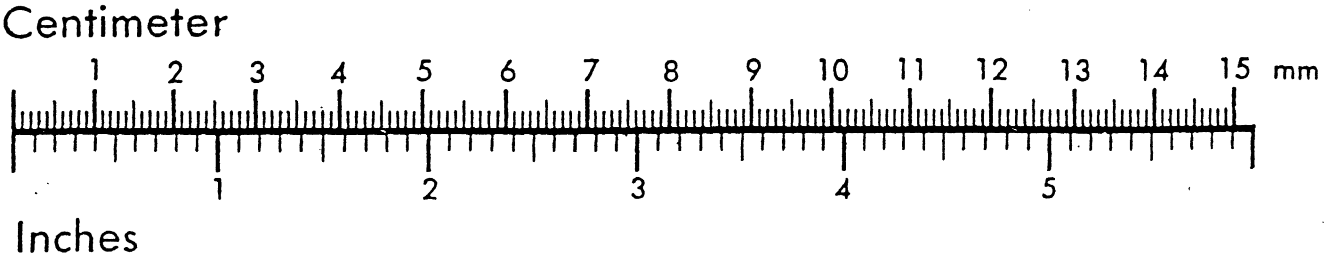
Centimeter
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
mm
1
2
3
4
5
Inches

Late Holocene Environmental Change in the Basin of Pátzcuaro, Michoacán, México.

Thesis submitted for the Degree of
Doctor of Philosophy
in the Faculty of Anthropology and Geography

by

Sarah L. O'Hara
St. Hilda's College, Oxford
Trinity Term, 1991. [i.e 1996] ??

[illegible]

[illegible]

ABSTRACT

Sarah L. O'Hara
St. Hilda's College

D. Phil. Trinity 1991 [ie 1996] ??

Late Holocene Environmental Change in the Basin of Pátzcuaro, Michoacán, Mexico.

This thesis describes late Holocene environmental changes in the Basin of Pátzcuaro, Michoacán, Mexico. Using palaeolimnological, geomorphological, sedimentological and historical evidence it is possible to conclude that the Basin of Pátzcuaro has suffered at least three episodes of disturbance within the last 3,600 years. A minor episode of erosion began about 3,500 years ago and is believed to have been triggered by the onset of sedentary agriculture within the basin. A second, more severe phase of disturbance, occurred between about 2,500 and 1,200 years B.P. during which time there was extensive degradation in the northern part of the catchment; widespread gullying is believed to have occurred at this time. The recent, most intense period of erosion began about 850 years B.P., coinciding with the arrival of the Purépecha in the basin. There is no evidence to suggest that degradation within the catchment intensified after the arrival of the Spanish 470 years B.P. However, a change in the style of erosion from predominantly sheet-wash to gully erosion occurred at approximately 400-500 years B.P. and may reflect the introduction of new agricultural techniques by the Spanish.

Fluctuations in the level of Lake Pátzcuaro have been used to infer late Holocene climatic change. Prior to 4,000 years B.P. dry conditions prevailed. An abrupt change to wetter conditions occurred between about 3,600 and 3,200 years B.P. before becoming more arid. Wetter conditions between 2,500 and 1,200 years B.P. can be inferred from the lake sediment record. The driest period in the record occurred between 1,200 and 850 years B.P. Fluctuations in the level of the lake over the last 600 years have been determined from historical records. The lake rose between 600 and 470 years B.P. and remained high until approximately 300 years B.P. after which time the lake level fell once again.

TABLE OF CONTENTS

CHAPTER NINE: SEDIMENT CHEMISTRY RECORD OF LAKE PATZCUARO

CHAPTER 10: DISCUSSION

LIST OF TABLES.

LIST OF PLATES

LIST OF FIGURE

ACKNOWLEDGEMENTS

This project has been funded by the following bodies: The Natural and Environmental Reasearch Council Research Studentship (GT4/86/AAPS/60; 1986-1988 and 1989-1990); Consejo Nacional de Ciencias y Technologia (CONACYT), Government of Mexico (1988-1989); The Muriel Wise Travel Fund (St. Hilda's College, Oxford); The Interdepartmental Committee for Latin American Studies, University of Oxford; The Vaughan Cornish Bequest (University of Oxford); The Henrietta Hutton Trust (Royal Geographical Society); The Dudley Stamp Memorial Trust (The Royal Society); The Percy Sladen Memorial Fund (Linnean Society). I am grateful to these societies, institutions, and reserach bodies for their generous support towards my research.

This project has been jointly supervised by Dr. F. Alayne Street-Perrott and Dr. Timothy P. Burt. Alayne has been a constant source of ideas and information and I wish to thank her for her encouragement, many long telephone calls to discuss this project, the considerable amount of time she spent reading and correcting my thesis and finally for introducing me to Mexico. Tim has not only acted as supervisor, but proved to be an excellent field assistant! I am grateful for his continual support and advice and, in particular, for the speed with which he read any work I gave him.

Dr. Sarah Metcalfe has been of considerable assistance to this project and I wish to thank her for her

continual advice and encouragement over the last few years. I am grateful to J. Platt Bradbury (USGS) who allowed me to take samples from the Mastercore. I must also thank Alan Perrott for his assistance in the field and laboratory in the early stages of this project.

This project would not have been possible with out the help of numerous people both here and in Mexico. I wish to thank Alberto and Silvana Lopez who have always made me feel at home in Mexico. Alberto also acted as my supervisor during a year of study at UNAM on a CONACYT scolarship. In Patzcuaro thanks must be extended to the Asencion Medina family with whom I lived for much of my stay in Patzcuaro. I am grateful to Dr Ricardo Klimek G. and Dra. Norma Alaya R. who allowed me access to their laboratories in PESCA, and to the Centro de Estudios Sociales y Ecologicos (CESE) who provides me with a considerable amount of information regarding the Basin of Patzcuaro and the idigenous population. Jorge Pablo of CESE acted as interpreter when conducting interviews.

I am indebted to the fishermen of the Island of Yunuen who, despite thinking I was mad, provided the boat and helped with the coring: without their assistance it would have been impossible to collect the cores. Don Ramirez helped construct the corer. Maestro Geraldo Perez, Escuela de Historia, UMSNH, introduced me to a whole new area of research when he took me to the Archivos General del Estado de Michoacán. It was one of the few parts of my field work that didn't involve me getting covered in mud.

I would also like to thank the following people for the many things that helped made my stay in Mexico a wonderful experience: Dr. Arturo Chacon T., Dra. Teresa Oceja C., Dora Ascencion M., Laura Gonzalez C., Marilu Altimirano S., Eva Caraballo B., Lydia Espinoza M., Dra. Maricruz Mendez C., Miguel Angel Nunez and Sra. Paris.

During the course of this project I spent a considerable amount of time in the laboratories of the School of Geography, and I wish to thank Chris Jackson who was always at hand to help fix temperamental machinery and to give advice on laboratory procedure and analyses. I am grateful to the following who have also provided technical advice and support; Nick Barber, Phil Hales, Dr. John Walden and Dr. John Dearing. Penny Johnes and I spent may hours in the laboratory 'baby-sitting' each other during the long hot summer of 1990 and her continual good humour helped to make it all bearable. Many people, too numerous to mention, in the School of Geography have provided help and encouragement over the last few years especially the inmates of the 'upper research room'. I am grateful to the Department of Geography, University of Sheffield, for allowing me sufficient time to write up and for the support from my collegues in that department. Special thanks to Alistair Kirkebride, David Nash, Marcus Blake and Dr. Louise Heathwaite.

I would like to thank my friends, who for the last year have spent many hours listening to me moan about how much I have 'enjoyed' the experience of writing this thesis;

special thanks go to Diane Bonardi, Eve Parsons, Jill Parker, Viv Jones, Laura Lettice, Lorraine O'Donnell, Viv Broughton, and in particular to Aylish Wood who was always there when I needed her.

Finally, I would like to thank my parents Jim and Maureen O'Hara who put up with me being a scrounging student for 10 years and never once asked me when I was going to get a proper job!

CHAPTER ONE: INTRODUCTION

Soil erosion is one of the most severe environmental problems facing México with approximately 75% of the country classified as eroded (Tamayo, 1964). Although much of the Mexican landscape is susceptible to erosion, the problem has been exacerbated by the recent huge increase in population and the need to farm more marginal lands. It is widely assumed, however, that the problem of erosion in México is a legacy of the Spanish. Chevalier (1963), for example, concluded that:

> *'Overgrazing of hillslopes, plowing of the lower slopes and deforestation through the heavy cutting of timber for colonial building and for the production of charcoal... resulted in sheet erosion and gullying which quickly turned the highland areas of Central México ... into an agricultural wasteland'.*

while Eckholm (1976) suggested that the:

> *'European conquerors competing for empires in the New World took environmentally destructive habits with them. Oversized herds of cattle, sheep and goats bought from the Old World have helped destroy needed woodlands, create deserts and degrade rangeland throughout much of ... México...'*

The assumption that soil erosion and colonialism in México go 'hand-in-hand' has been questioned since in the 1940s (eg. Vaillant, 1944; Cook, 1949), although it has only been in recent years that concrete evidence of Prehispanic environmental degradation in México has been obtained (eg. Deevey et al. 1979, 1983; Metcalfe et al, 1989).

The relationship between environmental change and cultural development in México has been of interest to researchers since the turn of the century (Huntington, 1913, 1914). Attempts to establish links between, climate, palaeoecology and human activity began in the 1940s, and traditionally have been based on palaeolimnological investigations (Deevey, 1944; Sears and Clisby, 1955; Clisby and Sears, 1955; Bradbury, 1971, 1989; Watts and Bradbury, 1982; Ohnegmach and Straka, 1983; Metcalfe, 1985; Gonzales Quintero, 1986; and Leyden, 1987). The main aim of many of these studies has been to establish the history of climatic change based on pollen and diatom analyses. Attempts to reconstruct the late Holocene record have proved difficult, however, as many lake basins in México have a long history of settlement. Consequently, it is has been almost impossible to distinguish the impact of climate from the impact of humans on the sediment record.

It has only been in the last decade that investigators working on Mexican palaeolimnological records have realised the potential of these lake sediment records for assessing the long term human impact on the environment (Deevey et al, 1979, 1983; Leyden, 1987; Metcalfe et al., 1989, 1991). By adopting a similar approach to palaeolimnologists in Europe (Mackereth, 1966; Pennington, 1978; Oldfield et al, 1978) and North America (Bradbury, 1975; Engstrom et al, 1991), researchers have been able to establish that many areas of México have experience periods of environmental degradation which can be associated with the development of Prehispanic cultures (Deevey et al, 1979, 1983; Leyden, 1987; Metcalfe et al., 1989, 1991).

Many of these investigations have reported periods of increased lake sediment accumulation that have been used to infer accelerated erosion. While these studies have added substantially to our understanding of late Holocene environmental change, and provide additional information which have helped clarify changes in the climate, they are unfortunately of limited value for assessing the extent of past environmental degradation. One of the main reasons for this has been the reliance of these studies on a single core. Liken and Davis (1975) and Edwards and Rowntree (1980), have inferred relative changes in sediment yields from changes in sediment accumulation at a single lake core, and it has been suggested by Lehman (1975) that using such data it is possible to estimate rates of sediment accumulation using theoretical models. The use of a single core for determining sediment accumulation rates and hence rates of erosion within a catchment have been criticised by a number of studies (eg. Bloemendal et al, 1979; Dearing et al, 1981; Davis et al, 1984), who have demonstrated that sediment accumulation proceeds in a complex and shifting manner, and that maximum deposition occurs at different positions at different times. Moreover, Hakanson (1977) noted that because of density dependent sedimentation the chemical composition of sediments can vary spatially throughout a lake further limiting the representivity of a single core.

The aim of this study is to reconstruct late Holocene environmental change in the Basin of Pátzcuaro, Michoacán, México. This small intermontane basin, has been the subject of a number of previous palaeolimnological investigations (Deevey, 1944; 1957; Hutchinson et al., 1957; Saporito, 1975; Watts and Bradbury, 1982), which together with the study of Street-Perrott et al. (1989), on terrestrial sediments, indicates that there is a long history of settlement and human disturbance within this catchment. The questions to be addressed are:

i) can periods of accelerated erosion, as inferred from the lacustrine and terrestrial record, be associated with Prehispanic cultures within the basin?

ii) is it possible to determine spatial and temporal variations in sediment accumulation using multiple cores, and using this information determine the source of sediment input into the lake?

iii) by using a number of different lines of investigation and a variety of complimentary analytical techniques, is it possible to separate the human disturbance record from the climate record?

CHAPTER TWO: PHYSICAL BACKGROUND TO THE BASIN OF PATZCUARO

2.1 LOCATION

The Basin of Pátzcuaro is a small intermontane basin situated in the highlands of the Tarascan Neovolcanic sub-province of Michoacán, México. It is located approximately 250 km west of México City, mid-way between the towns of Morelia and Uruapan (Fig. 2.1). The catchment is one of a series of closed lake basins created by the disruption of the drainage of an ancient tributary of the Río Lerma by volcanic activity in the Pleistocene (De Buen, 1943; Waitz, 1943; Barbour, 1973). This tributary is believed to have drained northwards from Zirahuén, entering Lake Pátzcuaro *via* the valley of Ajuno, and exiting through the valley of Chapultepec. The river then flowed north-eastwards to the Valley of Morelia following the drainage of the Río Grande, and passing through Lake Cuitzeo finally draining into the Río Lerma.

The 1990 census (INEGI, 1990) gave the population of the basin as 111,341 located in four municipios; Pátzcuaro, Quiroga, Tzintzuntzan and Erongarícuaro (Fig. 2.2). Today as in the past the Basin of Pátzcuaro forms the focal point of the indigenous Purépecha (Tarascans), who have lived in this region since Prehispanic times. The area is a major tourist centre attracting a large number of visitors each year. At the festival of the 'Day of the Dead' an estimated 150,000-200,000 people visit the area.

2.2 GEOLOGY

A simplified diagram of the geology of the study area is shown in Figure 2.3. The oldest features are large composite volcanoes which probably formed during the Cenozoic period, the most important being Cerro *El Zirate* located in the northern part of the basin. These features have certain characteristics similar to the vulcanism of the north-eastern part of Michoacán, and consist of andesites and dacites rich in olivine, albite, biotite, augite and hypersthene (Villarello, 1909). Their craters have suffered

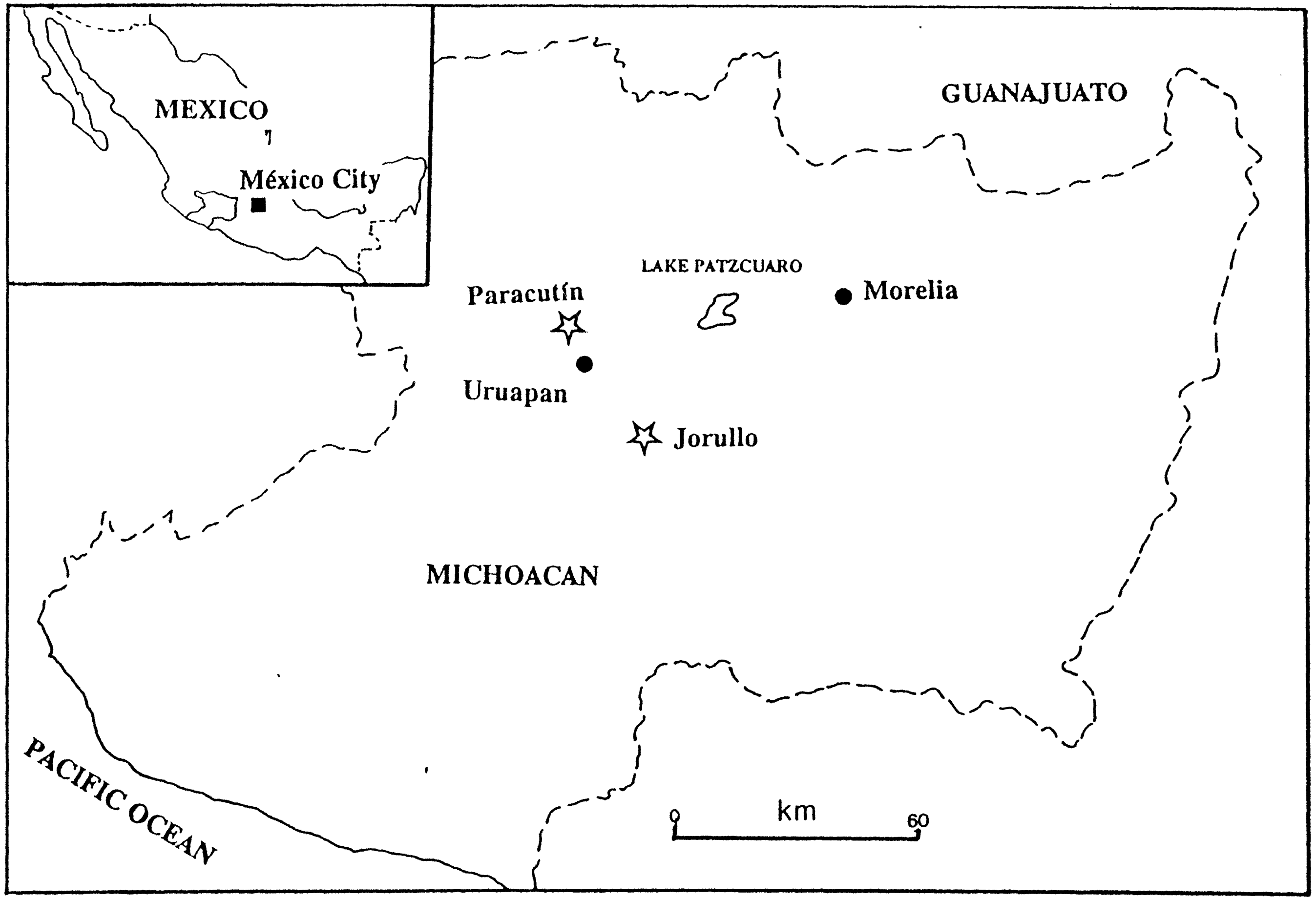

Figure 2.1 Location of the study area.

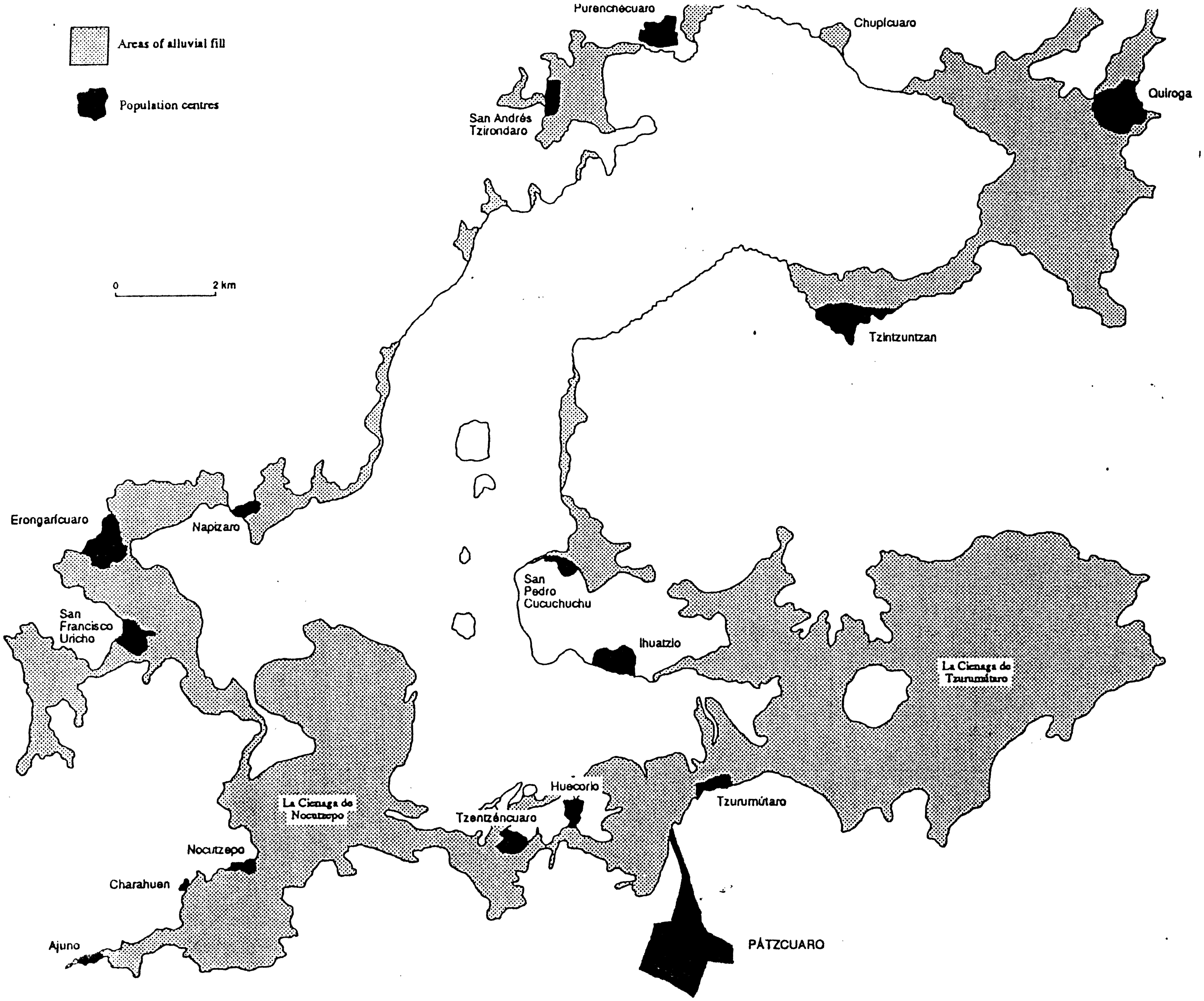

Figure 2.2 The Basin of Pátzcuaro.

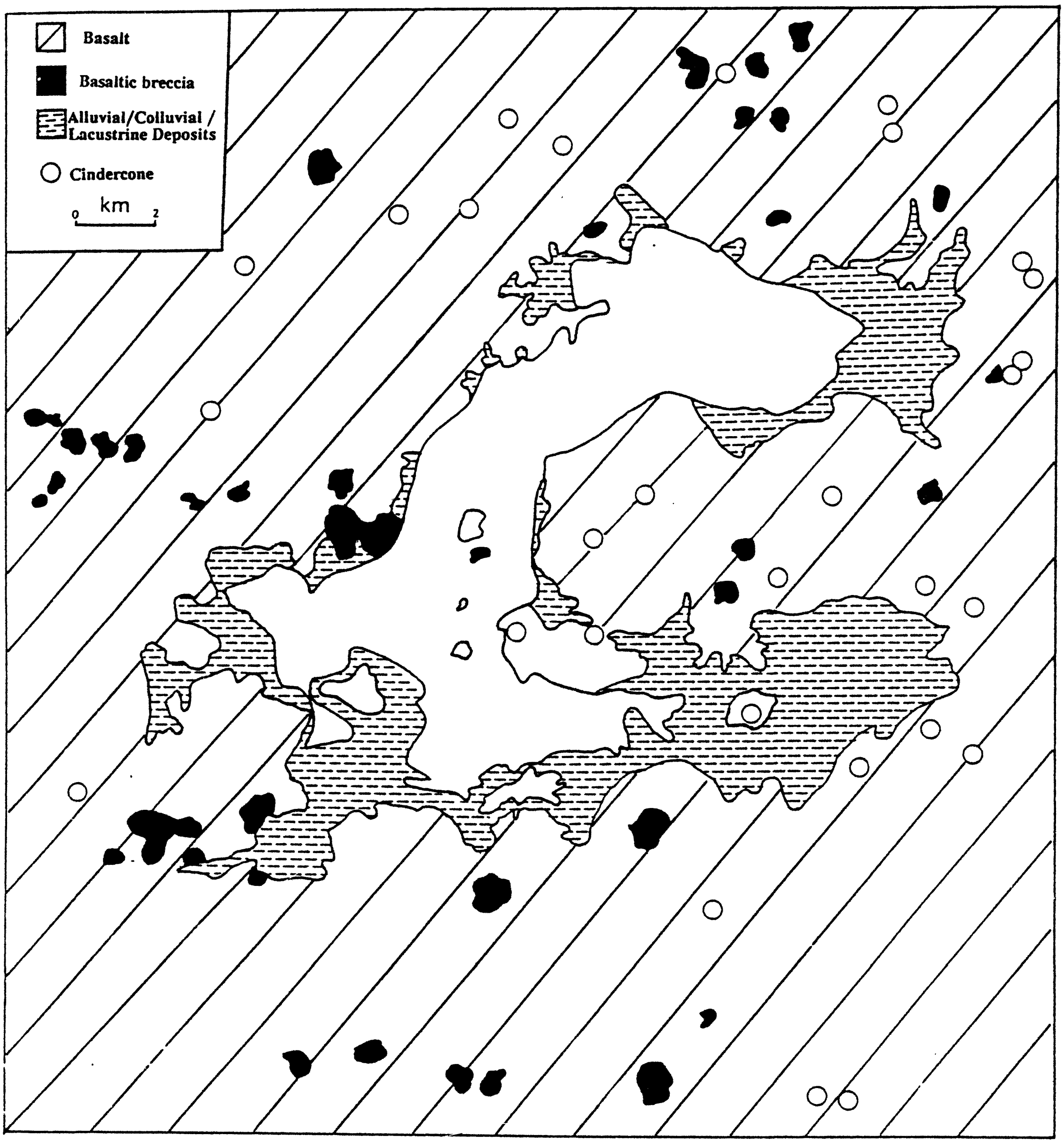

Figure 2.3 Simplified geology map of the study area

intense erosion and are dissected by many deep gullies (barrancas) that often form a radial pattern (Barrera, 1986).

Barrera (1986) reported the presence of 130 volcanic cones within the basin. These are composed of semi-consolidated ash and cinder blocks; in general those of greatest altitude and volume represent the oldest features. They are similar in morphology to Paracutín (Plate 2.1) and have generally been formed in a single period of activity. Their well-preserved form attests to their relative youth. Two types of cone are observed: symmetrical cones with well developed flat floored crater and breached cones with one side generally blown away.

Numerous small lava flows have been recognised within this area. The majority are confined to the southern portion of the drainage basin and are the product of solidification of very fluid degassified lavas (Barrera, 1986). They are locally called *zacapurhu* or *malpaises* ('badlands') as their highly porous character causes water to drain through them rendering such regions useless for agricultural purposes.

2.3 MORPHOLOGY OF THE LAKE PATZCUARO BASIN

Lake Pátzcuaro is one of the most important water bodies in Central México. Standing at an elevation of 2,036 m a.s.l. the distinct C-shaped lake has an area of 126.4 km^2 (Chacón Torres, 1989) and drains a catchment of 927 km^2 (Gorenstein and Pollard, 1983, Chacón Torres, 1989). The catchment can be divided into eight major sub-basins which vary in area from 33 to 301 km ^{2} (Fig. 2.4). The lake has no surficial outlet and is fed by ephemeral streams, rainfall and groundwater seepage.

The lake is surrounded by a number of volcanic cones. To the north and west these form the steep slopes of the mountains of Comanja, Tigre and El Zirate. The last, rising to an elevation of 3,330 m a.s.l. (DETENAL, 1978) is the highest peak in the area. To the south, the catchment is delimited by the mountains of Tingambato and Santa Clara del Cobre while to the east the lake is bordered by the relatively gentle slopes of the Sierras of Prieto and Gachupin.

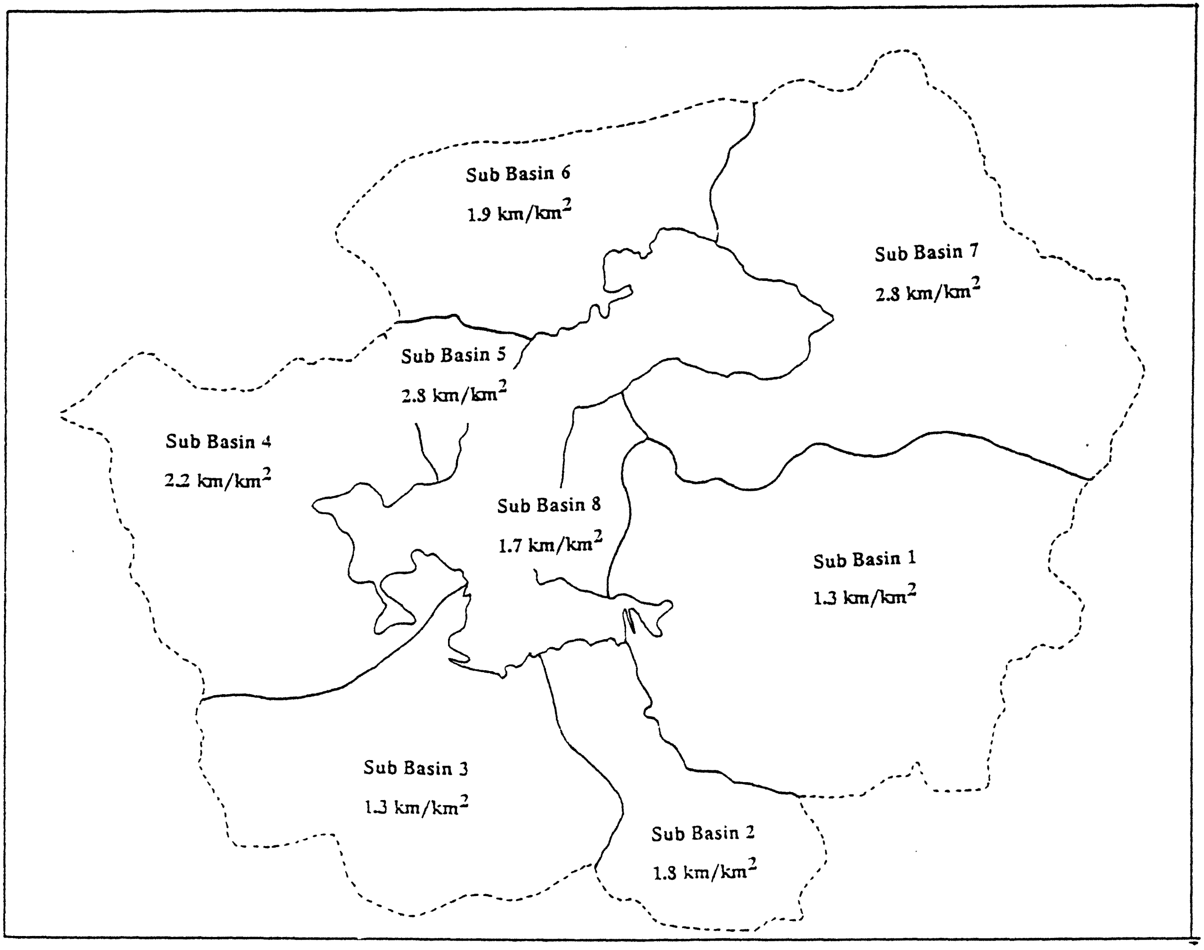

Figure 2.4 Main sub-basins within the catchment showing the drainage density.

Gently sloping alluvial, colluvial and lacustrine deposits, border the lake. These areas are most extensive in the southern part of the basin although large expanses of sediment are also found around Quiroga (Fig. 2.3). The extent of these deposits depends on the level of the lake and even quite small lake level variations can result in a considerable change in their dimensions. In recent years the large drop in the level of the lake (ca. 4 m) has caused quite extensive areas of relatively flat land to be uncovered (Plates 2.2 and 2.3) which have been immediately utilised for agricultural purposes.

2.4 CLIMATE

Although the Basin of Pátzcuaro lies in the tropics, its altitude and distance from the sea have modified the climate considerably. The region experiences humid temperate conditions and falls into the Köppen category Cwb. Data from the two weather stations that currently operate within the basin, 'Estacion Pátzcuaro` and 'Estacion Santa Fé de la Laguna` (Fig. 2.2), demonstrate that there are quite significant climatic variations within the basin.

There is little variation in mean monthly temperatures for the Pátzcuaro region (Table 2.1). The mean temperature for May, the warmest month, is 19.1 °C and for January, the coldest month, 12.4 °C. The mean maximum temperature varies between 31 °C in May and 24.4 °C in December and the mean minimum temperatures range from 12.9 °C in June and 4 °C in January. Differences are also noted in the temperatures experienced in the north and south of the area, with slightly higher temperatures recorded in the north (Table 2.2).

Precipitation exhibits a marked seasonal distribution with over 80% of the total annual rainfall falling between May and October as intense, convectional rainstorms of short duration. The wettest month is July with an average of 225.5 mm (1970-1986). Between November and April little rain falls, the driest month being April which has an average of 9.6 mm (Table 2.1). There is a considerable difference in the amount of precipitation received annually in the southern and northern part of the basin. The mean

Main Climatic parameters for the Basinof Patzcuaro; 1921-1944 and 1970-1986

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
TEMPERATURE														
MEAN	1921-1944	12.4	14.1	16.2	18.2	19.9	19.5	17.7	17.3	17.1	16.4	14.9	12.8	18.3
(CELSIUS)	1970-1988	12.8	13.7	15.8	17.7	19.1	18.8	17.6	17.6	17.5	16.6	14.9	13.5	18.3
MEAN MAX	1921-1944	20.2	23.0	24.7	27.0	28.0	25.4	23.6	22.7	22.4	22.7	21.6	20.4	23.5
(CELSIUS)	1970-1988	24.6	25.8	20.1	30.2	31.0	29.2	26.3	25.4	25.4	23.6	24.8	24.4	20.7
MEAN MIN	1921-1944	4.5	5.6	7.7	9.6	12.1	13.6	12.4	12.6	12.1	10.2	7.2	5.5	9.4
(CELSIUS)	1972-1982	4.0	5.0	6.4	8.7	10.7	12.9	12.4	12.2	12.0	10.1	6.3	5.8	0.8
RAINFALL	1921-1944	14.3	12.0	9.6	4.0	35.2	176.0	236.6	236.9	190.1	76.6	29.1	19.8	1040.8
(mm)	1970-1986	13.8	6.7	5.5	9.6	38.9	144.9	224.5	198.5	164.8	63.2	16.0	14.0	900.7
MAX. RAINF.	1921-1944	35.0	27.0	25.0	19.7	33.8	50.0	48.7	75.7	61.5	51.5	44.7	52.5	75.7
IN 24 HRS	1972-1982	52.0	15.7	16.5	57.7	28.0	57.0	62.5	56.0	64.0	60.1	20.3	28.0	64.0
EVAPORATION	1921-1944	100.6	124.4	158.7	203.1	197.9	112.5	125.1	112.6	91.7	101.7	89.5	96.5	1524.5
(mm)	1970-1986	89.8	115.6	168.7	187.3	180.9	134.9	115.5	112.1	89.2	96.3	86.6	77.6	1437.0
WIND SPEED	1939-1944	2.2	3.8	3.8	2.2	2.2	0.8	2.2	2.2	2.2	2.2	2.2	2.2	2.2
(m/s)	1976-1986	4.4	9.4	9.4	4.4	4.4	2.2	2.2	2.2	4.4	4.4	4.4	4.4	4.4
DIRECTION	1939-1944	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	25.0	225.0	225.0	225.0	225.0
(DEGREES)	1972-1982	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0

Source: Chacon Torres, 1989.

Table 2.1

Average rainfall

Station	# of years of observation	J	F	M	A	M	J	J	A	S	O	N	D	Annual Year
PATZCUARO	I-15	14.3	14.9	17.0	18.7	20.3	19.5	18.2	18.2	18.1	17.2	15.8	14.7	17.3^{O}C
	P-16	19.8	9.6	6.2	10.0	65.7	179.	234.4	256.6	176.5	136.2	13.9	16.6	1124.5 mms.
SANTA FE	T-12	13.1	14.2	15.9	18.0	19.3	18.9	17.9	1.78	17.6	16.9	14.8	13.5	16.5^{O}C
	P-12	7.2	4.1	21.6	17.2	34.4	148.3	215.7	214.2	169.7	63.6	12.2	14.3	922.5 mms.

Source Bassols (1986)

Table 2.2 Variations in temperature and precipitation between the northern and southern part of the Basin of Pátzcuaro.

annual rainfall for the period 1968-1980 at 'Estacion Pátzcuaro' was 1124 mm while at 'Estacion Santa Fé de la Laguna', for the period 1965-1978 it was 922 mm. Thus, on average, the northern part of the Basin of Pátzcuaro receives about 13% less rain than the southern portion of the basin.

Although `Estacion Pátzcuaro' has been collecting meteorological data intermittently since 1886, much of the information has been lost. The most complete set of data obtained to date is that of Chacón Torres (1989) who presented an analysis (of the available information) for the periods 1921-1944 and 1970-1986 (Table 2.1). He found little difference between the mean annual temperatures of these periods, but noted a considerable reduction in the mean annual precipitation. In 1921 and 1944 the mean annual precipitation was 1040 mm compared to 900 mm for the period 1970-1986. A decrease in the amount of precipitation in the warm season, June to September, accounts for most of this variation (Table 2.1).

South-westerly and south-easterly winds predominate in this area with an average of 40.2% of winds from the former and 25.5% for the latter direction. During the winter months, outbreaks of cold polar air '*nortes*' bring lower temperatures and increased wind speeds. Maximum average wind speeds are 6.7 ms^{-1}, mostly blowing from the southwest and southeast (Chacón Torres, 1989), with high winds occurring more frequently during the winter months.

The Basin of Pátzcuaro experiences a moisture deficit over the year, evaporation being considerably greater than precipitation. Evaporation rates are lowest in the winter months, but are still greater than precipitation, and reach their highest in April and May, during the warmest months. Only during the period June-September are precipitation amounts in excess of evaporation (Table 2.1).

2.5 SOILS

Soils in the Basin of Pátzcuaro fall into a number of distinct types. Their formation is influenced by a number of factors, the most important being recent volcanic activity, climate, proximity to the lake, vegetation cover and human interference. The main physical and chemical characteristics of the most important soil types in the basin are shown in Table 2.3.

Andosols, covering over 50% of the basin, represent the most important soil type in this region. In general, these are confined to the upper mountain slopes in particular those that border the eastern shore of the lake (Fig. 2.5). These soils have developed on recent volcanic deposits and retain certain characteristics of their parent material. Because the andosols are moisture-retentive it is possible to plant crops two months before the onset of the rains and consequently these soils are referred to as *'tierra de humidad'* (West, 1948). As these are relatively young soils, they contain large quantities of weatherable material and on the whole are extremely fertile. However, once the natural vegetation is removed they tend to be very susceptible to erosion (Toledo and Barrera, 1984).

The soils in the western portion of the basin are dominated by luvisols. These differ from andosols in that they exhibit a much greater degree of leaching. Luvisols dominate the more gently-sloping areas of the southern and eastern parts of the basin, and in general have developed on surfaces that have remained relatively undisturbed by erosion. Luvisols are frequently found in association with other soil types, the relation depending on microclimate and topography.

Acrisols account for approximately 9 % of the soils in the study area (CRAC, 1981) and are confined to the southern and eastern parts of the basin where the slopes are between 15-25^{o} (Fig. 2.5). Acrisols have developed on old parent material under conditions much more humid than are currently experienced in this region (Barrera, 1986). They are particularly important in the vicinity of Tzintzuntzan where the soils covering the mountains of *Tariaqueri* and *Yahuarato* consist entirely of acrisols.

A variety of soil types are found in the areas surrounding the lake itself. In order of importance these are gleysols, cambisols, vertisols and phaeozems representing approximately 3.22%, 2.04%, 1.85% and 1.75% of the soils in the drainage basin

Physical and Chemical Parameters of the Major Soil types in the Basin of Patzcuaro

SOIL TYPE		STRUCTURE	TEXTURE	COLOUR	PROFILE DEPTH (CM)	% SAND	% SILT	% CLAY	pH	Ca PPM	Mg PPM	K PPM	P PPM
Humic Andosol	A	Blocky	Crumbly	10YR4/4	0-27	6	22	72	6.2	4.1	1.1	0.4	6.9
	B	Blocky	Crumbly	75YR3/4	27-69	2	48	50	6.4	3.8	0.6	0.1	4.1
Acrisol	A	Blocky	Fine	5YR3/3	0-10	22	38	40	6.0	3.1	2.9	0.8	6.1
	B	Massive	Sandy	5YR3/5	10-45	60	18	20	6.1	2.1	0.3	0.1	5.8
Luvisols	A	Blocky	Fine	5YR3/3	0.23	30	34	36	6.3	6.6	3.0	1.0	6.4
	B	Blocky	Very Fine	5YR3/3	25-58	38	34	28	6.3	6.6	2.9	0.4	7.4
Cambisol	A	Blocky	Fine	7.5YR3/2	0.12	20	40	40	6.5	12.5	2.6	0.8	4.9
	B	Blocky	Fine	7.5YR3/4	12-45	22	34	44	6.8	10.5	5.6	0.5	4.3
Vertisols	A	Blocky	Fine	7.5YR3/1	0-30	48	26	26	6.4	10.7	4.7	0.5	82.2*
	B	N/A	N/A	10YR3/1	30-60	48	22	30	6.9	11.9	7.2	0.5	35.2*
Phaeozem	A	Blocky	Medium	7.5YR2/2	0.26	32	38	30	6.0	8.9	3.9	1.0	18.9
	B	Blocky	Fine	5YR2/2	26-82	38	30	32	6.5	8.9	2.7	0.1	7.9
Gleysols		NO DATA							NO DATA				

* Agricultural land. High P valves possibly reflect use of fertilizers

Source - Bassols, 1986.

Table 2.3

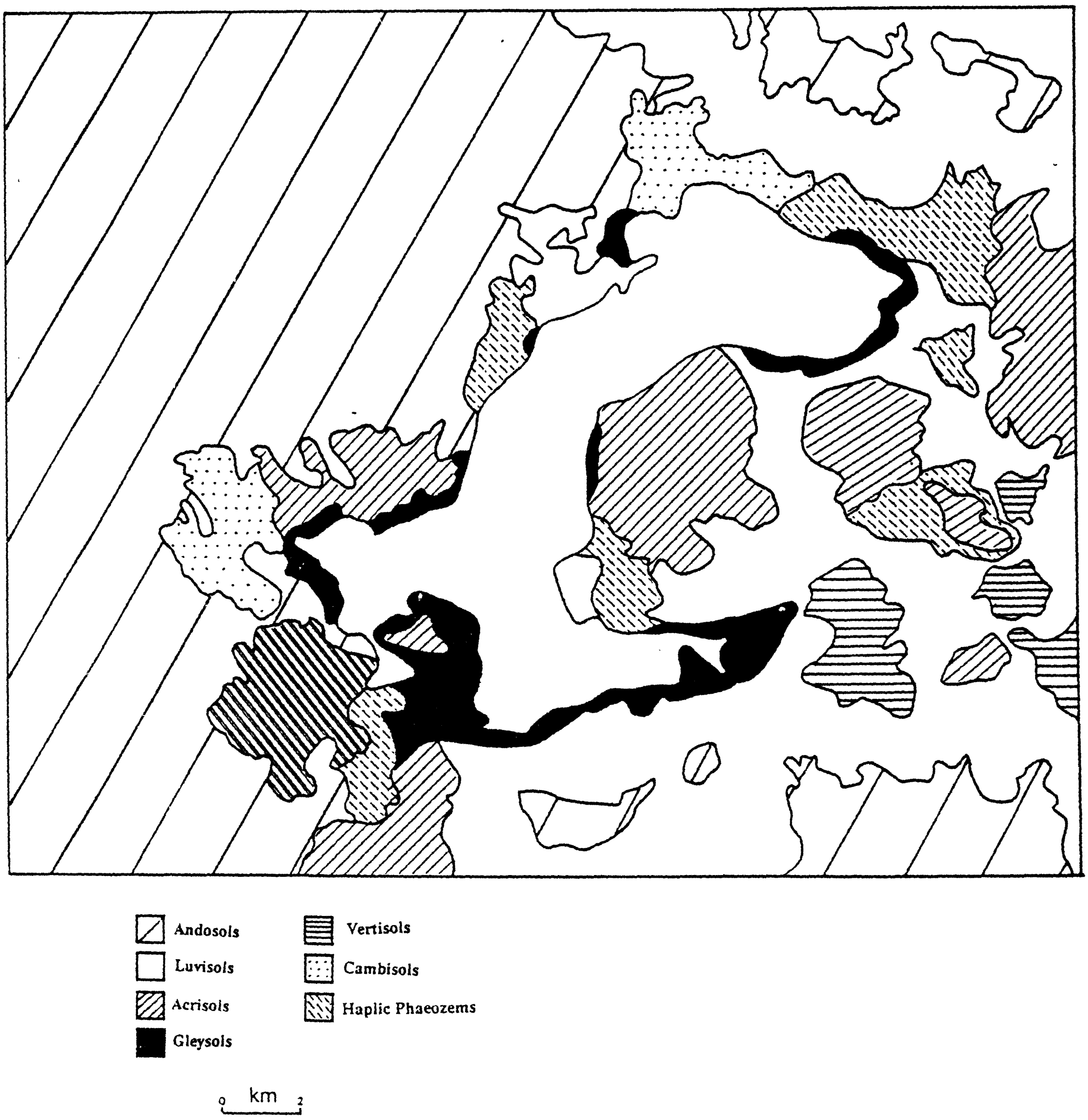

Figure 2.5 The distribution of the major soil types in the Basin of Pátzcuaro.

respectively (CRAC, 1981).

In the low-lying area to the west of Tzurumutaro (Fig. 2.2) referred to locally as '*La Ciénaga de Chapultepec*', the soils are dominated by vertisols. These soils have developed on almost flat surfaces and in general have a soil profile less than 1 m in depth. Small areas of soils designated cambisols are located in the western part of the basin in the vicinity of Erongarícuaro.

Bordering much of the lake, in particular the southern part, are gleysols, which remain inundated for long periods of the year: molic gleysols predominate. Gleysols have developed on recently deposited colluvial sediments which have been washed down from the upper slopes of the basin (Barrera, 1986).

Haplic phaeozems have been mapped in a number of restricted locations in the areas around Ihuatzio, San Pedro Cucuchuchu and Quiroga (Fig. 2.5). It is noticeable that those areas where phaeozems are found correspond to those parts of the basin that are most severely eroded. It is possible that these soils are not correctly classified and in fact represent soils that have developed on freshly exposed bedrock.

2.6 VEGETATION

The long history of human disturbance has produced a mosaic of vegetation communities in the Basin of Pátzcuaro. A simplified diagram of the main vegetation assemblages is shown in Figure 2.6. Although it is difficult to determine what the "natural vegetation" was, Watts and Bradbury (1982) believe that a pine/oak assemblage dominated the lower slopes of the basin with stands of fir above 2,500 m a.s.l. Barrera (1986) recognised a number of present-day vegetation types which roughly corresponded to different elevations within the basin.

In the high altitude areas (2,900 to 3,300 m a.s.l) the vegetation is dominated by fir with some pine. Only the highest peaks in the region fall into this category. The most important species found in this association are *Abies religiosa* and *Pinus pseudostrobus.*

Pine is the most important species represented in the Basin of Pátzcuaro. Pine-

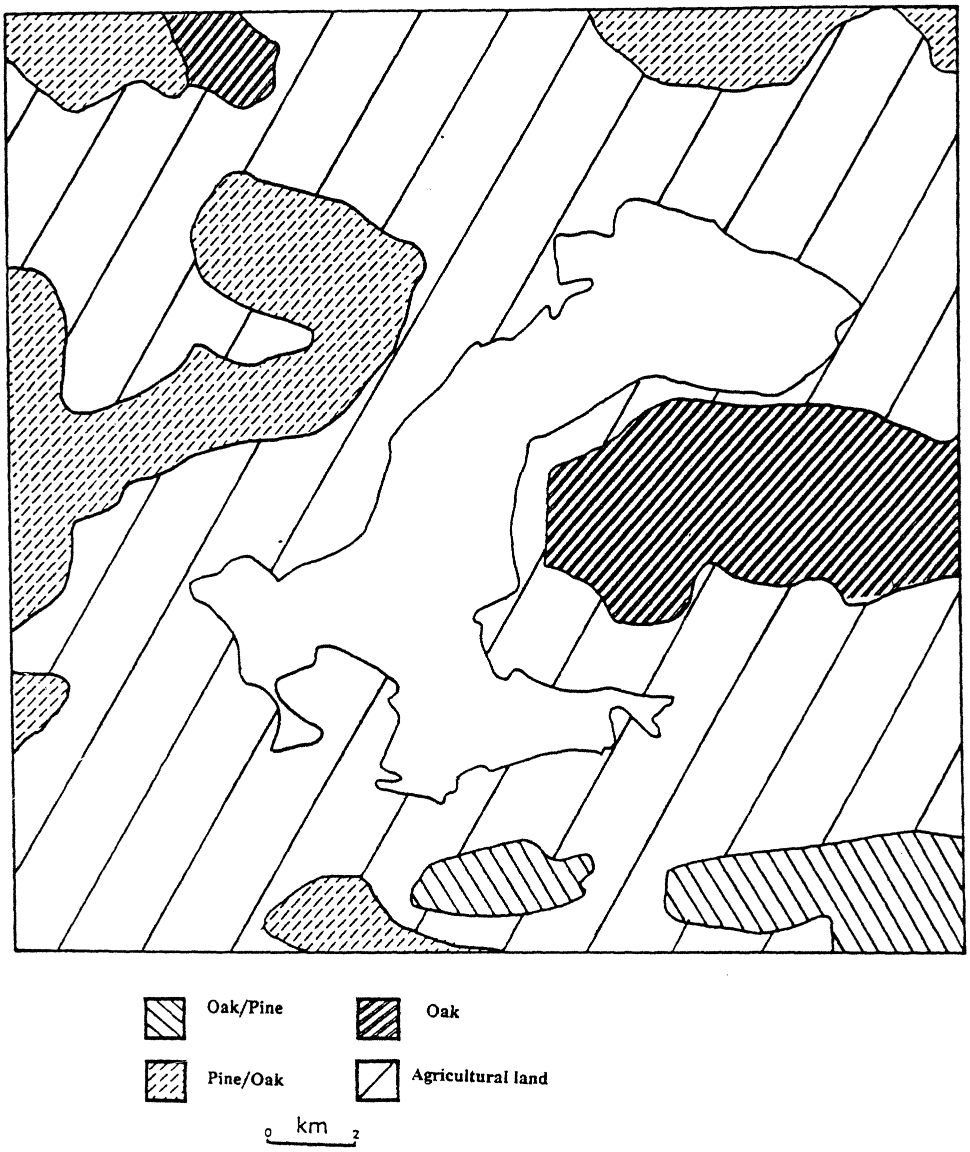

Figure 2.6 Simplified diagram of the main vegetation assemblages in the Basin of Pátzcuaro.

dominated forests are still found situated between 2,100 and 3,000 m a.s.l. Various species have been recognised, the most common being *Pinus teocote, P. lawsonii, P.leyophylla, P. michoacana, P. montezuma* and *P. pseudostrobus* (Barrera, 1986).

Oak communities are characteristic of the mountain areas of México and together with pine constitute a large percentage of the vegetation cover in areas with sub-humid temperate climates (Rzedowski, 1978). Oak and pine share certain ecological characteristics and are frequently found in association with one another. In the Basin of Pátzcuaro pine/oak assemblages are found between 2,100 and 2,800 m a.s.l.; oak assemblages are dominated by *Quercus rugosa, Q. ostusta, Q.castanea, Q. candicaris*, and *Q. laurina.*

Barrera (1986) reported that two types of *matorral* are characteristic of this region: *Matorral de Baccharis* and *Matorral Xerófilo. Matorral de Baccharis* is believed to recolonize areas of pine/oak forest which have been overgrazed and are subject to frequent burning (Rzedowski and McVaugh, 1966). In the Basin of Pátzcuaro this vegetation type tends to be found between 2,500 and 3,000 m a.s.l., and develops on nearly all the soil types found in the area, especially andosols, luvisols and acrisols (Barrera, 1986); the principal components are *Baccharis concerta, B. ramulosa, P. leyophylla, P. lasonii, Mimosa bucifera* and *Yuca filifera.*

Matorral Xerófilo is found on the lower slopes of the basin between 2,037 and 2,300 m a.s.l. The main species of this vegetation assemblage are *Euphorbia calyculata, Opuntia* spp. and *Verbesina* spp. These species are frequently found in areas that are severely degraded and are considered to represent a sub-climax vegetation that is the result of human disturbance (Caballero et al., 1981)

2.7 PRESENT DAY LAND USE

Apart from the steepest slopes, the majority of the land in the basin is used for agriculture. The more gently-sloping areas which border the lake are the most intensively cultivated. A number of large irrigation schemes are currently in operation, the most important in the areas of La Ciénaga de Chapultepec, Erongarícuaro and Quiroga are administered by the Seccretaria de Agricultura y Recursos Hidraulicos (SARH). Elsewhere, local farmers have cut channels from the lake to bring water to irrigate their fields. Although traditional farming techniques continue to flourish, there has been an increase in the amount of machinery used in agriculture. This has resulted in a significant change in the method and nature of agriculture within the basin in recent years (CREFAL, 1979).

Settlement within the basin is concentrated on the lower slope areas. The main population centres are located at Pátzcuaro and Quiroga. In recent years the rapid increase in the population has resulted in increased urbanization in the area. Pátzcuaro which was built 3 km from the lake now stretches down to the lake shore.

2.8 HYDROLOGY

The slopes surrounding Lake Pátzcuaro are incised by a dense network of gullies and arroyos (Fig. 2.7). Except in the most intense rain events many of these remain dry throughout the year. The most important are the Arroyos San Gregorio and Chapultepec which flow from the springs of La Alberca and Chapultepec, respectively, and discharge into the southern part of the lake. As these arroyos are fed by springs they tend to be perennial. In recent years, however, a considerable proportion of their discharge has been used for irrigation, resulting in a significant reduction in flow (Barrera, 1986). The Arroyo Santa Fé which enters the lake between the communities of Santa Fé and Quiroga (Fig. 2.2) is also an important source of inflow to the lake. However, like Chapultepec and San Gregorio, much of its discharge is now diverted to irrigate farm land. Two other arroyos of importance are the Guani and San Miguel which flow through the City of Pátzcuaro and Erongarícuaro respectively. Water from these streams is utilized by the towns and is finally discharged into the lake as sewage.

As mentioned above, the drainage density in the lake basin varies considerably

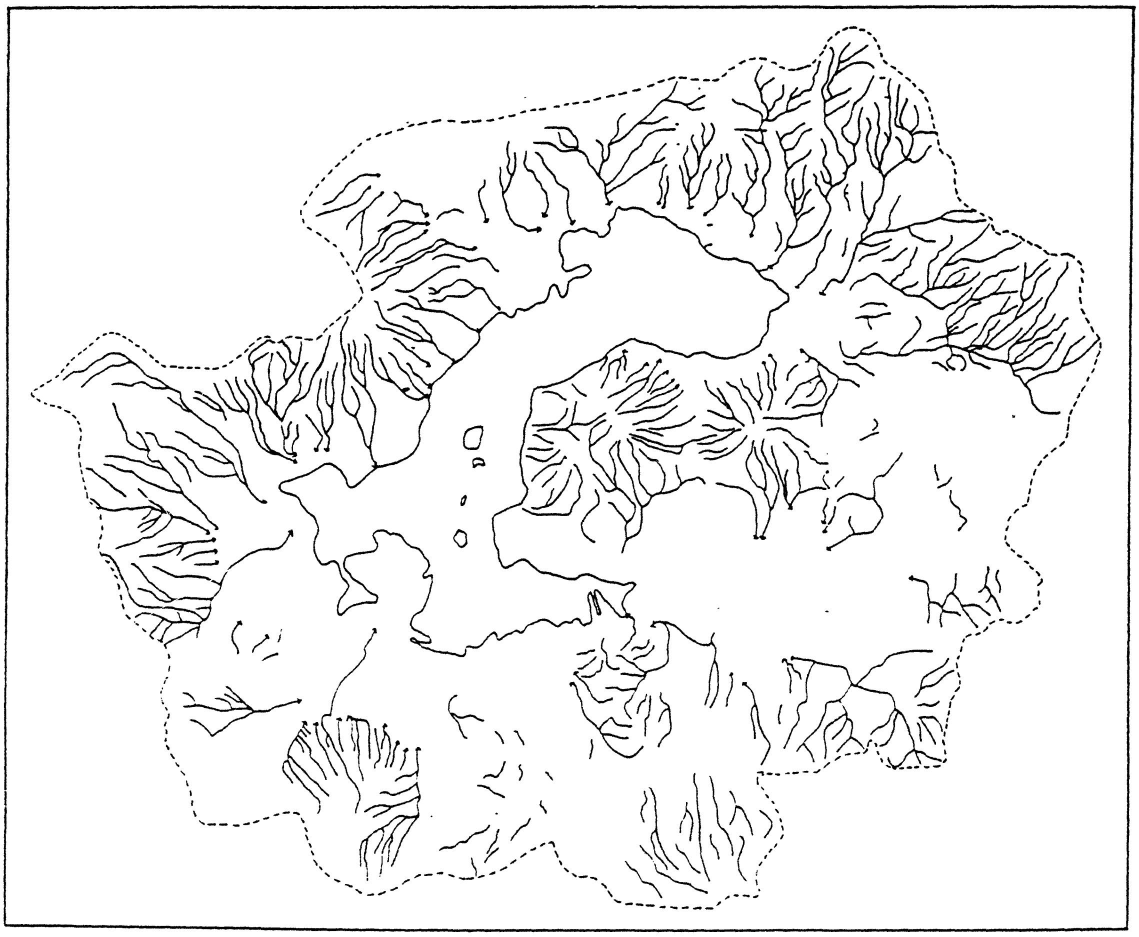

Figure 2.7 The drainage network in the Basin of Pátzcuaro.

in the northern part of the basin (Fig. 2.4) where it ranges between 1.9 and 2.8 km km^{-2} compared to between 1.3 to 2.2 km km^{-2} in the southern part. With few exceptions these streams are ephemeral. The form of the drainage network also differs, being more dendritic in the north of the basin while in the south the gullies form smaller, unbranching and more intermittent networks. These variations probably reflect a number of factors, the most important being lithology and geology. In the northern part of the basin where the mountain ranges are steepest and the geology is dominated by older andesitic volcanics, little runoff is able to percolate into the soils; consequently there is a greater possibility of erosion and eventual channel development. Furthermore, the catchment area to the north of the lake is much greater than to the south, adding to the amount of runoff generated in each sub-catchment.

In the southern part of the basin large areas of lava flows are found, and as discussed above these are locally referred to as *zacapuhru* or 'badlands' because their extremely porous nature has made them unusable for agricultural purposes. Due to this, surface channels have not developed and any precipitation that falls on these areas percolates through and eventually reaches the lake as through-flow.

2.9 MORPHOMETRY AND BATHYMETRY OF THE LAKE

It was not until 1980 that the first detailed bathymetric map of Lake Pátzcuaro was produced (Tellez and Motte, 1980). Since then three separate investigations have produced new versions (SARH, unpubl.; PESCA, unpubl.; Chacón Torres, 1989). Of these, only that of Chacón Torres (1989) makes any attempt to analyse the morphometry of the lake; the following description is taken from his study.

Lake Pátzcuaro covers an area of 126.4 km^2 and has a perimeter of 114 km. The maximum length of the lake is 19.8 km and lies along a SSW-NNE trend following the direction of the main axis. The mean width is 6.4 km with a maximum of 10.9 km in the southern basin.

The distribution of shoreline gradients reflects the nature of the slopes surrounding the lake (Fig. 2.8). In the southern part of the basin where the lake is bordered by gently-sloping deposits the shoreline slope is generally less than 2%. Slightly steeper slope angles, between 2 and 5%, are found on the western shore and in the area around Tzintzuntzan and Quiroga, while the slope angle of the northern shore tends to be much steeper, falling between 5 and 25%.

The shallowest areas are found in the southern part of the lake where depths rarely exceed 3-4 m (Fig. 2.9). Depths of water in the "neck" of the lake vary between 6 and 10 m while the greatest depth is observed in the northern basin which has a maximum depth of 12.2 m. The mean depth of the lake is 4.5 m.

2.10 THE WATER BUDGET

The water budget for any given lake depends on a number of factors that determine the inputs and outputs from the lake. Pátzcuaro, being a closed lake with no major inputs, will be sensitive to changes in such parameters as precipitation, evapotranspiration, runoff and groundwater seepage. To enable the water budget to be calculated, information on all these parameters is required. Unfortunately, such data from the Basin of Pátzcuaro are limited although Chacón Torres (1989) has attempted to reconstruct a simple water balance for the lake.

Annually, Lake Pátzcuaro receives 123.3 million m^3 of water through direct precipitation inputs, while 186.2 million m^3 is lost to evaporation. Thus, assuming that there are no other losses, 62.9 million m^3 is transferred to the lake from the catchment annually. This amounts to 8% of the total input of precipitation into the watershed. Using these data Chacón Torres has shown that there is a very strong positive correlation (r=0.93) between the observed and expected lake levels over the period 1970-1986 (Fig 2.10), and certainly annual fluctuations in the level of the lake closely reflect the wet and dry seasons. In view of this, it would appear that the actual amount of rainfall which falls directly into the lake is one of the most important factors influencing its level. As the lake appears to respond very quickly to changes in these parameters it is possible to classify

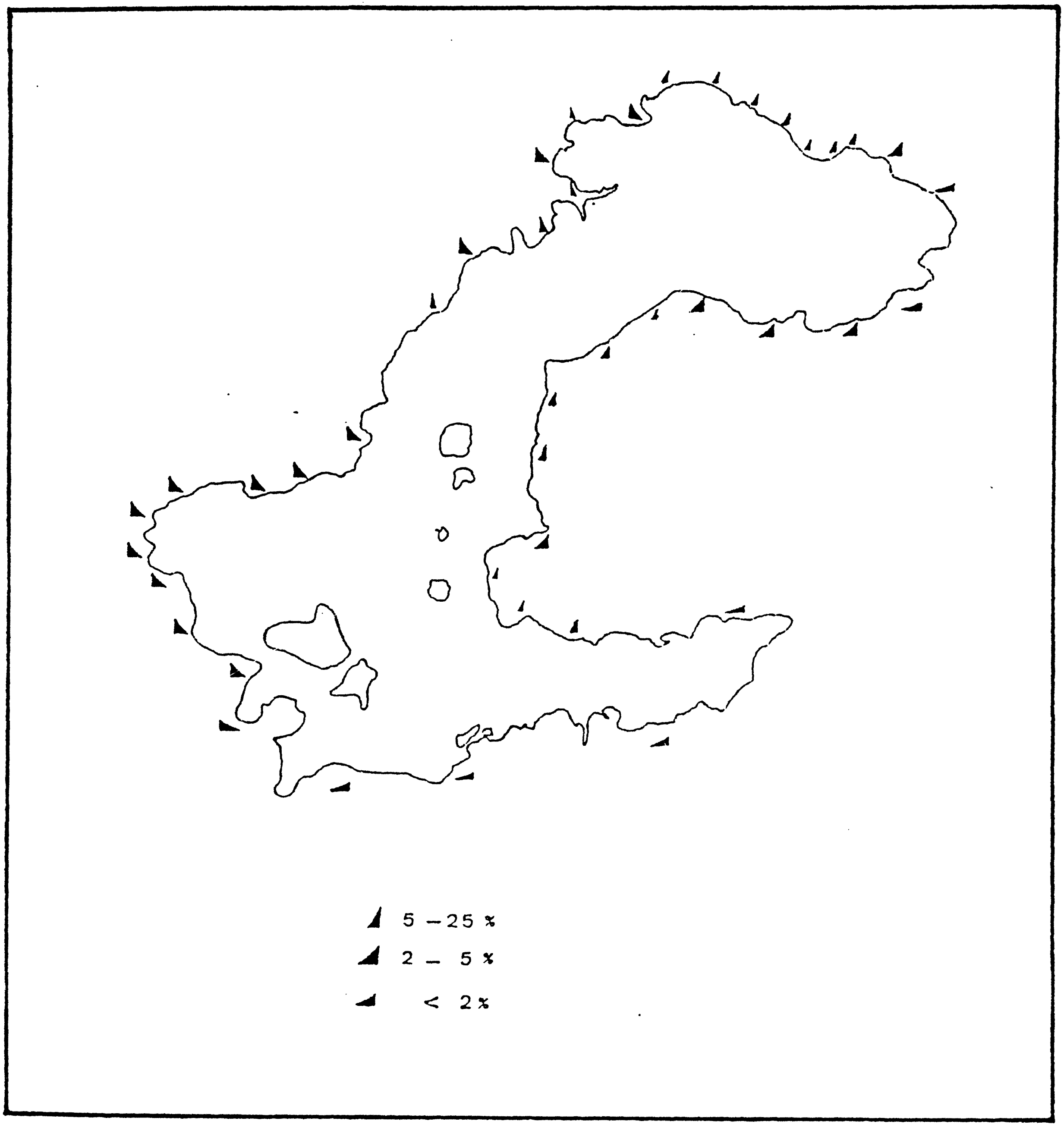

Figure 2.8 Variations in the shoreline gradients of Lake Pátzcuaro.

Figure 2.9 Bathymetric map of Lake Pátzcuaro.

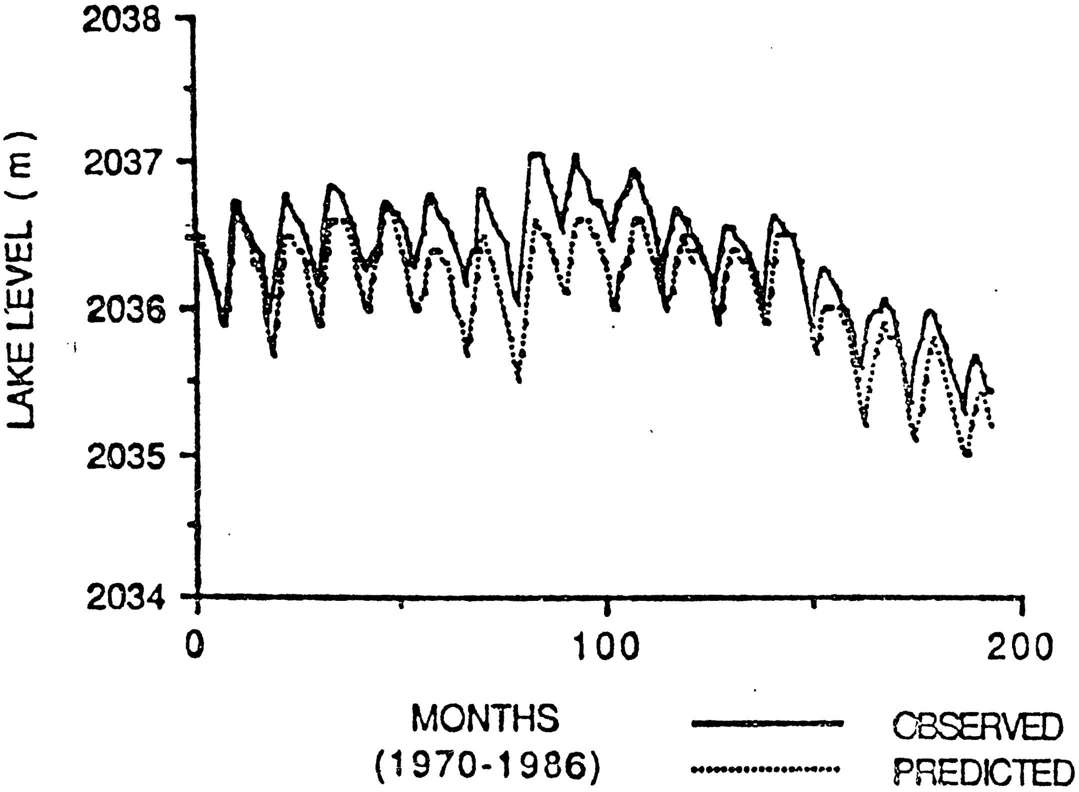

Figure 2.10 Observed and expected lake level variations for Lake Pátzcuaro, 1970-1986.

it as an amplifier lake as outlined by Street-Perrott and Harrison (1985).

2.11 MODERN LIMNOLOGY

A detailed analysis of the water quality of Lake Pátzcuaro has recently been completed by Chacón Torres (1989), based on data collected over a six-month period in 1986-1987. Chacón Torres (1989) noted that variations in the surface temperature of the lake varied between 14.5°C in January to approximately 22°C in June and July. The temperature of the bottom waters being about 2°C less than the upper waters. These results confirm those of earlier investigations by De Buen (1941) and Tellez and Motte (1980). De Buen (1944) classified Lake Pátzcuaro as a third order tropical lake as the surface temperature is never below 4°C, and the temperature of the bottom waters varies little from the recorded at the surface. The lake thus lacks thermal stratification and following Lewis' (1974) classification of lakes based on mixing, Lake Pátzcuaro can be described as a continuous warm polymictic type.

Observations on the surface currents have been made by Chacón Torres (1989). In a series of tests run over a three-month period between 1986-1987, he found that the surface current predominantly follows the direction of the wind, which for most of the year blows from the south west (Fig. 2.11).

Levels of dissolved oxygen recorded by Chacón Torres (1989) were similar to those reported by Yamashito (1939), De Buen (1941) and Tellez and Motte (1980). He concluded that the lake was saturated in respect to oxygen and no major horizontal or vertical differences in oxygen levels were detected.

Using secchi disks, Chacón Torres (1989) carried out readings in all parts of the lake to determine the degree of light penetration and recorded levels between 0.33 m and 0.48 m with a mean of 0.4 m. This is considerable less than the average secchi values of 5.75 m reported for Lake Zirahuén, one of the deeper lakes in the Central Mexican plateau, located to the south west of Pátzcuaro (Chacón Torres, 1989). Lake Pátzcuaro was found to be very turbid with maximum turbidity readings found in the

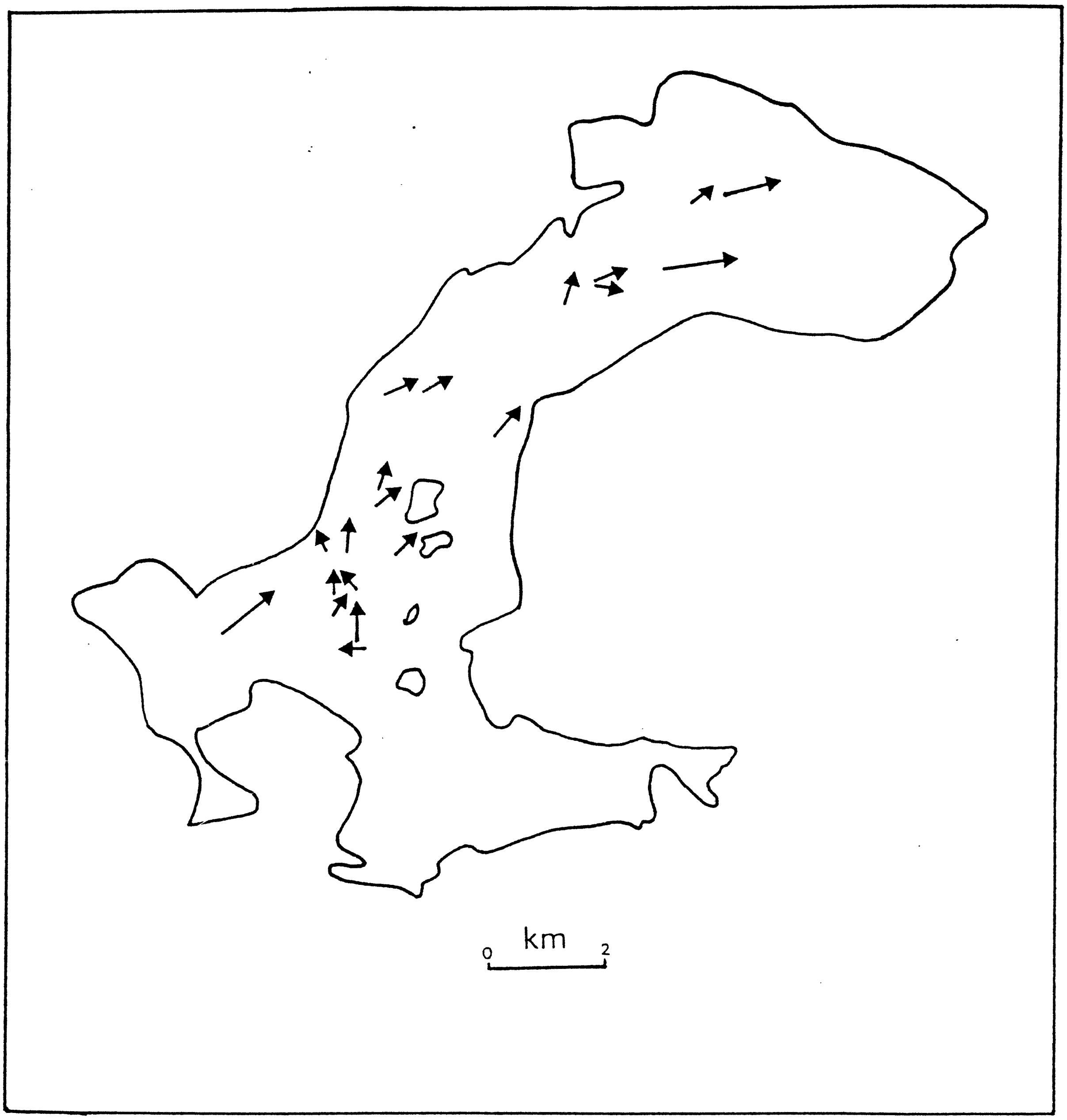

Figure 2.11 Main water currents of Lake Pátzcuaro.

northern part of the lake.

A comparison with previous investigations of light penetration in the lake carried out since 1938 clearly indicate that Lake Pátzcuaro has suffered a reduction in the transparency (Table 2.4). This has been most notable in recent years for which the majority of data are available. While this trend may reflect an increase in the input of sediment into the lake, it may also be a result of lower water levels and the effect of wind keeping sediment in suspension for longer periods of time or re-suspending sediment from the lake bottom.

Based on the water chemistry of the lake, Chacón Torres (1989) concluded that the lake is of Na-HCO_3-CO_3 type which accords with the results obtained by the Tropical Palaeoenvironments Research Group (TPRG) in 1982 and 1985 (Fig. 2.12). An average value of electrical conductivity of 820 $\mu s/cm^{-1}$ was observed while the water was always alkaline with an average pH of 9.7.

The results from Chacón Torres water chemistry analysis have been re-analysed by Nick Barber (University of Oxford) using PCWATEQ (Truesdell and Jones, 1974) to determine what elements the lake water are saturated in. The results from this indicate that Lake Pátzcuaro is saturated in respect to haematite, magnetite, maghemitite, geotherite, dolomite, calcite and aragonite, and undersaturated in respect to siderite, halite, and tronanite. Phosphorus, chlorophyll-a and suspended solids (Fig. 2.13) clearly showed horizontal variations across the lake, levels being low in the south and increasing to their highest levels in the northern basin. Mean total phosphorus concentrations for the lake over the period of study were high, 64.4 $\mu g\ l^{-1}$. Goldman and Horne (1983) concluded that total phosphorus levels of this order are a clear manifestation of high inputs from erosion and/or municipal sewage.

Based on the results from his investigation, Chacón Torres (1989) concluded that the trophic status of the lake ranged from mesotrophic in the southern to eutrophic and hypereutrophic in the northern part of the lake (fig. 2.14). Thus the lake is considered to have high levels of fertilization and biological productivity.