JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NATIONAL INSTITUTE OF DEVELOPMENT (INADE)
THE REPUBLIC OF PERU

THE STUDY ON THE INTEGRATED WATER POLLUTION CONTROL FOR PUNO INTERIOR BAY OF LAKE TITICACA IN THE REPUBLIC OF PERU

SUPPORTING REPORT

JANUARY 2000

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
in association with
ENVIRONMENTAL TECHNOLOGIC CONSULTANT CO., LTD., TOKYO

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Estimate of Base Cost: as of 1998 price

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Currency	Exchange Rate / US$
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Japanese Yen (¥)	116.70

(31 December, 1998)

Numerical Notation: Decimal marker : "." (period)
Digit separator : "," (comma)

THE STUDY
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FOR PUNO INTERIOR BAY OF LAKE TITICACA
IN THE REPUBLIC OF PERU

(SUPPORTING REPORT)

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CHAPTER - V SEWERAGE SYSTEM

ABBREVIATIONS

1. Peruvian Organizations

ALT :	Binational Autonomous Authority of Lake Titicaca
APECO :	Peruvian Association of Conservation
CAPET :	Chamber of Fishery in Titicaca
CONAM :	National Environmental Council
DIGESA :	General Administration of Environmental Health, Ministry of Health
EMSAPUNO :	Municipal Enterprise for Potable Water and Sewerage
ENAFER :	National Railroad Company
GOP :	The Government of Peru
INADE :	National Institute of Development
INADUR :	National Institute of Urban Development
INEI :	National Institute of Statistics and Information
INRENA :	National Institute of Natural Resources
MITINCI :	Ministry of Industry, Tourism, Integration and International Trade Negotiations
MTCVC :	Ministry of Transport, Housing and Construction
PELT :	Special Binational Project for Lake Titicaca
PRONAA :	National Program of Nutrition Assistance
PRONAP :	National Program of Potable Water and Sewerage
SENAMHI :	National Service of Meteorology and Hidrology
SUNASS :	National Superintendence of Sanitation Service
SUNAT :	National Superintendence of Taxes
UNA :	National University of The Altiplano – Puno

2. Japanese/International Organizations

CEPIS :	Pan American Center for Sanitary Engineering and Environmental Sciences, WHO
GOJ :	The Government of Japan
IBRD :	International Bank for Reconstruction and Development (World Bank)
IDB :	Inter-American Development Bank
IMF :	International Monetary Fund
JICA :	Japan International Coöperation Agency
JST :	JICA Study Team
KfW :	German Bank for Reconstruction
OECD :	Organization for Economic Cooperation and Development
WHO :	World Health Organization

3. Measuring Units

1) Physical

mm : millimeter(s)
cm : centimeter(s)
m : meter(s)
km : kilometer(s)
ha(s) : hectare(s)
l, ltr : liter(s)
g, gr : gram(s)
kg : kilogram(s)
t, ton : tonnage(s)
s, sec : second(s)
min : minute(s)
h(hrs) : hour(s)
d(dys) : day(s)
y, yr(yrs) : year(s)

2) Chemical

mg/l : milligram(s)

3) Others

a.s.l. : above sea level
inh/ha : inhabitants per hectare
nos/l : numbers per liter

4. Monetary Terms

¥ : Japanese Yen
US$: United States Dollar
S/. : Peruvian Nuevo Sol
DM : Deutsche Mark

5.Others

BOD : Biological Oxygen Demand
CIF : Cost, Insurance and Freight
COD : Chemical Oxygen Demand
Chl-a : Chlorophyll-a
D/D : Detailed Design
D/S : Definitive Study
DF/R : Draft Final Report
DID : Densely Inhabited District
DL : Datum Line

DO	:	Dissolved Oxygen
E/S	:	Engineering Service
EIA	:	Environmental Impact Assessment
EIRR	:	Economic Internal Rate of Return
F/R	:	Final Report
F/S	:	Feasibility Study
FDS	:	Final Disposal Site
FIRR	:	Financial Internal Rate of Return
FY	:	Fiscal Year
GDP	:	Gross Domestic Products
GNP	:	Gross National Products
IC/R	:	Inception Report
IEE	:	Initial Environmental Evaluation
IGV	:	General Sales Tax (Impuesto General a las Ventas)
IT/R	:	Interim Report
M/P	:	Master Plan
MSL	:	Mean Sea Level
N	:	Nitrogen
NGO	:	Nongovernmental Organization
P	:	Phosphorous
P/R	:	Progress Report
S/W	:	Scope of Work
SS	:	Suspended Solids
STP	:	Sewage Treatment Plant
SWM	:	Solid Waste Management
TDS	:	Total Dissolved Solids
VAT	:	Value Added Tax
WWTP	:	Wastewater Treatment Plant
WWTS	:	Wastewater Treatment System

CHAPTER – I INTRODUCTION

CHAPTER - I

INTRODUCTION

1. BACKGROUND OF THE STUDY

The City of Puno is expected to experience a substantial growth of population in the future due to newly emerging communities in the outskirts of the city in addition to population influx. However, improvement and expansion of urban infrastructure has fallen behind the rate of such population growth and most of the sewage is directly discharged into Puno Interior Bay without treatment. Besides, there are other problems, such as inflow of solid wastes into the interior bay during rainfall because of insufficient waste collection system.

The Bay is suffering from progressive water pollution and eutrophication caused by inflow of sewage and other wastes from Puno city. Beneficial large hydrophyte such as Totora (a kind of reed) has been decreasing while *Lemna* (duckweed) has developed in large quantity and covers a wide lake surface. In order to overcome the lake water environmental problems, both the state and the local governments are wrestling with countermeasures against pollution of the Bay, but could not yet implement any specific measures.

In view of the background described above, the Government of Peru requested the Government of Japan in September, 1995, for technical cooperation for the conduct of the Study on the Integrated Water Pollution Control of Puno Interior Bay of Lake Titicaca. In response to this request, the Government of Japan dispatched a Preparatory Study Team in July, 1996, which held meetings with the Government of Peru and other authorities concerned and reached an agreement on the Scope of Work (S/W) concerned to this study.

According to the S/W, this Study was conducted by the Study Team of the Japan International Cooperation Agency (JICA) in cooperation with the National Institute of Development (INADE) from September 1998 to January 2000.

2. OBJECTIVES OF THE STUDY

The objectives of this study are as follows:

1) To formulate a Master Plan of integrated water quality improvement of Puno Interior Bay.

2) To conduct a feasibility study (F/S) on priority project(s) identified from the Master Plan.

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

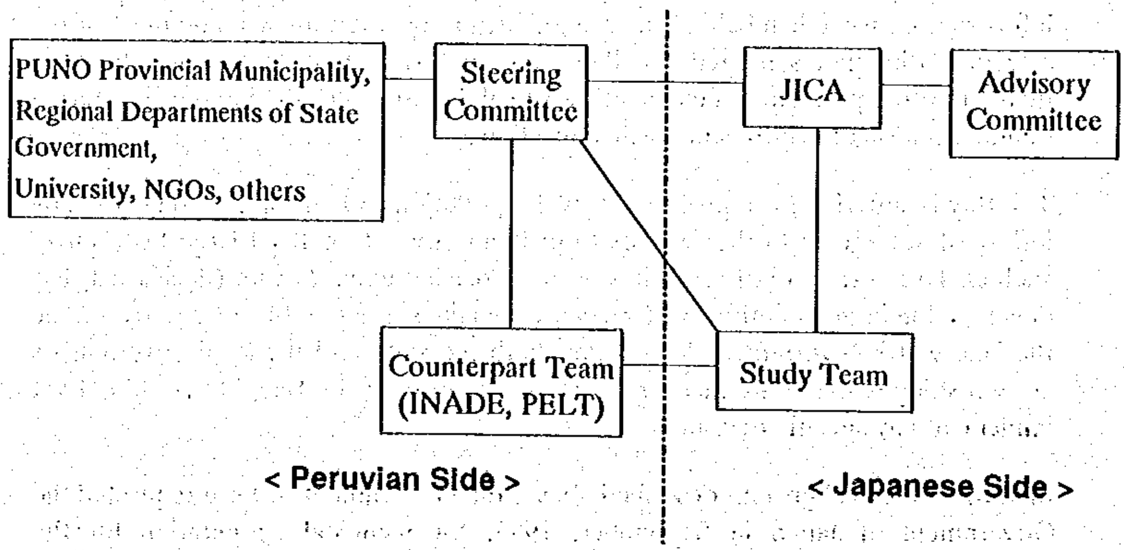
3. STUDY AREA

This study will cover Puno Interior Bay (about 17 km^2) and its surrounding catchment area (about 36 km^2). The study area is as shown in *Figure I.1*.

4. STUDY ORGANIZATION

(1) Overall study organization

The overall study organization is shown below:



(2) Members of the Study Team

The members of the Study Team are as follows:

Assignment	Name
Team Leader	Tsutomu Kurihara
Hydrology/Water Quality	Masahiro Kawachi
Natural Environment and Ecology	Marcus .R. Chambers
Wastewater and Stormwater Management Planning	Koji Yoshina
Solid Waste Management Planning	Akio Kuramochi
Urban Planning	Hiroshi Matsuo
Facility Design and Cost Estimation (wastewater)	Toru Yagi
Facility and Equipment Design and Cost Estimation (solid waste)	Ryousuke Okamura
Facility Design and Cost Estimation (bottom sediment)	Hikaru Maki
Organization and Institution	Yasuhira Minami
Economic and Financial Evaluation	Takio Oshio
Study Administration	Yosuke Abe

(3) Members of the Advisory Committee

The members of the Advisory Committee are as follows:

Assignment	Name
Chairman/ Environmental Sanitation	Hidenori Aya Professor, Department of Civil Engineering, Faculty of Engineering, Musashi Institute of Technology
Waste Water Treatment Planning	Mamoru Suwa Researcher, Advanced Waste Water Treatment Division, Public Works Research Institute, Ministry of Construction
Solid Waste Management	Takahide Tatsunari Senior Researcher, Japan Waste Research Foundation
Lake water Quality Control Planning	Kiyoshi Nomura Chief, The Water Environment Division, Shiga Prefectural Institute of Public Health and Environment Science

(4) Members of the Counterpart Team

National Institute of Development (INADE)

Albert YAMAMOTO MIYAKAWA (Chief)
Máximo HATTA SAKODA / Juan Carlos SEVILLA GILDEMEISTER (General Manager)
Esperanza SANO (Counselor of Chief)
Plinio GUTIÉRREZ DEL POZO (Manager of Studies)
Cristina MASUDA MATSUURA (Chief of Technical, Financial and International Cooperation Office)

Special Binational Project for Lake Titicaca (PELT)

Ariel BERMEJO LIRA / Julián BARRA CATACORA (Executive Director)
Hugo RODRIGUEZ BENAVIDES (Director of Agriculture and Fishery Development)
Héctor SALINAS FRANCO (Director of Studies)
Juan José OCOLA SALAZAR (Coordinator)

(5) Members of the Steering Committee

Ministry of Health

Eloy Enríquez Encinas (Regional Director of Puno)

Ministry of Education

José Luis Choque Mamani (Regional Director of Puno)

The Navy

Dane Markovinovic (Captain of Puno Port)

National University of The Altiplano – Puno (UNA)

Fernando Cáceda Diaz (President of UNA)

Ministry of Transport, Housing and Construction (MTCVC)

Angel Achata Núñez (Regional Director)

Ministry of Fishery

Arturo Blondet Gago (Regional Director)

Ministry of Industry and Tourism (MITICI)

Juana García Pineda (Regional Director)

National Program of Nutrition Assistance (PRONAA)

Ricardo Orbegoso Carrasco (Director)

Basic Sanitation Municipal Utility of Puno (EMSAPUNO)

Rogelio Flores Franco (General Manager)

Ministry of Agriculture

Gustavo Ibarra Imata (Regional Director)

Transitional Council of Regional Administration (CTAR-PUNO)

Ramón Serruto Colque (Executive President)

Central Office for the Barrios of Puno (CUBUP)

Félix Flores Mamani (President)

Ecology and Environment Multisectorial Committee

Gregorio Ticona Gomez (President; Mayor of Municipality of Puno Province)

National Institute of Development (INADE)

Plinio Gutiérrez del Pozo (Manager of Studies)

Special Binational Project for Lake Titicaca (PELT)

Ariel Bermejo Lira / Julián BARRA CATACORA (Executive Director)

5. CONTENTS OF THE REPORT

The Study reports prepared are as follows:

Main Report (English)

Main Report (Spanish)

Supporting Report (English)

Summary Report (English)

Summary Report (Spanish)

Data Book (English)

The main report presents the summarized results of the whole study. It consists of 11 chapters. The existing basic data concerning the study area are shown in *Chapter II*. The exising physical, chemical and biological conditions of Puno Interior Bay are shown in *Chapter III*. The framework of the Integrated Water Pollution Control Plan for Puno Interior Bay is shown in *Chapter IV*, as basic policies and targets of the plan. As components of the Integrated Water Pollution Control Plan for Puno Interior Bay, structural measures, non-structural measures and environmental monitoring are discussed in *Chapter V*, *Chapter VI*, *Chapter VIII*, and *Chapter IX*. *Chapter V* shows the existing sewerage system and the master plan for its development, as a component of the integrated plan. *Chapter VI* shows the existing solid waste management and the master plan for its development. *Chapter VII* shows the other structural measures including urban drainage improvement or in-lake management such as internal load reduction or replanting Totora. *Chapter VIII* shows the non-structural measures which encourage or support the structural measures. *Chapter IX* shows the master plan for the environmental monitoring which detects the water pollution problems and checks the effects of the measures. *Chapter X* shows the feasibility study on the solid waste management project selected from the master plan. *Chapter XI* shows conclusions and recommendations to encourage the implementation of the Integrated Water Pollution Control Plan for Puno Interior Bay

The supporting report describes in detail the same contents presented in the main report.

The Spanish versions of reports are prepared as reference.

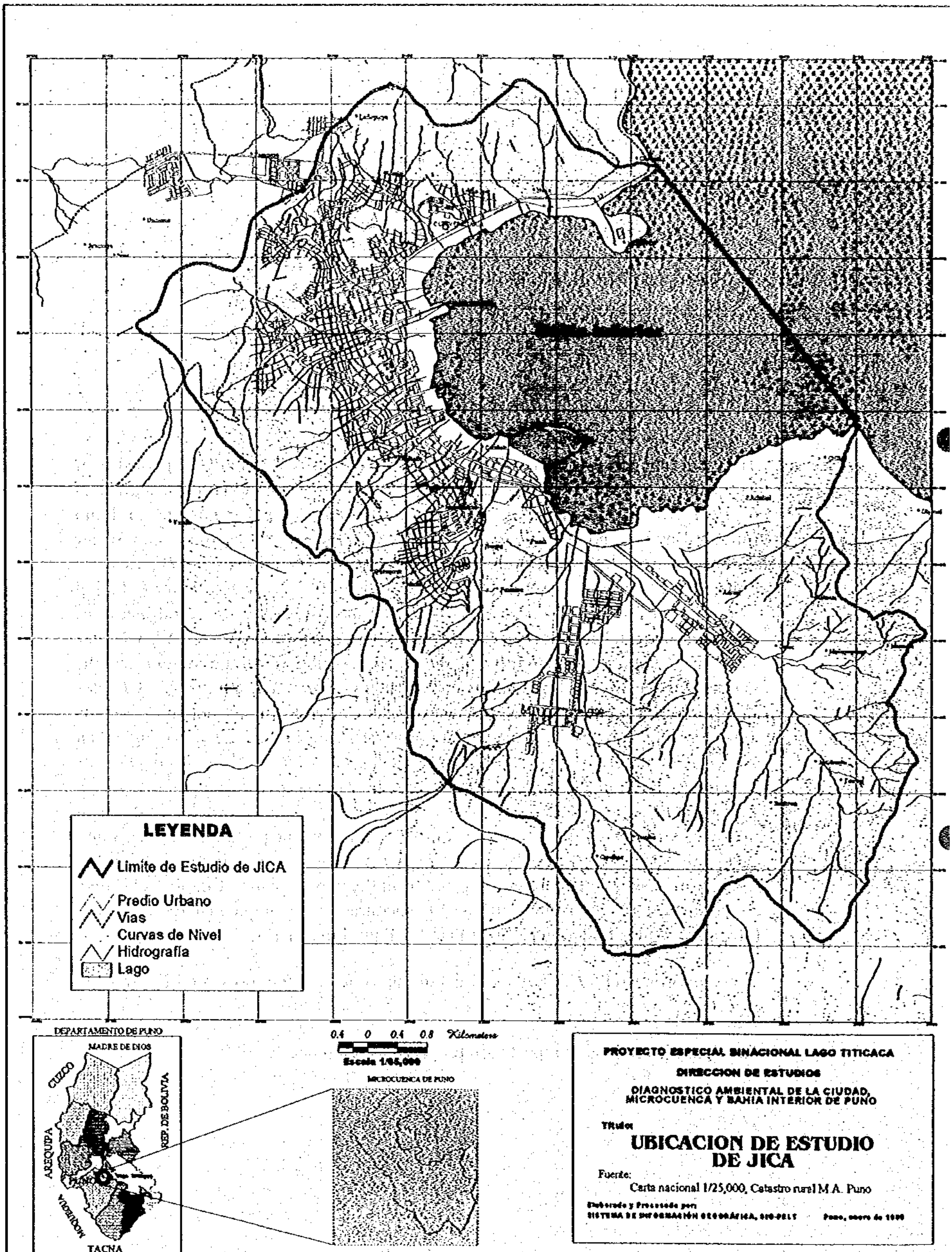


Figure I.1 Study Area

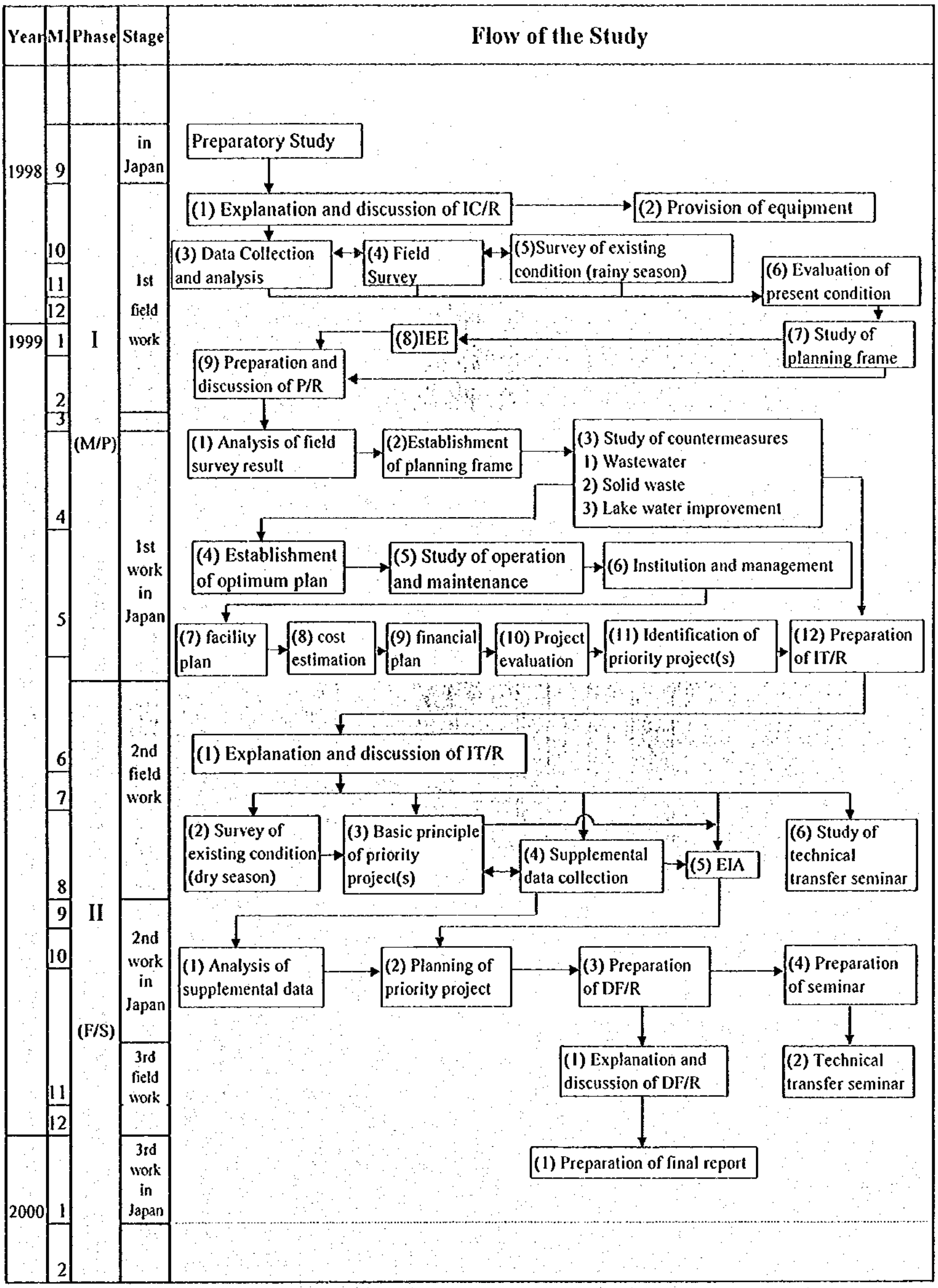


Figure I.2 Flow Chart of the Study

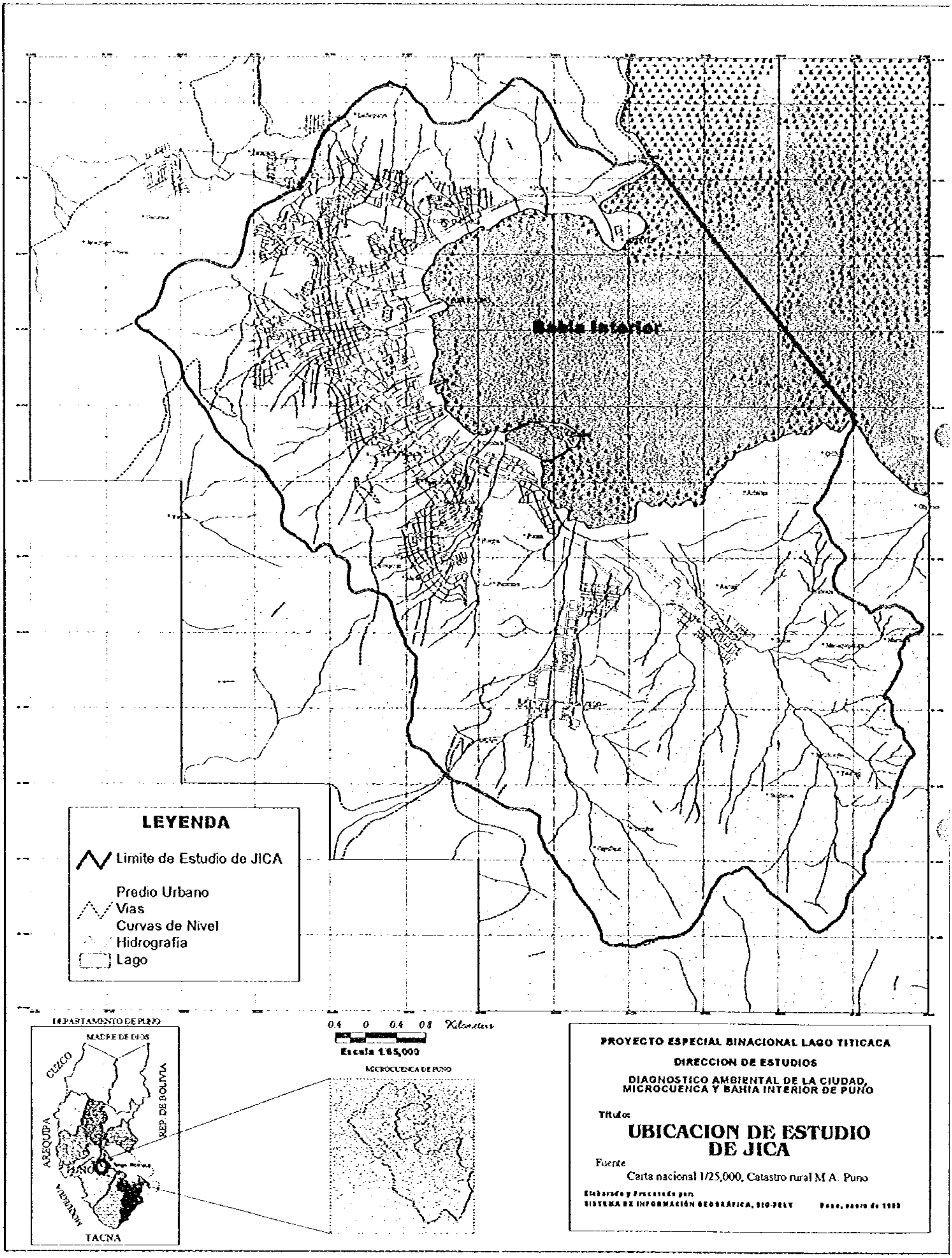


Figure I.1 Study Area

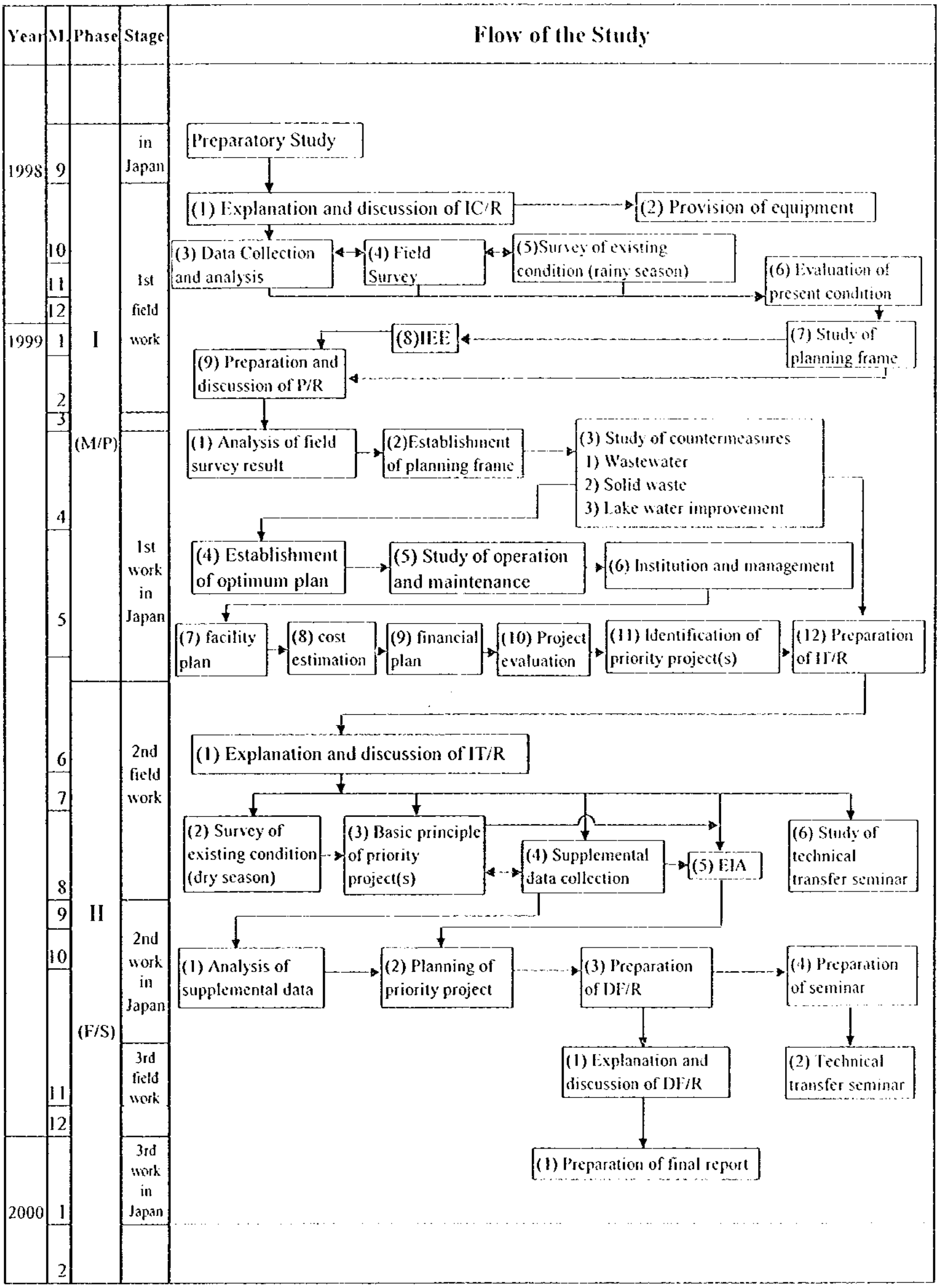


Figure I.2 Flow Chart of the Study

CHAPTER - II BACKGROUND OF THE STUDY AREA

CHAPTER - II
BACKGROUND OF THE STUDY AREA

1. NATURAL CONDITIONS

1.1 LOCATION

The project is located in the Department of Puno, southern Peru. The area of the Department is 71,999 km^2 and in 1993 the census population was 1,103,689, equivalent to 4.9% of Peru's population and the 5th most populated Department of the country. Much of the Department is situated in the Peruvian altiplano, a high plateau in the Andes mountains ranging in altitude from 3809 m to over 5000 m.

The specific project area (*Figure I.1*) is located in the town of Puno (population 96,717 in 1995), its surrounding mountains and Puno Interior Bay of Lake Titicaca. The total area of these components is 52.75 km^2 of which the watershed basin area is 35.50 km^2 and the Interior Bay 17.25 km^2. Puno town is mainly built around the western shores of Puno Interior Bay, which is itself a part of Puno Bay (550 km^2), a large bay at the north western corner of Lake Titicaca (8,167 km^2).

Lake Titicaca is at an altitude of 3809 m and the town extends up the surrounding mountain slopes to about 3950 m. The study area therefore forms a self-contained watershed unit or basin within the general watershed area of Lake Titicaca. The area is located within the southern tropics around latitude 15° 50'S and longitude 70°W.

1.2 TOPOGRAPHY, GEOLOGY AND GEOMORPHOLOGY

1.2.1 Topography

The study area basin consists mainly of steep hills with slopes from 20° - 45°. They are highest (to 4500 m) and steepest at the western part behind Puno town where they consist mainly of extinct volcanic cones. The surrounding hills are lower and generally less steep to the north and south of the Interior Bay although cliffs and rocky outcrops occur at the southern side. At the eastern side of the study area Puno Interior Bay is bounded by two peninsulas (Chullune to the north and Chimu to the south) that partially isolate it from the main (outer) part of Puno Bay. The distance between the points of these two peninsulas is about

2 km and is occupied by a vegetated mud bank that is continuous apart from two narrow navigation channels that connect the Interior Bay and the Exterior Bay.

There are only two valley systems of significant size in the Puno basin. Both are located in the south west, the largest being the Jayllihuaya valley (17.5 km^2) and the other the Salcedo valley. In total, the Puno basin contains 123 river and stream beds and rainwater gullies or drains that collect and discharge water to Puno Interior Bay. Flows vary from zero in the dry season to a maximum of a few m^3/sec in the wet season.

1.2.2 Geology

The geology of the Puno basin is described in two recent reports (PELT, 1996 and 1997). The geological setting of the study area is the altiplano depression of the Peruvian Andes mountains. The altiplano itself is a vast intermontane basin in the central Andes of Peru, Bolivia and Argentina lying between the Western and Eastern Cordilleras. In total it is about 2000 km long and 200 km wide, with the northern parts occupied by large permanently flooded lakes (Titicaca and Poopo) and the southern by arid salt pans.

The mountains of the Puno basin are mainly of igneous origin, but there are also considerable areas of sedimentary and metamorphic rocks (*Figure II.1.1*). The lower areas are occupied by alluvial and lacustrine (lake) sediments. The many geological units are briefly described below.

(i) Pre-Quaternary Litho-stratigraphic Units

These are surface sedimentary formations (5 in number) which together cover 50% of the study area, forming Puno Interior Bay and on which much of Puno City is located. They were formed between Lower Cretaceous and Lower and Middle Tertiary periods.

The oldest of these, the Muni formation, covers 244 ha and dates from the Lower Cretaceous. It is composed of reddish-brown sandstone with strata of sandy clays and limestones. Structurally it forms fault blocks with moderate cliffs and weathers differentially to form unstable depressions, particularly in steeper areas.

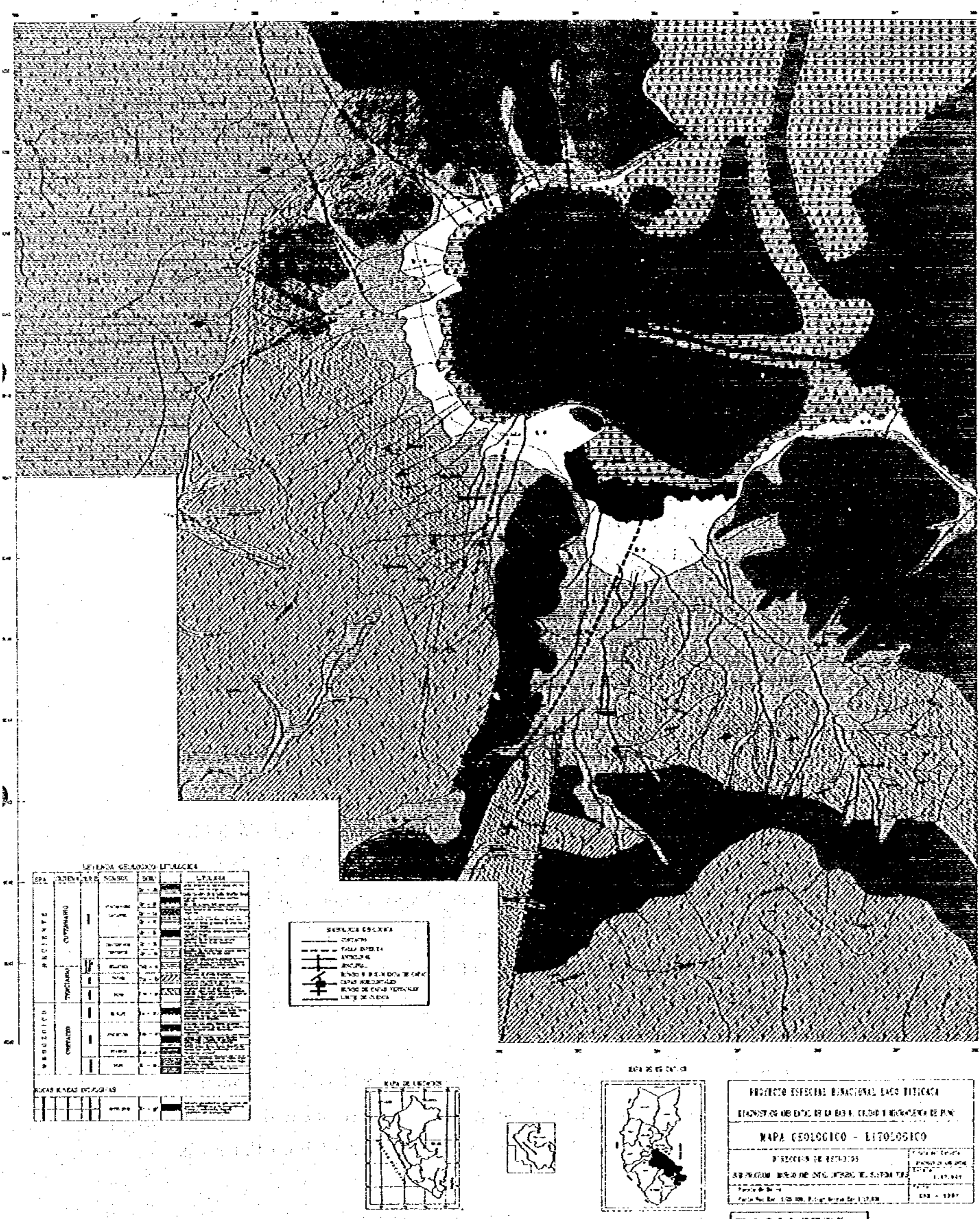


Figure II.1.1 Geology and Lithology of the Study Area

The Ayabaca limestone and conglomerate formation (Middle Cretaceous) covers 625 ha. It now forms hills in the Puno basin which in some areas are unstable and liable to landslides. In some areas the rocks have weathered to form soils and groundwater contaminated with copper, mercury and silver. The Angostura formation of sandstone/quartz (Middle Cretaceous) covers 396 ha. It is resistant to weathering and forms rocky ridges on Llallahuane, Vacachune and Huacaparque hills. At the bottom of these hills the rocks have weathered to form accumulations of angular blocks, sands and clays with deep unstable soils.

The Munani formation (Upper Cretaceous) covers 1225 ha and consists of sandstone/quartz conglomerates. These are resistant to erosion and now form spectacular steep or vertical cliffs on Pacocahua and Putina mountains. These areas are important aquifers. The Puno formation (Lower and Middle Tertiary) covers 958 ha and consists of limestones and conglomerates. The rocks are soft and have weathered to form gentle slopes and depressions on which part of Puno town is built.

(ii) Pre-Quaternary Volcanic Igneous Rocks

There are three volcanic igneous units in the Puno Basin. The smallest of these (8.25 ha) is the granodiorite unit that is intrusive in the Cretaceous and Tertiary sedimentary formations. It is composed of quartz and feldspars and forms the small islands (Devils, Chullune and part of Esteves) in Puno Interior Bay.

The Tacaza formation of andesites, rhyolites, basalts and dactolites (2,639 ha) was produced by igneous eruptions in the Middle Tertiary and now forms the hills of Putina, Cancharane, Negro Peque and Huayllane, the principal volcanic hills that surround the Puno basin. The rocks of Cancharane have mineralisations of copper, silver, lead and gold that in the past were commercially mined, and which now form a contamination source for soils and water.

The Sillapa formations of andesites and basalts (1730 ha) were formed in the Upper Tertiary and Pleistocene periods and are located between Putuputune and Yanamayo hills. They now consist of both flat areas and escarpments.

(iii) Recent Quaternary Units

In total these cover 4895 ha and consist of two fluvio-alluvial units and five lacustrine units. They were formed since the last glaciation period and are still accumulating.

The fluvio-alluvial deposits mainly occur in the valleys of Jayllihuaya and Salcedo. They consist of sands, clays and gravels that have formed terraces on the bottoms and lower slopes of the valley sides. They are good agricultural soils and also provide the ingredients for the brick-making industries of the Salcedo valley. Much of Puno town is also built on these recent sedimentary deposits.

The lacustrine deposits of sands, clays and organic materials extend from the littoral (flood zone) of the Interior Bay to the centre of the Bay (about 7 m deep). They are mainly carried in from the numerous streams and drainage canals emptying the watershed's rain into the Bay. The five units consist of the flood zone (inundated at high lake levels), the totora zone around much of the shallow water at the Interior Bay's perimeter, a narrow zone between this and the main Bay, the main part (open water) of the Interior Bay itself and the river Huile (Willy). The latter is outside the Interior Bay, but connected to it by a narrow navigation channel which brings in sediments from the Ilpa and Totorane rivers that discharge to Puno Exterior Bay. Similar sediments also enter from the main navigation channel.

(iv) Geotechnical Stability

Areas of geotechnical stability can be defined on a combination of lithology, structure and slope. Within the Puno basin there are four areas of differing geotechnical stability. The most stable areas (Class 1) are generally those of the high mountain tops with low slopes and no structural deformations. Also included are the islands of Espinar and Esteves. Class 2 areas are the fluvio-alluvial deposits of the principal basin valleys of Jayllihuaya and Salcedo and much of the areas on which the lower parts of Puno town are built. Class 3 areas are those of moderate to steep slopes with an unfavourable geological structure. Much of upper Puno town is built in such areas. The most unfavourable area (Class 4) is the zone of lacustrine deep mud around much of the perimeter of Puno's Interior Bay. Some of this area is being poorly reclaimed and built upon.

(v) Seismicity

Puno is located in Peru's Seismic Zone No. 2 according to the National Construction Regulations. This means there is little risk of significant earthquake activity. There are no recorded major earthquakes from the area.

1.2.3 Geormophology

The Puno basin is geomorphologically very active - due to lake dynamics, rainfall and human activity (*Figure II.1.2*). Wind erosion is of minor importance.

(i) Lacustrine Processes

Sediments are transported into Puno Interior Bay from the surrounding watershed and from Puno Exterior Bay by the two navigation channels. The former is by far the major source. These sediments accumulate in the Interior Bay and will eventually (over geological time) cause it to fill in completely. Sediments are transported into Puno Exterior Bay by the Coata, Ilpa and Totorone rivers as well as from the main part of Lake Titicaca through the Capachica - Chicuito Straits. These have already filled in much of Puno Exterior Bay, more than half of which is covered with emergent macrophyte vegetation (totora) growing on these lacustrine deposits. Small amounts of these sediments enter Puno Interior Bay via the two navigation channels. Lake Titicaca undergoes cyclical changes in levels. Between 1933 and 1943 the level was 5.5 m below average, whilst from 1970 to 1986 it was 2.6 m above average. During periods of high lake levels, deposition rates of sediments will increase and build up the lake bottom, which serves to extend the land area during low lake levels when the lake waters recede.

(ii) Fluvio-Alluvial Processes

The Puno basin has intense river and rainwater erosion activities during the rainy season. These processes are accelerated by human activities. Within the Puno basin these are more than 20 micro-basins with a total of 123 rivers, streams and drainage channels. These carry the products of erosion and weathering into Puno Interior Bay, usually after spilling out over the inundation (flood) zone of the Bay. Much of the sediment is deposited on the inundation zone, leading to its gradual increase in height and reclamation as dry land.

The management of these fluvio-alluvial processes is a major priority for the environmental management of the Puno Basin.

(iii) Human Processes

The Puno Basin is an area of intense human activity - house building, road construction and agriculture. Much of it is carried out in an ill-considered manner, exposing rocks and earth to the rain and leaving mounds of earth lying exposed to the elements. These activities accelerate erosion and greatly increase the amounts of sediments entering Puno Interior Bay, thereby speeding up the process of filling it in.

(iv) Wind Processes

The basin's persistent winds exert an erosive force when there is deforestation or a lack of trees - as is the situation in nearly all of the basin. The process is accelerated by human activities that leave much exposed soils, particularly during the dry season. In the highest parts of the basin, winds assist in the weathering of rocks, loosening them and increasing the risk and occurrence of landslides.

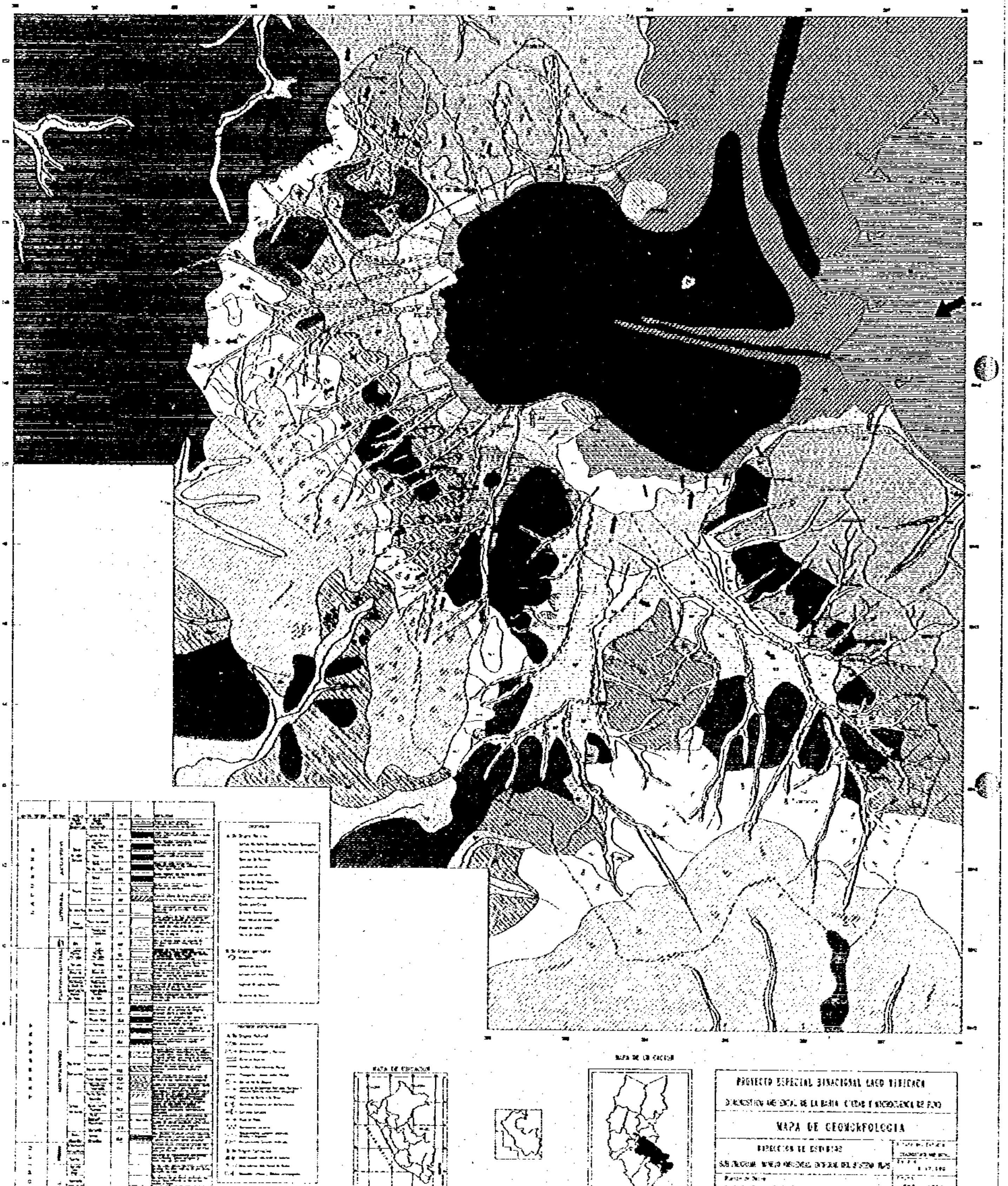


Figure II.1.2 Geomorphology of the Study Area

1.3 CLIMATE

The climate of the Puno Basin has been described by Ocola (1996) and this description has been further supplemented by data from SENAMHI. Puno's climate is mainly determined by latitude and altitude together with its proximity to Lake Titicaca and the presence of the surrounding mountains.

In South America, the general atmospheric conditions are determined by three semi-permanent systems of circulating high pressure. These are the North Atlantic (cyclonic) and South Pacific (anticyclonic) circulations with between them the zone of Intertropical Convergence (ZIC). The ZIC persists the whole year but is displaced according to whether the North Atlantic or South Pacific circulations receive the most solar radiation. The pressure differences between these two zones and the ZIC create movements of air between the tropics and equatorial regions.

In Puno's summer (November-February) the South Pacific anticyclone is situated over the Pacific Ocean and conducts air masses towards central South America. This gives rise to strong convection currents which increase the already high humidity produced by evaporation from Lake Titicaca. This causes large cloud masses to form over the altiplano which give rise to the heavy summer rains. During the winter period the ZIC is displaced to the north, resulting in the altiplano's dry season and high rains in the equatorial regions.

The Peruvian altiplano does not have a typical tropical climate due to its altitude. The Puno climate is classified as cold and semi-wet with relatively low average temperatures and pronounced wet and dry seasons. At Puno, the annual average temperature (1930-1998) is 8.7°C, with monthly averages ranging from a maximum of 10.4°C (December) to a minimum of 6.0°C (July). This is the mildest climate of the Peruvian altiplano and is due to its relatively low altitude and proximity to Lake Titicaca, whose temperature never falls below about 10°C.

There is comparatively little temperature variation over the year. The average maximum daytime temperatures (1964-1998) range from 13.3°C (June and July) to 16.1°C (November), with an annual average of 14.3°C. The absolute maximum recorded temperature is 22.0°C. The average minimum night time temperatures for the same period range from -1.0°C (June) to 5.3°C (January). The absolute recorded minimum is -7.2°C.

Pan evaporation rates are high and exceed annual rainfall. The maximum rates occur between September and December and average 200.2 mm/month. Minimum rates occur during the colder months of May to August with an average of 145.6 mm/month. Over the year as a whole the pan evaporation totals about 2000 mm, about three times the annual rainfall.

Puno has a generally sunny climate, with an annual average of 8.2 hours/day. The sunniest months occur in the dry winter and transitional months, with July having the highest average (9.6 hours/day). The lowest sunshine occurs during the wet summer season, the lowest average being in January (6.2 hours/day). Estimates of solar radiation received at Puno range from a maximum of 549 calories/cm^2/day (November) to a minimum of 390 calories/cm^2/day in May and July. Average cloud cover values range from 6.5 octaves in January to 2.4 octaves in July.

The atmospheric pressure at Puno is 61.2% of that at sea level. There is little seasonal variation, with average values ranging from 645.2 mb (November and December) to 646.7 mb (May). Slight pressure differences between the Puno Basin and Lake Titicaca are responsible for the observed dominant wind directions - onshore during the day and offshore at night.

Puno has a generally low relative humidity, in part explaining the high evaporation rates. The annual average is 49%, ranging from a maximum of 61% in the wet season to a minimum of 39% in the dry season months of June and July.

Rainfall in Puno is determined mainly by latitude and altitude and to a smaller extent by orographic conditions created by the surrounding mountains and distance from the lake. The annual average rainfall at Puno (1964-1998) is 711.3 mm. Averages range from 391.4 mm (1966) to 1290.6 mm (1984). There is a pronounced wet season from November to March when 79% of the annual rainfall occurs, with transitional periods in April and September/October. In the dry winter period (May-August) only 3.8% of the annual rainfall occurs, with zero rainfall recorded commonly in these months. The highest daily maximum rainfall averages occur in December (26 mm/day) and the lowest in July (1.4 mm/day). The highest recorded daily rainfall is 71.6 mm, in October 1984. Heavy rainstorms are frequent in the wet season and intensities during these will greatly exceed the daily averages. Little rainfall occurs as snow or hailstones, though the latter are very damaging to agricultural crops when they do occur.

Detailed wind statistics are only available for the period June 1995 to May 1996, and consist of recordings of wind speed and direction taken daily at 07.00, 13.00 and 19.00 hours. At 07.00 conditions in Puno are generally calm, with 64.2% of days recorded as having no measurable winds at this time. On those mornings with wind, the dominant directions are from E to SE (onshore, 19.1% of occasions) and NW (9.0% of occasions). There is little seasonal variation, though offshore winds occur more frequently from June to November. At 13.00 hours, only 2 days were recorded as calm, with the strongly dominant direction being from the east (73.7% of occasions) with no seasonal variations. At 19:00 hours, 15.3% of days were recorded as calm, with the dominant directions from the south (28.1% of occasions), W-SW (26.0%) and east (24.0%), with little seasonal variation. Average wind speeds were low, ranging from 1.0 m/s to 6.5 m/s. The strongest average winds were generally from the south (8 m/s) and had an absolute maximum speed of 15 m/s.

1.4 HYDROLOGY

The total area of 7,500 km², a quarter lying in Bolivia and three quarters in Peru. The catchment area covers 49 the Lake Titicaca basin, to the outlet of the Desaguadero and including the area of open water, is 5,010 km², or 85% of the total basin. Three quarters of the catchment area is drained by six rivers: the Rios Ramis (31%), Ilave (15%), Coata (11%), Catari (7%), Huancane (7%) and Suchez (6%).

The zero datum of the Lake Titicaca is at 3,809.93 m above sea level. Lake Titicaca undergoes changes in level of a time-scale of several years. Since the 1910s, the range of variation has been 6.06 m at Puno. The highest level is 3,812.57 m (in 1986) and the lowest is 3,806.51 m (in 1943).

Lake Titicaca is fed by inflows from the surrounding rivers and by rain falling directly onto the lake. Losses are due to evaporation and surface drainage leaving via the Desaguadero.

Catchment area of Puno Interior Bay is about 40 km², and quite smaller than that of Puno Exterior Bay (4,650km²) or the whole Lake Titicaca (49,010 km²). The water level of Puno Interior Bay shows annual fluctuation similar to that of precipitation, though evaporation does not show significant fluctuation. Therefore, the water level of the Interior Bay is supposed to strongly depend on the outflows of major rivers.