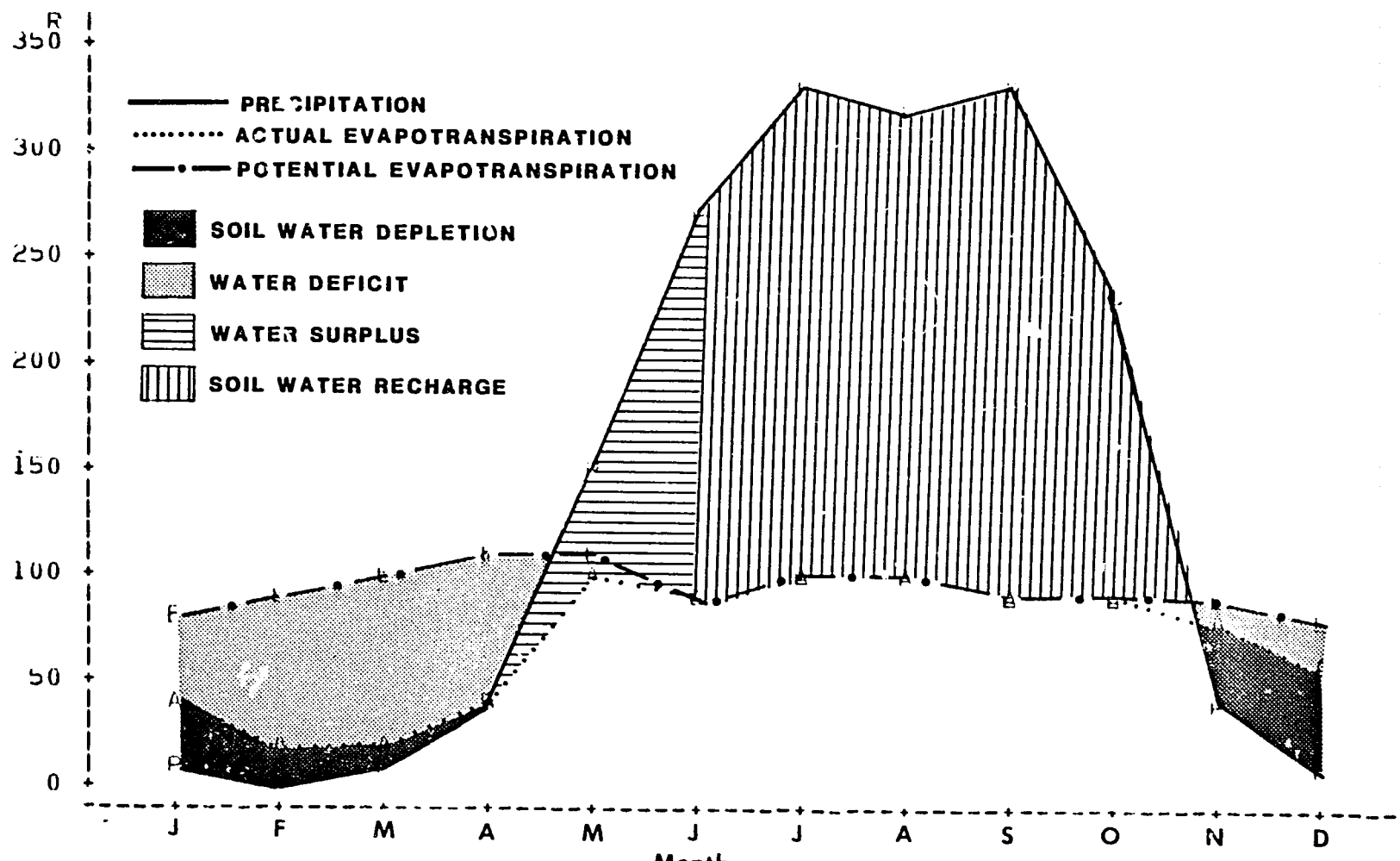
CLIMATIC DIAGRAM
ACAJUTLA



CLIMATIC DIAGRAM
LOS ANDES



CLIMATIC DIAGRAM
SAN SALVADOR



SOIL MOISTURE BUDGET FOR Acajutla, 1974

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0	0.0	0.0	0.0	6.0	25.4	25.4	15.2	25.4	0.0	0.0	0.0
SU	7.1	1.9	1.1	0.1	0.1	150.0	150.0	150.0	150.0	117.6	19.5	3.9
S	7.1	1.9	1.1	0.1	6.1	175.4	175.4	165.2	175.4	117.6	19.5	3.9
PCP	0.0	0.0	69.0	14.0	165.0	334.0	178.0	138.0	514.0	83.0	0.0	0.0
PET	128.1	128.1	144.0	163.6	158.9	137.6	148.0	148.1	124.2	146.1	146.2	140.0
ET	19.4	5.2	69.8	14.9	158.9	137.6	148.0	148.1	124.2	140.7	98.1	15.6
PR	148.8	168.2	173.4	174.2	175.2	169.2	0.0	0.0	10.1	0.0	57.7	155.8
R	0.0	0.0	0.0	0.0	6.0	169.2	0.0	0.0	10.1	0.0	0.0	0.0
PL	19.4	5.2	1.5	1.0	0.1	6.1	130.2	130.3	108.4	128.6	98.1	15.6
L	19.4	5.2	0.8	0.9	0.0	0.0	0.0	10.1	0.0	57.7	98.1	15.6
PRO	26.5	7.1	1.9	1.1	0.1	6.1	175.4	175.4	165.2	175.4	117.6	19.5
RO	0.0	0.0	0.0	0.0	0.0	27.0	29.9	0.0	379.6	0.0	0.0	0.0

SOIL MOISTURE BUDGET FOR Los Andes, 1975

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0	0.0	0.0	0.0	25.4	25.4	25.4	25.4	25.4	25.4	25.4	0.0
SU	76.1	33.6	13.8	2.8	150.0	150.0	150.0	150.0	150.0	150.0	150.0	118.7
S	76.1	33.6	13.8	2.8	175.4	175.4	175.4	175.4	175.4	175.4	175.4	118.7
PCP	54.0	3.0	29.0	9.0	361.0	147.0	259.0	546.0	446.0	352.0	86.0	0.0
PET	84.0	101.0	132.0	148.0	98.0	88.0	107.0	115.0	75.0	75.0	66.0	62.0
ET	69.7	45.5	43.7	19.9	98.0	88.0	107.0	115.0	75.0	75.0	66.0	56.6
PR	83.4	99.2	141.7	161.5	172.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R	0.0	0.0	0.0	0.0	172.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PL	44.0	43.8	25.3	11.7	1.6	78.9	95.1	102.0	67.8	67.8	60.1	56.6
L	15.7	42.5	19.7	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.6
PRO	91.9	76.1	33.6	13.8	2.8	175.4	175.4	175.4	175.4	175.4	175.4	175.4
RO	0.0	0.0	0.0	0.0	110.4	59.0	152.0	431.0	371.0	277.0	20.0	0.0

SOIL MOISTURE BUDGET FOR San Salvador, 1975

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0	0.0	0.0	0.0	8.0	25.4	25.4	25.4	25.4	25.4	0.0	0.0
SU	19.6	5.1	0.5	0.0	0.0	57.6	145.6	150.0	150.0	150.0	121.2	35.5
S	19.6	5.1	0.5	0.0	8.0	83.0	171.0	175.4	175.4	175.4	121.2	35.5
PCP	12.0	0.0	10.0	3.0	146.0	209.0	232.0	348.0	294.0	378.0	50.0	0.0
PET	125.0	129.0	168.0	173.0	138.0	134.0	144.0	149.0	111.0	115.0	109.0	124.0
ET	47.5	14.4	14.6	3.4	138.0	134.0	144.0	149.0	111.0	115.0	104.1	85.7
PR	120.2	155.7	170.2	174.8	175.3	167.3	92.3	4.3	0.0	0.0	0.0	54.1
R	0.0	0.0	0.0	0.0	8.0	75.0	88.0	4.3	0.0	0.0	0.0	0.0
PL	39.3	14.4	4.9	0.5	0.0	8.0	64.3	128.0	98.6	102.0	96.8	85.7
L	35.5	14.4	4.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	54.1	85.7
PRO	55.1	19.6	5.1	0.5	0.0	8.0	83.0	171.0	175.4	175.4	175.4	121.2
RO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	194.6	183.0	263.0	0.0	0.0

Key

: Surface Layer Storage
: Underlying Layer Storage
: Total Water Storage
P: Rainfall

PET: Potential Evapotranspiration
ET : Actual Evapotranspiration
PR : Potential Recharge
R : Recharge

PL : Potential Loss
L : Loss
PRO: Potential Runoff
RO : Runoff

MONTHLY TOTAL PRECIPITATION(mm) FOR SELECTED WEATHER STATIONS

OBS	NAME	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	YEAR
1	FINCA LOS ANDES	54	3	29	9	381	147	259	546	446	352	86	0	1975
2	AHUACHAPAN	3	1	6	46	121	174	171	377	255	235	39	0	1975
3	ACAJUTLA	28	3	0	0	20	159	68	316	504	296	109	0	1975
4	COJUTEPEQUE	17	0	0	1	98	240	132	383	271	345	126	0	1975
5	SANTA CRUZ PORRILLO	5	0	8	16	130	110	317	402	488	338	109	0	1975
6	SANTA ANA, EL PALMAR	18	1	12	10	130	106	164	279	408	268	73	0	1975
7	GUIJA	6	5	17	61	77	110	151	290	215	240	46	0	1975
8	SAN ANDRES	40	0	1	0	140	288	290	409	271	266	24	0	1975
9	SAN SALVADOR	12	0	10	3	146	209	232	348	295	378	50	0	1975
10	NUEVA CONCEPCION	0	0	36	26	115	249	130	402	279	239	29	0	1975
11	LA PALMA	3	16	38	72	220	263	227	441	484	325	76	0	1975
12	CHORRERA DEL GUAYABO	8	0	29	0	158	263	347	290	476	455	90	0	1975
13	SENSUNTEPEQUE, POSTA	38	0	10	1	359	199	344	340	433	345	183	0	1975
14	APASTEPEQUE	7	0	0	0	127	251	208	410	395	218	86	0	1975
15	SANTIAGO DE MARIA	1	0	0	55	155	81	225	338	539	313	117	0	1975
16	SESORI	1	4	19	0	302	117	206	384	496	335	88	0	1975
17	LA GALERA	10	1	1	0	275	155	109	244	433	307	90	0	1975
18	BENEFICIO EL PAPALON	2	0	3	0	173	118	135	283	421	186	108	0	1975
19	LA UNION	0	0	0	0	274	166	97	260	607	262	49	0	1975
20	INTIPUCA	1	0	0	1	163	234	169	326	514	275	89	0	1975
21	POLOROS	2	0	0	3	238	208	112	296	551	324	146	0	1975
22	SAN FRANCISCO GOTERA	0	0	5	0	210	156	264	392	492	331	138	0	1975
23	BENEFICIO LA CARRERA	1	0	1	0	99	89	168	314	541	269	73	0	1975

NORMAL PRECIPITATION (mm) FOR SELECTED WEATHER STATIONS

OBS	NAME	PBAR1	PBAR2	PBAR3	PBAR4	PBAR5	PBAR6	PBAR7	PBAR8	PBAR9	PBAR10	PBAR11	PBAR12
1	ACAJUTLA	3	2	11	51	146	310	264	314	372	227	50	6
2	AHUACHAPAN	2	0	8	34	119	282	281	308	336	154	24	4
3	SAN ANDRES	7	2	12	69	178	288	327	289	310	173	33	7
4	COJUTEPEQUE	6	2	11	36	155	288	269	288	315	221	52	7
5	LA UNION	1	0	6	32	205	316	180	214	390	294	39	4
6	SAN SALVADOR	6	4	10	54	179	315	312	307	317	230	36	10
7	SANTA ANA, EL PALMAR	3	3	14	71	222	330	302	303	329	193	33	8

MONTHLY TOTAL EVAPORATION (mm) FOR SELECTED WEATHER STATIONS

1975

OBS	NAME	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
1	ACAJUTLA	207	190	244	219	201	180	164	173	111	142	144	164
2	AHUACHAPAN	169	156	188	209	147	138	159	166	115	123	133	164
3	APASTEPEQUE	182	184	220	228	165	147	152	170	110	120	126	169
4	BENEFICIO EL PAPALON	223	212	244	270	201	165	130	170	126	139	120	170
5	BENEFICIO LA CARRERA	185	188	222	223	176	149	198	186	104	136	129	149
6	CHORRERA DEL GUAYABO	235	225	266	294	223	183	182	176	135	145	147	186
7	COJUTEPEQUE	155	163	207	227	120	82	82	83	48	60	85	151
8	FINCA LOS ANDES	49	67	96	96	49	45	68	52	30	27	24	37
9	GUIJA	155	170	211	215	169	150	162	155	108	114	111	191
10	INTIPUCA	198	188	184	194	125	90	86	79	53	63	68	81
11	LA GALERA	88	114	143	171	106	106	120	113	62	70	67	83
12	LA PALMA	142	151	182	195	99	75	74	58	30	62	84	127
13	LA UNION	279	254	303	309	235	168	201	192	114	142	153	204
14	NUEVA CONCEPCION	207	207	235	255	186	159	167	158	138	145	141	182
15	POLOROS	281	201	316	341	178	119	136	111	80	68	132	231
16	SAN ANDRES	241	226	254	273	170	120	96	93	75	83	111	167
17	SAN FRANCISCO GOTERA	220	210	241	210	189	129	176	148	132	142	129	186
18	SAN SALVADOR	173	151	161	165	105	90	117	108	75	77	150	229
19	SANTA ANA, EL PALMAR	226	212	238	264	148	123	120	111	69	96	147	220
20	SANTA CRUZ PORRILLO	189	173	201	198	151	150	151	173	123	158	141	176
21	SANTIAGO DE MARIA	192	168	182	207	74	90	96	74	42	58	75	130
22	SENSUNTEPEQUE, POSTA	186	169	183	217	110	80	83	69	53	58	75	150
23	SESORI	216	221	243	273	191	159	172	153	116	133	118	177

MONTHLY AVERAGE TEMPERATURE (°C) FOR SELECTED WEATHER STATIONS
1975

OBS	NAME	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
1	ACAJUTLA	26.9	26.5	27.7	28.6	28.5	28.0	27.3	26.9	26.2	26.5	26.2	25.5
2	AHUACHAPAN	21.9	21.8	23.2	24.5	23.8	23.4	22.7	22.6	21.9	22.1	21.9	20.4
3	APASTEPEQUE	22.5	24.0	23.7	24.7	25.5	24.2	23.8	23.0	22.8	22.1	22.4	21.9
4	BENEFICIO EL PAPALON	26.6	26.0	27.5	28.8	28.2	27.6	26.7	26.0	25.2	25.5	25.0	23.7
5	BENEFICIO LA CARRERA	26.2	25.5	26.7	27.9	27.5	27.3	26.3	26.1	25.1	25.5	25.5	24.2
6	CHORRERA DEL GUAYABO	27.1	27.1	28.2	29.6	27.4	26.4	25.6	25.4	24.7	25.0	24.9	24.7
7	COJUTEPEQUE	21.3	21.6	22.5	23.4	22.4	22.4	21.8	21.4	20.4	20.0	20.4	19.5
8	FINCA LOS ANDES	14.7	15.6	17.4	18.2	17.9	17.4	16.7	17.0	16.1	16.0	14.7	13.1
9	GUIJA	24.8	25.4	27.1	27.9	26.7	26.1	24.9	24.0	23.9	23.9	23.7	23.9
10	INTIPUCA	27.2	25.8	26.9	27.9	27.1	26.8	25.9	25.8	25.0	25.5	25.3	25.6
11	LA GALERA	12.9	14.0	15.2	16.2	16.0	15.8	15.2	15.2	14.7	14.5	13.4	11.6
12	LA PALMA	19.8	20.6	22.3	22.9	21.9	23.5	20.5	20.5	20.1	20.1	19.6	18.4
13	LA UNION	28.3	27.8	28.9	29.8	28.4	28.1	27.4	26.9	25.9	26.3	26.3	26.2
14	NUEVA CONCEPCION	25.6	25.9	27.1	28.5	27.0	25.0	25.2	24.5	24.6	24.4	24.0	23.1
15	POLOROS	25.1	25.0	26.5	27.6	26.1	25.5	24.5	24.0	23.3	22.2	23.4	22.9
16	SAN ANDRES	23.5	23.3	24.9	26.0	25.8	25.1	24.0	24.0	23.5	23.4	22.7	21.0
17	SAN FRANCISCO GOTERA	26.6	26.4	27.8	28.9	27.7	27.2	26.0	25.6	24.7	25.3	24.9	24.1
18	SAN SALVADOR	22.7	22.7	24.2	25.3	24.4	24.1	23.3	23.1	23.3	22.1	22.0	21.2
19	SANTA ANA, EL PALMAR	22.4	22.4	23.6	24.9	24.0	23.5	22.8	23.0	22.2	22.3	21.8	20.5
20	SANTA CRUZ PORRILLO	26.8	26.2	27.1	27.9	27.9	27.6	26.5	26.4	25.7	26.0	25.8	25.3
21	SANTIAGO DE MARIA	21.9	21.5	22.7	23.6	22.1	22.5	21.7	22.1	20.7	21.1	20.9	20.1
22	SENSUNTEPEQUE, POSTA	23.3	23.2	24.2	25.8	24.7	24.1	23.3	22.6	22.4	22.3	22.0	21.1
23	SESORI	26.0	25.9	27.3	28.7	27.2	26.3	25.4	24.8	24.5	24.0	24.0	23.0

MONTHLY AVERAGE RELATIVE HUMIDITY (%) FOR SELECTED WEATHER STATIONS
1975

OBS	NAME	HR1	HR2	HR3	HR4	HR5	HR6	HR7	HR8	HR9	HR10	HR11	HR12
1	ACAJUTLA	69	71	70	70	76	76	78	82	86	84	78	72
2	AHUACHAPAN	66	69	69	66	79	79	79	80	86	84	73	67
3	APASTEPEQUE	86	57	58	63	61	79	80	82	83	89	78	62
4	BENEFICIO EL PAPALON	56	59	61	55	70	73	73	78	86	83	79	66
5	BENEFICIO LA CARRERA	62	64	66	62	75	75	76	78	86	82	78	68
6	CHORRERA DEL GUAYABO	57	56	56	50	70	73	78	81	85	83	75	65
7	COJUTEPEQUE	68	64	70	67	83	82	81	84	91	86	81	70
8	FINCA LOS ANDES	83	77	71	70	81	84	81	83	89	90	91	88
9	GUIJA	90	83	82	80	88	89	89	90	92	95	94	94
10	INTIPUCA	55	62	66	59	77	79	80	81	88	85	79	63
11	LA GALERA	87	62	74	68	88	85	78	85	92	93	93	91
12	LA PALMA	74	69	66	65	80	83	84	85	81	87	81	74
13	LA UNION	54	53	56	51	69	71	71	75	83	80	72	58
14	NUEVA CONCEPCION	57	56	61	55	70	71	76	81	81	82	74	63
15	POLOROS	56	54	53	52	74	76	76	82	89	76	78	62
16	SAN ANDRES	53	68	66	64	72	77	80	80	83	83	76	69
17	SAN FRANCISCO GOTERA	52	52	53	51	66	69	69	74	80	76	72	60
18	SAN SALVADOR	66	65	66	62	74	76	76	78	81	82	73	64
19	SANTA ANA, EL PALMAR	63	64	63	61	74	74	76	77	81	81	73	66
20	SANTA CRUZ PORRILLO	63	64	67	65	76	78	80	82	84	83	80	66
21	SANTIAGO DE MARIA	73	73	74	71	90	82	81	81	89	87	80	72
22	SENSUNTEPEQUE, POSTA	60	62	66	58	76	79	81	83	86	85	77	64
23	SESORI	58	56	59	53	73	79	80	83	87	84	79	68

HOURLY AVERAGE SUNLIGHT (hour) PER MONTH FOR SELECTED WEATHER STATIONS
1975

OBS	NAME	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	AHUACHAPAN	9.0	8.7	9.6	9.7	7.1	6.4	7.9	7.4	4.9	5.9	7.5	9.7
2	APASTEPEQUE	6.7	9.9	9.2	10.1	9.1	6.6	6.7	7.8	8.4	5.3	7.6	10.2
3	BENEFICIO EL PAPALON	9.4	10.0	9.9	10.1	7.4	8.2	8.6	8.5	5.9	7.4	7.7	9.9
4	BENEFICIO LA CARRERA	9.4	9.9	9.9	9.9	6.7	7.3	7.7	8.6	4.8	7.4	7.2	9.9
5	FINCA LOS ANDES	6.6	8.4	8.7	9.7	4.7	4.2	5.9	6.6	3.5	3.8	4.3	4.5
6	LA GALERA	7.0	14.3	8.9	9.8	5.6	6.4	7.3	6.4	6.3	4.5	.	6.6
7	LA UNION	9.8	10.1	9.7	10.0	8.0	8.5	8.6	8.1	6.1	7.5	8.3	9.7
8	NUEVA CONCEPCION	9.0	9.6	9.6	9.3	7.3	7.7	8.8	7.4	5.7	6.5	7.4	8.6
9	SAN ANDRES	8.3	8.7	7.9	7.3	4.6	6.3	7.3	.	4.8	6.1	7.2	9.3
10	SAN FRANCISCO GOTERA	9.2	10.1	9.7	9.4	7.2	7.7	8.6	8.3	5.6	7.0	7.5	9.3
11	SAN SALVADOR	8.6	9.0	9.5	9.3	6.3	6.5	7.2	7.7	5.2	6.2	7.1	9.5
12	SANTA ANA, EL PALMAR	8.6	9.3	9.2	9.0	5.5	5.9	7.6	7.9	4.9	6.1	7.2	9.4
13	SANTA CRUZ PORRILLO	8.9	9.8	9.7	9.5	6.9	7.2	7.8	8.4	5.2	7.2	7.3	9.2
14	SANTIAGO DE MARIA	9.0	9.3	9.2	9.6	5.2	6.1	7.5	7.5	3.7	5.6	6.6	9.2
15	SESORI	9.1	10.3	9.8	9.8	7.0	7.5	8.3	7.7	4.8	6.5	6.8	9.7

AVERAGE MONTHLY WIND SPEED (km/hour) FOR SELECTED WEATHER STATIONS
1975

OBS	NAME	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	WS11	WS12
1	ACAJUTLA	5.91	5.66	5.94	5.57	4.66	5.16	5.06	4.71	4.80	4.54	4.76	4.77
2	AHUACHAPAN	7.85	7.16	6.76	7.10	6.15	6.52	6.55	6.08	4.84	5.10	7.65	9.59
3	APASTEPEQUE	9.76	10.14	11.54	13.92	11.63	11.59	13.93	14.36	10.34	10.43	7.85	13.19
4	BENEFICIO LA CARRERA	4.11	6.02	7.60	5.94	8.79	5.76	5.56	5.69	3.55	5.25	5.71	6.28
5	COJUTEPEQUE	3.56	7.58	11.63	10.52	10.31	6.83	9.10	8.24	8.39	6.02	8.76	11.16
6	GUIJA	6.96	6.46	6.14	6.50	5.98	5.85	4.14	5.00	5.74	5.51	5.21	9.18
7	INTIPUCA	3.70	4.38	3.62	3.80	6.48	2.88	3.15	3.58	2.87	3.12	2.11	4.12
8	LA GALERA	10.60	4.16	4.89	6.61	4.77	7.06	8.10	12.03	5.80	5.28	10.28	11.61
9	LA UNION	10.14	10.76	10.80	11.71	9.54	7.42	7.91	7.13	6.63	6.26	6.07	8.89
10	NUEVA CONCEPCION	6.85	5.96	5.77	6.78	3.72	3.85	3.54	4.33	3.92	3.56	4.44	6.16
11	POLOROS	13.81	9.44	6.72	5.84	9.59	6.62	6.61	13.41	8.82	9.98	11.00	14.59
12	SAN ANDRES	6.31	6.91	6.23	8.03	6.29	6.31	5.55	5.63	5.49	5.17	5.33	6.60
13	SAN SALVADOR	7.43	7.36	7.66	8.05	6.08	6.23	5.92	5.62	6.28	6.34	7.76	9.62
14	SANTA ANA, EL PALMAR	8.77	8.54	8.37	8.95	6.57	6.70	6.28	6.23	6.18	6.14	7.91	10.13
15	SANTA CRUZ PORRILLO	7.54	6.94	6.39	7.08	5.03	5.33	5.06	4.85	4.57	4.71	5.07	6.08
16	SENSUNTEPEQUE, POSTA	10.34	8.35	7.61	3.89	6.99	3.30	3.43	3.22	3.72	2.94	3.53	4.81
17	SESORI	7.69	4.95	6.92	6.49	4.70	2.73	3.19	2.29	3.26	1.69	5.68	6.99

MONTHLY SOLAR RADIATION (cal/cm^{2}day) FOR SELECTED WEATHER STATIONS

OBS	NAME	ALAT	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	QA9	QA10	QA11	QA12
1	ACAJUTLA	13.57	727	808	879	925	934	926	927	923	894	834	753	704
2	AHUACHAPAN	13.95	727	808	879	925	934	926	927	923	894	834	753	704
3	APASTEPEQUE	13.70	727	808	879	925	934	926	927	923	894	834	753	704
4	BENEFICIO EL PAPALON	13.43	740	817	884	925	930	921	921	920	897	841	764	716
5	BENEFICIO LA CARRERA	13.33	740	817	884	925	930	921	921	920	897	841	764	716
6	CHORRERA DEL GUAYABO	14.00	727	808	879	925	934	926	927	923	894	834	753	704
7	COJUTEPEQUE	13.72	727	808	879	925	934	926	927	923	894	834	753	704
8	FINCA LOS ANDES	13.88	727	808	879	925	934	926	927	923	894	834	753	704
9	GUIJA	14.23	727	808	879	925	934	926	927	923	894	834	753	704
10	INTIPUCA	13.20	740	817	884	925	930	921	921	920	897	841	764	716
11	LA GALERA	14.05	727	808	879	927	934	926	927	923	894	834	753	704
12	LA PALMA	14.30	727	808	879	925	934	926	927	923	894	834	753	704
13	LA UNION	13.33	740	817	884	925	930	921	921	920	897	841	764	716
14	NUEVA CONCEPCION	14.13	727	808	879	925	934	926	927	923	894	834	753	704
15	POLOROS	13.82	727	808	879	927	934	926	927	923	894	834	753	704
16	SAN ANDRES	13.82	727	808	879	925	934	926	927	923	894	834	753	704
17	SAN FRANCISCO GOTERA	13.70	727	808	879	925	934	926	927	923	894	834	753	704
18	SAN SALVADOR	13.72	727	808	879	925	934	926	927	923	894	834	753	704
19	SANTA ANA, EL PALMAR	13.98	727	808	879	925	934	926	927	923	894	834	753	704
20	SANTA CRUZ PORRILLO	13.43	740	817	884	925	930	921	921	920	897	841	764	716
21	SANTIAGO DE MARIA	13.48	740	817	884	925	930	921	921	920	897	841	764	716
22	SENSUNTEPEQUE, POSTA	13.87	727	808	879	925	934	926	927	923	894	834	753	704
23	SESORI	13.72	727	808	879	925	934	926	927	923	894	834	753	704

MONTHLY PET VALUES (mm) USING THE PENMAN METHOD FOR SELECTED WEATHER STATIONS

1975

OBS	NAME	PENMAN1	PENMAN2	PENMAN3	PENMAN4	PENMAN5	PENMAN6	PENMAN7	PENMAN8	PENMAN9	PENMAN10	PENMAN11	PENMAN12
1	AHUACHAPAN	96	84	101	113	88	85	87	83	66	68	83	96
2	APASTEPEQUE	70	132	158	169	169	108	116	109	88	72	78	135
3	BENEFICIO LA CARRERA	93	98	128	126	122	99	96	93	67	78	78	92
4	LA GALERA	54	61	69	82	63	66	77	76	56	52	.	48
5	LA UNION	186	178	204	239	149	121	125	109	83	88	92	142
6	NUEVA CONCEPCION	121	110	123	152	96	89	83	79	73	69	72	93
7	SAN ANDRES	111	89	108	130	105	92	84	.	74	71	71	80
8	SAN SALVADOR	97	93	115	130	97	90	90	85	79	74	84	105
9	SANTA ANA, EL PALMAR	109	101	123	137	98	93	90	89	76	75	84	101
10	SANTA CRUZ PORRILLO	124	108	118	131	99	93	88	84	74	76	73	98
11	SESORI	130	101	139	154	99	76	78	70	65	60	72	91

MONTHLY PET VALUES (mm) USING THE HARGREAVES METHOD FOR SELECTED WEATHER STATIONS

1975

OBS	NAME	HARGRS1	HARGRS2	HARGRS3	HARGRS4	HARGRS5	HARGRS6	HARGRS7	HARGRS8	HARGRS9	HARGRS10	HARGRS11	HARGRS12
1	AHUACHAPAN	44	44	55	58	58	55	56	56	51	49	43	41
2	APASTEPEQUE	44	47	55	58	62	56	58	57	53	49	44	43
3	BENEFICIO EL PAPALON	50	50	61	64	65	61	62	61	56	55	48	45
4	BENEFICIO LA CARRERA	50	49	60	63	63	61	61	61	55	55	48	46
5	FINCA LOS ANDES	35	37	46	49	49	46	47	48	42	41	34	31
6	LA GALERA	33	36	44	46	46	44	45	45	41	39	.	30
7	LA UNION	52	52	63	66	65	62	63	62	57	56	49	48
8	NUEVA CONCEPCION	48	49	60	64	63	59	61	59	54	52	46	43
9	SAN ANDRES	45	46	57	59	60	57	58	.	53	51	44	41
10	SAN FRANCISCO GOTERA	49	50	61	64	64	61	62	61	55	54	47	45
11	SAN SALVADOR	44	45	56	59	59	56	57	57	53	49	43	42
12	SANTA ANA, EL PALMAR	44	45	55	58	58	55	57	57	51	50	43	41
13	SANTA CRUZ PORRILLO	50	50	61	63	64	61	62	62	56	55	48	47
14	SANTIAGO DE MARIA	44	44	54	57	55	53	55	55	49	48	43	41
15	SESORI	48	49	61	64	63	60	61	59	54	52	46	44

MONTHLY PET VALUES (mm) USING THE THORNTHWAITE METHOD FOR SELECTED WEATHER STATIONS

1975

OBS	NAME	THORT1	THORT2	THORT3	THORT4	THORT5	THORT6	THORT7	THORT8	THORT9	THORT10	THORT11	THORT12
1	ACAJUTLA	139	131	156	177	175	163	148	139	126	131	126	113
2	AHUACHAPAN	82	81	95	110	102	97	90	89	82	84	82	68
3	APASTEPEQUE	85	102	99	111	121	105	100	91	88	81	84	79
4	BENEFICIO EL PAPALON	135	124	153	181	167	155	137	124	110	115	107	88
5	BENEFICIO LA CARRERA	128	116	137	161	153	149	130	126	110	116	116	96
6	CHORRERA DEL GUAYABO	145	145	167	200	150	131	117	114	103	107	106	103
7	COJUTEPEQUE	80	82	91	100	90	90	84	81	72	68	72	64
8	FINCA LOS ANDES	51	56	67	73	71	67	63	65	59	59	51	42
9	GUIJA	108	117	145	160	138	128	110	97	96	96	93	96
10	INTIPUCA	147	121	141	161	145	139	123	121	108	116	113	118
11	LA GALERA	47	53	60	66	65	63	60	60	57	56	50	40
12	LA PALMA	69	75	90	96	87	102	75	75	71	71	67	58
13	LA UNION	170	158	186	211	173	165	149	138	118	126	126	124
14	NUEVA CONCEPCION	120	124	145	172	143	126	113	103	104	101	96	84
15	POLOROS	114	112	135	154	129	120	105	99	90	77	91	85
16	SAN ANDRES	95	92	112	128	125	115	101	101	95	94	85	68
17	SAN FRANCISCO GOTERA	135	131	159	183	157	147	124	117	103	112	106	94
18	SAN SALVADOR	88	88	105	119	108	104	95	92	95	82	81	73
19	SANTA ANA, EL PALMAR	86	86	99	114	104	98	90	92	84	85	80	68
20	SANTA CRUZ PORRILLO	138	127	144	161	161	155	133	131	118	123	120	113
21	SANTIAGO DE MARIA	84	81	92	101	86	90	82	86	73	77	75	68
22	SENSUNTEPEQUE, POSTA	94	93	105	126	111	104	94	87	85	83	80	71
23	SESORI	126	124	149	177	147	131	116	107	102	95	95	82