CHAPTER III NATURAL AND SOCIOECONOMIC ENVIRONMENT OF LAKE YPACARAI AND ITS BASIN

3.1 Natural Environment of the Lake and its Basin

3.1.1 Topography

The topography of the basin can be almost entirely seen from the topographical map on the scale of 1/50,000 edited in 1980; in order to understand the detailed water system pattern and the state of land use, aerial photographs on the scale of 1/40,000 were taken on Feb. 5, 1988.

The water system could be seen in this photograph. Furthermore, the watershed boundary was defined on the topographical map on 1/50,000 scale, and landform classification map were drawn (Fig. M3111, Fig. M3112). Referring to these figures, the topographical features of the basin are described below.

The Lake Ypacarai basin extends north-west and south-east. To the north-east side of the central lowland, which is 5 to 8km in width, is plateau type upland 200 to 400m above the sea. To the south-east side are hills 100 to 300m above sea level.

The lake basin is basically composed of four catchment areas; the Yuquyry River water system, the Pirayu River water system, the Eastshore water system and the Westshore water system, and the total area including the lake is 892.6km^2. The Salado is the only outflowing river from the Lake.

The Yuquyry River water system is 343.9km^2 in its basin area, and its main stream flows into the marsh lying north of Lake Ypacarai but its direct relation to the lake is not clear through the topographical map only. However, whether the water from this water system flows into the lake or not is a great issue in planning the pollution control measures for the lake, as mentioned below. Therefore, in addition to the detailed interpretation of aerial photographs (Fig. M3113), aerial observations by navy helicopter and survey along the stream by boats were made to supplement the topographical map.

Subsequently, it was found that the Yuquyry River ran toward the lake even though its stream was dispersed by micro relief in the downstream marsh; and no clear water course connecting it to the Salado River was recognized. Therefore, it can be judged that almost all of its water flows into the lake directly or indirectly, and only a small portion indirectly flows into the Salado River penetrating the marsh.

The Pirayu River water system is 353.7km^2 in its drainage basin area, and, just before it flows into the lake in the vicinity of Route 2, it divides into three: the Yagua-Resa-u River, the Y-pucu River and the Pirayu River, but in the up-stream area, the water courses intersect each other, and it seems that they join together during floods and overflows. Mainly, on the right bank at 80 to 200m above the sea level, myriad small scalle ponds are found, and also old river

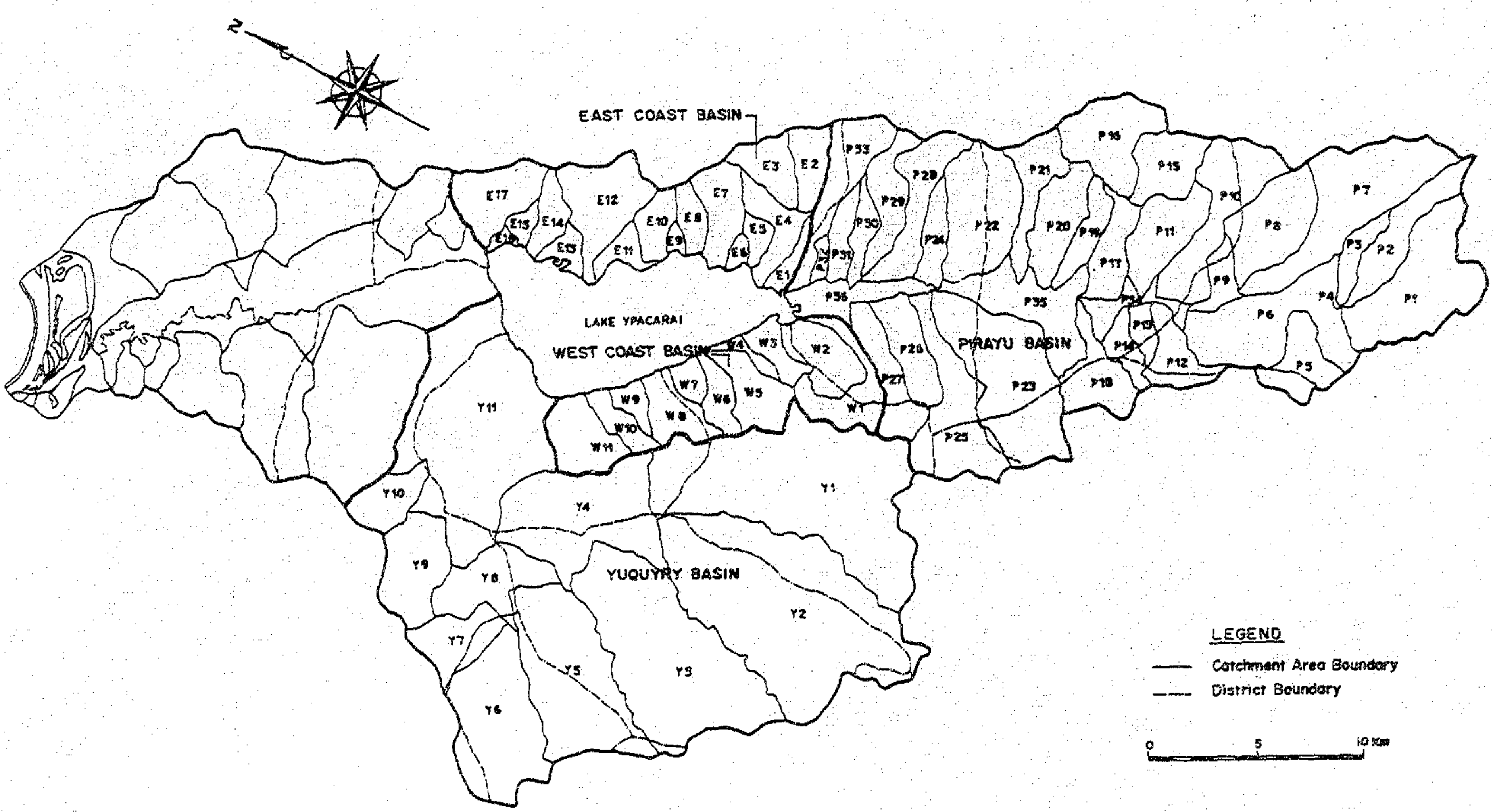

Fig. M3111 Catchment Area Subdivision Map

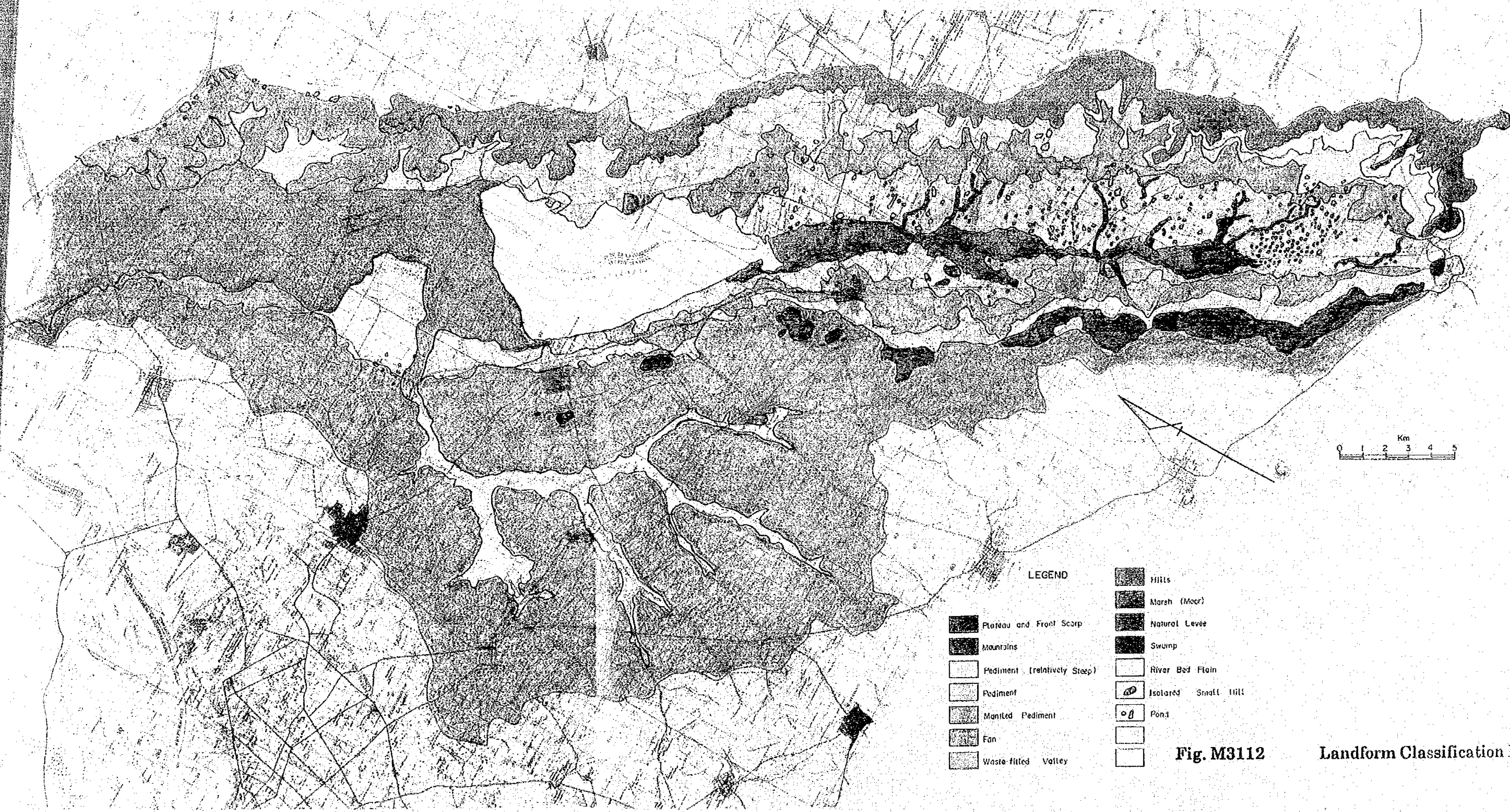

Fig. M3112 **Landform Classification Map**

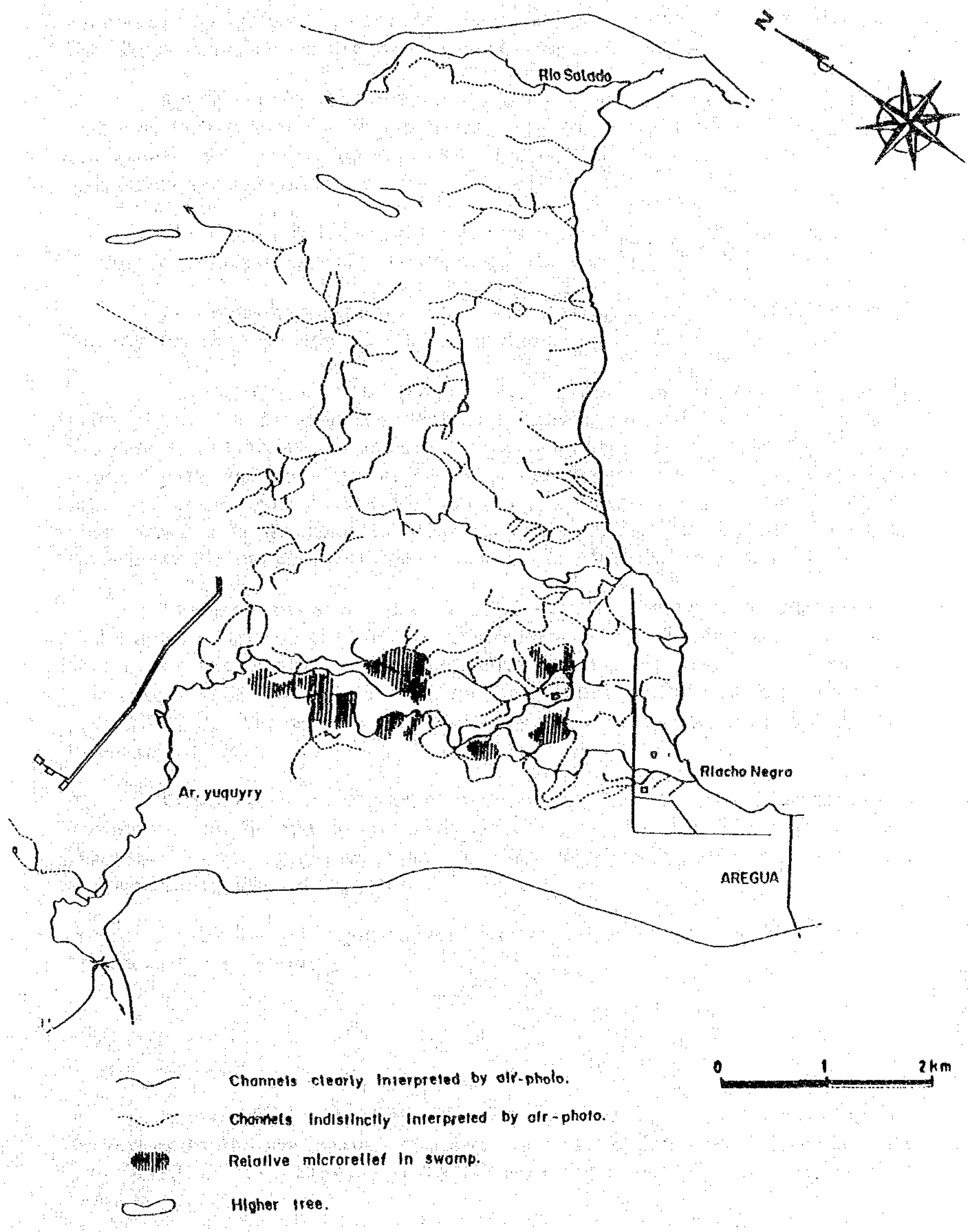

Fig. M3113 Airphoto-interpretation Map of Lower Stream Area of Yuquyry River

courses are recognized. From these facts it can be assumed that the lowland along the Pirayu River's main stream were once a continuous water area.

Many alluvial fans of small-scale gently sloping are found on both the east and west side of the Pirayu River lowlands. Within the east side alluvial fans, there is an underground stream, but on the west side, surface and gully erosion are remarkable.

The Eastshore catchment area which is composed of 17 streams directly flowing into the east side of the lake, has a total area of 75.2km^2.

The Westshore catchment area which is composed of 11 streams directly flowing into the west side of the lake, has a total area of 60.2km^2.

The contour of Lake Ypacarai is roughly trianglular, the western shore is linear, but the east shore is indented and shows an unusual shape. Previous to this study the lake bottom topography was not clear. Therefore, in this study, a depth survey was made by sonar (echo sounder) and a bathymetric chart of the lake was drawn (Fig. M3114). The mean water level is taken from the navy's observation records from the past 22 years, and it corresponds to 1.20m watermark (datum plane is 62.29m above sea level) located at San Bernardino.

The lake area at mean water level is 59.6km^2, with the maximum depth at 3m and the volume at 1.15×10^8m^3. As far as 500m off both the east and west shores, the lake bottom is inclined, however most of it is flat and with no discernible waterway, and its cross section resembles a flat bottom shallow dish (Fig. M3115). The water depth at the egress of the outflowing Salado was measured at 85cm.

To the north of the lake, a vast marsh (Pantanal) is spread as far as the Paraguay, and the marsh on the lower Yuquyry (15.7km^2 in area) is called Humedales, as it is plays an important role in adjusting the lake water level and in maintaining the water quality.

In the lower Pirayu, as well, there is a marsh whose scale is 1/8 to 1/9 that in the lower Yuquyry.

3.1.2 Geology

A geological map of the basin was drawn, based on the outcropping survey, and microscopic study and X-ray analyses of samples and existing data (Fig. M3121). The outline of the strata/rocks distributed in the basin is described below.

The oldest rock distributed in the basin is granite of the Cambrian period, which crops out on the San Bernardino lakeshore and east of the Ypacarai

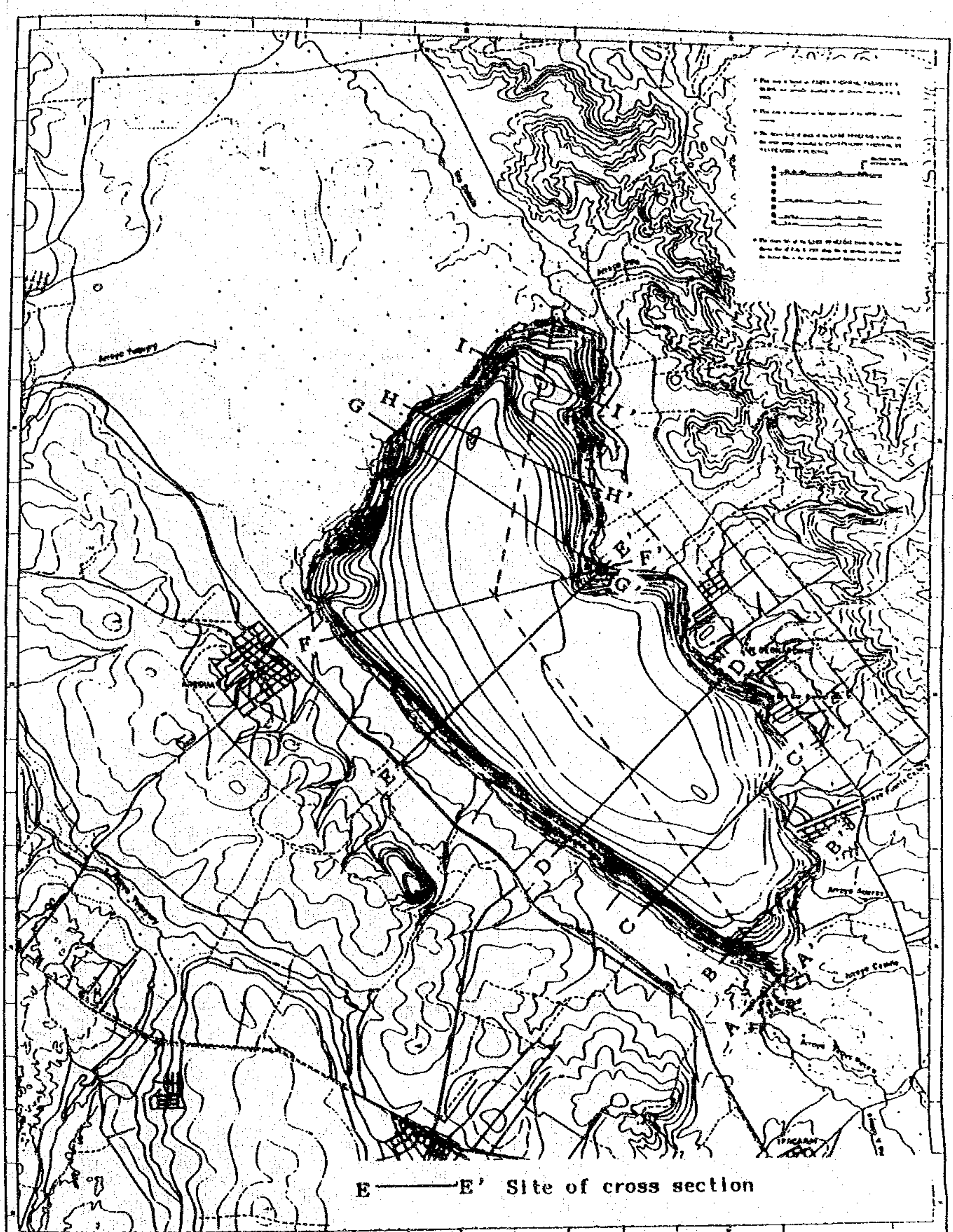

Fig. M3114 **Bathymetric Chart of Lake Ypacarai**

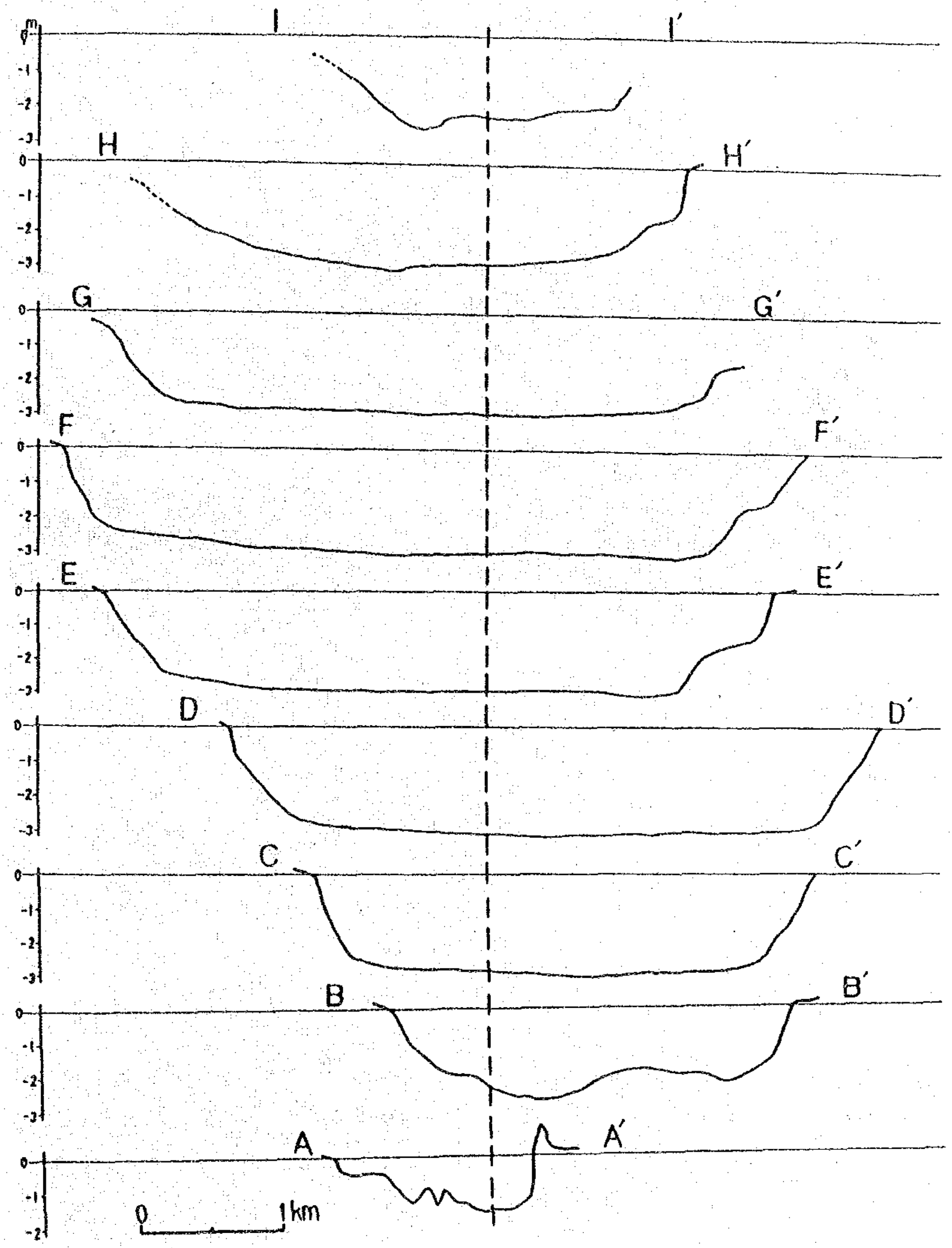

Fig. M3115 Cross Sections of Lake Ypacarai

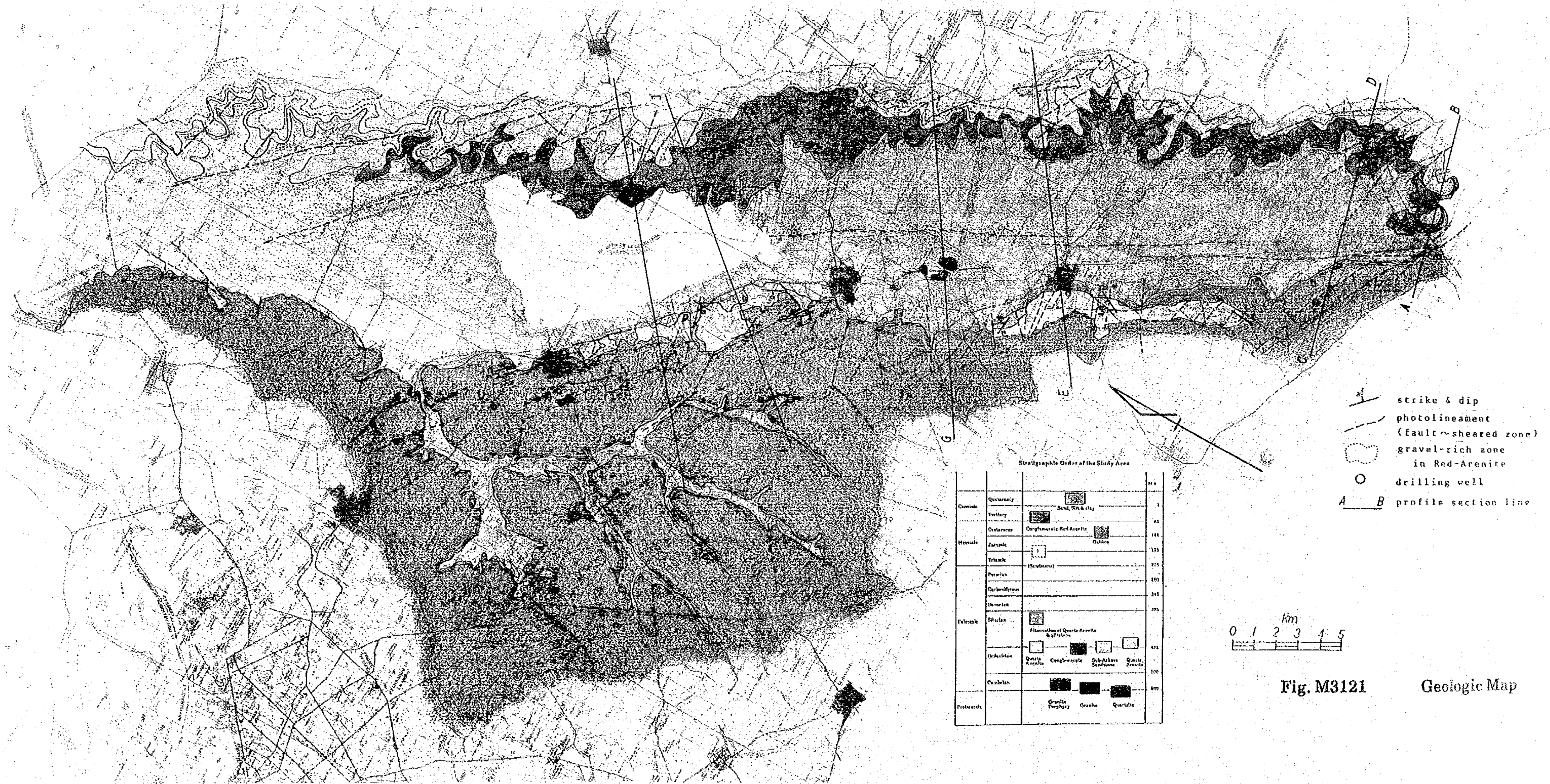

Fig. M3121 Geologic Map

on a small scale. According to survey data of SENASA, in the west of the central lowland, it lies concealed at depths of 55 m and 80 m underground.

The upper layer is of the Paleozoic group composed of conglomerate, sandstone and siltstone, and is distributed mainly on the axis of Los Altos Mountains in the east and Yaguaron Mountains in the west. The conglomerate layer is dug out for gravel as its matrix is easily weathered and pebbles are easily taken out. The sandstone layer is white, highly solidified and forms steep cliffs, and is dug out as building stone, due to its partially developed platy joint. The siltstone layer contains many fossils of the early Silurian period such as brachiopoda, and is mined for raw material of ceramics.

In the gentle hills which form the Yuquyry drainage basin, Cretaceous to Tertiary rocks composed of conglomerate and red sandstone are widely distributed. The surface layer is remarkably laterized, and the conglomerate layer is mined for gravel.

In addition, there are igneous rocks such as gabbro and porphyrite, even though their distribution is limited. As these are very hard, they form a jutting topography and are mined as paver.

About 1km west of Aregua, beautiful pentagonal /hexagonal pillar joints develop, and there is sandstone, recognized as in igneous dike, and designated a natural monument. This igneous rock is also distributed in San Lorenzo and Luque at very shallow depths, and largely dug out for construction stone.

In the central lowland, a Quaternary system composed of unconsolidated sand, silt and clay is distributed, however not very thick. And, in the Pirayu lowland, sections where the wall rock crops out directly can be observed. In the river bed of Yuquyry's main stream and its tributary, a dark-gray to dark-brown accumulation, rich in fairly solidified silt and/or clay, is distributed and mined for raw material of ceramics.

The distribution of the lake bottom sediment is shown in Fig. M3122. Near the lakeshore, good sorted brown sand rich in quartz is distributed, however almost all of the lake bottom is covered by black uniform mud. 99% of the mud is clay and silt, with a water content at 150 to 400%, and often including plant roots.

According to local people, at Aregua on the western shore, mud was found 10 m from the shore 10 years ago, but now, sand is found as far as 100 m off the shore. At San Bernadino on the eastern shore, mud was found 50 m off the shore about 30 to 40 years ago, but now there is sand as far as 300 m. This implies that the development in the river basin has accelerated the runoff of earth and sand and changed the lake bottom from mud to sand.

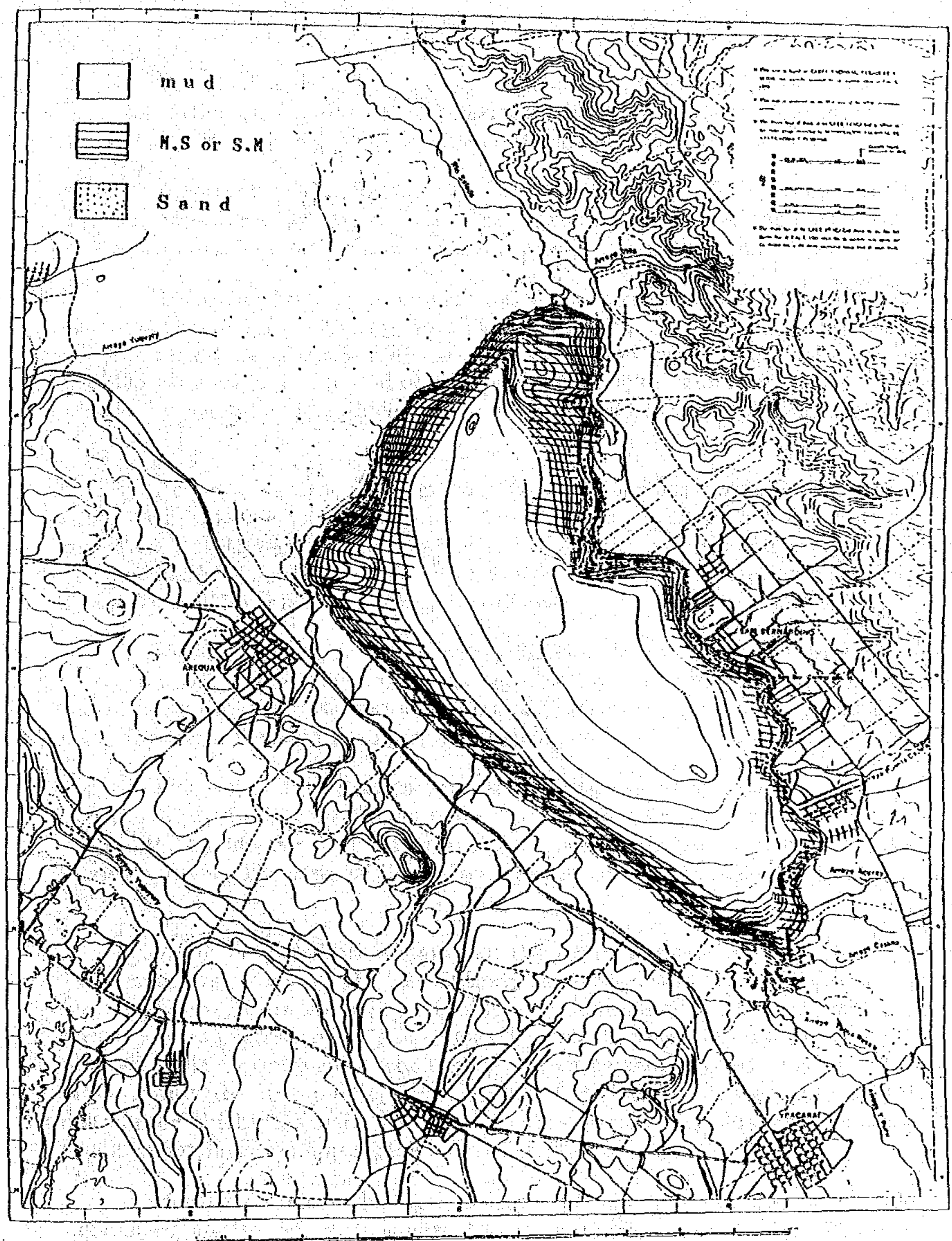

Fig. M3122 Distribution of Bottom Materials in Lake Ypacarai

3.1.3 Soil

The soil distribution map was drawn based on the test pit observation on-site, the particle size analysis and the existing data (Fig. M3131). The outline of the soil distributed in the drainage basin is described below.

According to the classification of FAO/UNESCO, four kinds of soil, lithosol, acrisol, regosol and planosol, are distributed in the drainage basin, and the distribution is closely related to the topography rather than the parent rock.

The coarse grained lithosol is distributed on relatively high steep slopes, where the soil layer is generally thin at under 10 cm. Conglomerate and rough particle sandstone is the parent rock and vegetation grows fairly well. Fine grained Lithosol is distributed on hills east of the lake, which were originally covered by vegetation but which were eroded by development of housing land and roads.

Acrisol generally red to brown in color is distributed widely over almost all of the hills in the Yuquyry drainage basin, at the foot of Los Altos Mountains and Yaguaron Mountains and in other areas. Due to its favorable topography, the land has been used greatly resulting in the loss of many sections of the surface layer. The soil layer is almost 2 m at its thickest.

Regosol is immature soil widely distributed as grassy marshland, of which the water retention capacity is high, as the sub-layer is non-permeable gleizationed conglomerate and sandstone of Palaeozoic group, and many small scale shallow ponds have sprung up everywhere.

Planosol is dark-gray to dark-brown soil, rich in silt and/or clay, and distributed in the Pirayu, in the main part of the lake bottom, in the marsh around the Salado and in the river bed of the main stream and tributary of the Yuquyry River. The permeability is low and gleization is advanced at the lower levels.

From the distribution state and the result of particle analysis of the above four kinds of soil, it can be said that: the lithosol and the acrisol are local soil formed directly on the parent rock; the regosol is sandy soil formed when the former are transferred to lowland and accumulate on grassy marshland; and the planosol is clayey soil formed when the above are further worked by river water leaving only the fine particles. It seems that these soils were originally distributed thickly as gentle hills, but, as a result of roads and housing development, large amounts of them have been lost.

Most of the soil in the basin is acidic (pH is 4 to 6) and poor in organic substances, and therefore, in addition to its low productivity, the resistance against erosion is also low. The cation exchange coefficient (CEC) and the

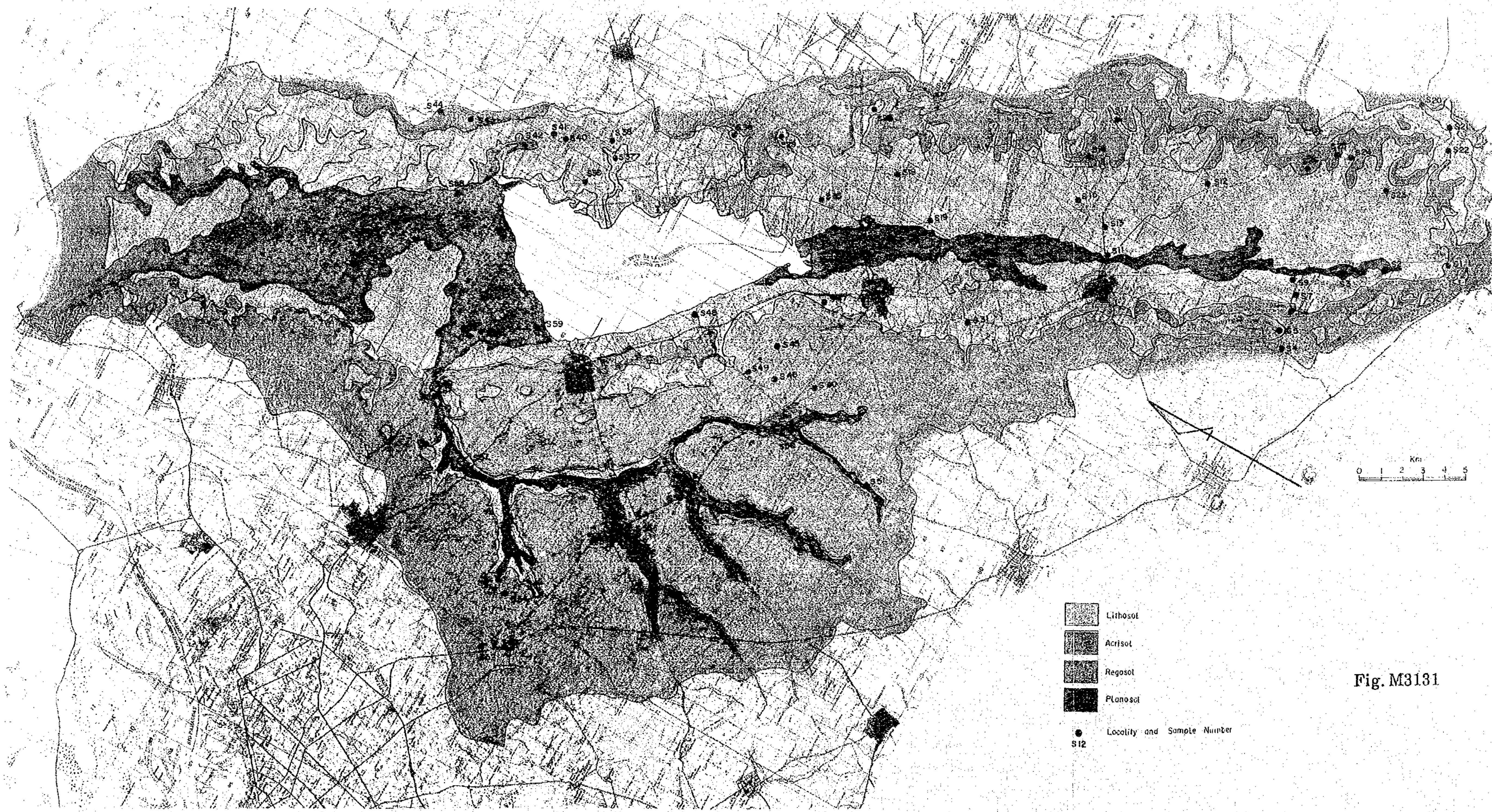

Fig. M3131 Soil Map

phosphate absorption coefficient (PAC) are small on the whole, but are relatively large for planosol which is rich in clay.

3.1.4 Weather

For the purpose of this study, meteorological observatories (3 locations) and rainfall amount observatories (3 locations) were installed. The meteorological characteristics of the basin were investigated through the record obtained on these sites (March 1988 though February 1989) and through existing data (on and after 1950).

No regional difference was recognized in temperature. However, the monthly average temperature of April through July of 1988 was lower than that of the normal year (in particular, May and July were the past lowest records), the monthly average temperature of March and in August was higher than that of the normal year (in particular, March had the past highest record) (Fig. M3142).

The humidity shows its highest in May (80%) and its lowest in November (62%) in a normal year. During this study period also, a similar annual trend was observed, however every month was 2 to 5% lower than a normal year.

The amount of rainfall is large from November to April (140 to 190mm) and small from June to September (50 to 100mm) in a normal year. The regional difference of the average monthly amount of rainfall is not so great. However, change from year to year is great, and the regional differences in same year and same month are also large. During this study period, the rainfall in March, June – September and November was less than the normal year and, on the contrary, in April and October was considerably larger than the normal year. The regional differences, are great. This shows a strong localization of rainfall (Fig. M3142).

If the Thiessen method is applied to the records from March 1988 to February 1989 from six rainfall observatories, the average rainfall in the basin is estimated as 1,485mm. As the average rainfall at Asuncion during past 38 years is 1,394mm and that at San Lorenzo during past 24 years is 1,525mm, it can be said that the rainfall during this study period is the annual mean of the normal year.

The daylight hours are about 250 in the summer, December – February, and 170 in the winter, June – August. The regional differences are small but the variation from year to year is comparatively large. The daylight hours observed during this study period at San Bernardino varied almost identically to past seasonal changes in daylight hours.

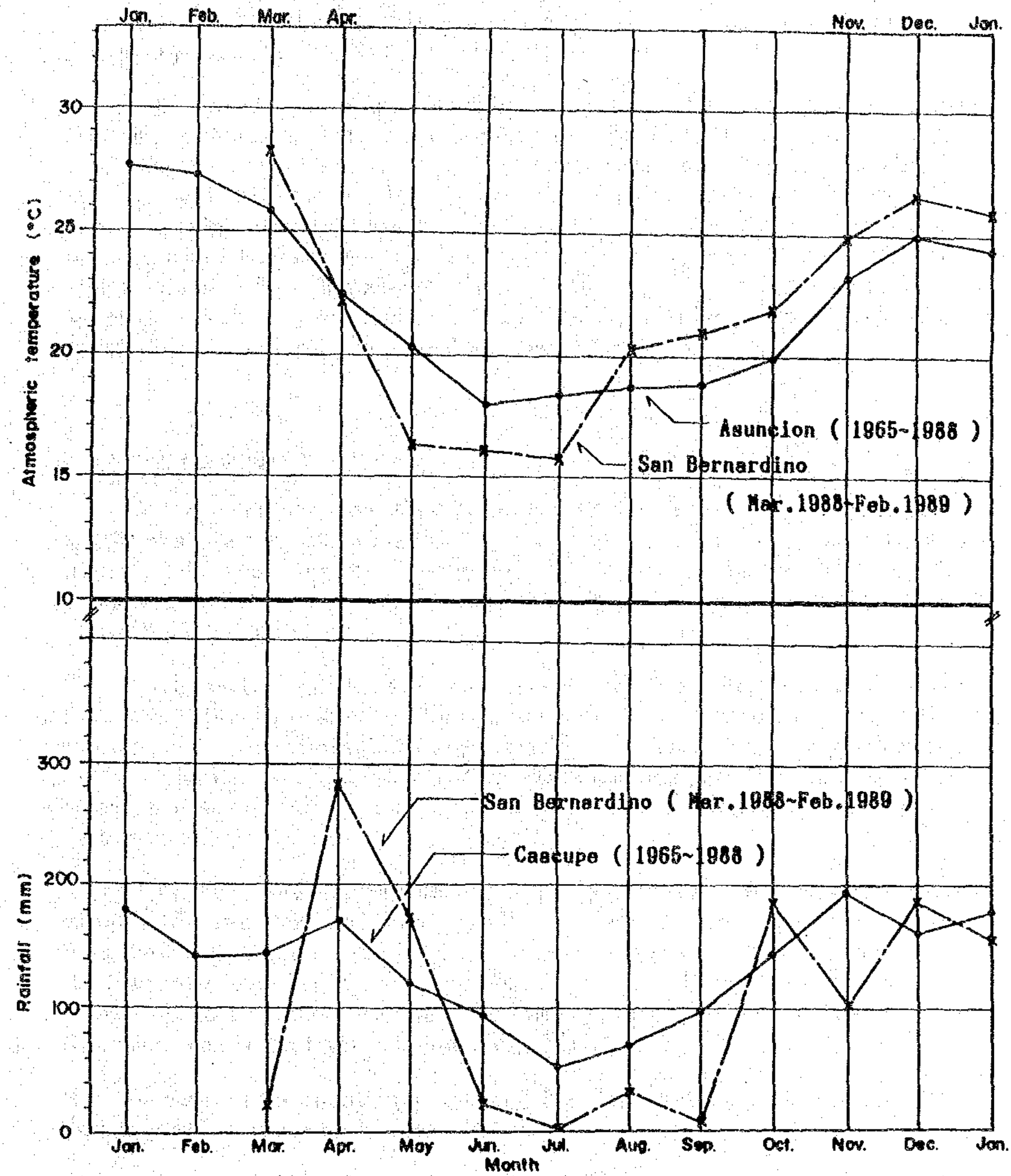

Fig. M3142 Monthly Mean Temperature and Monthly Precipitation

The evaporation is, according to past data (Caacupe), great in September – December at 200mm, and small in April – June at 120mm, and 1,900mm/year, but variation from year to year is large.

The wind state is such, according to past data on Asuncion, that winds from the north-east and south are prominent throughout the year, and that the wind velocity is about 1.7m/s June – November and about 1.4m/s December – May. According to the records on San Bernardino during this study period, the prominent wind directions were east-north-east and south-west-south and clear seasonal characteristics were not recognized. However, the wind velocity was high in winter, July – September, and low in summer, December – January. It seems the observatory location greatly affected the results, as the average wind velocity of San Bernardino shows 70% of that of Asuncion.

3.1.5 Hydrology/Hydraulics

The mean lakewater level obtained in Navy records of the past 20 years is 1.20 m above the datum plane. On the other hand, according to the records from the self-registering water gauge installed at San Bernardino lakeshore for this study, the lake water level during the study period was always 19 to 61 cm higher than that of the mean.

The average lakewater level of every month from 1965 on was calculated from observation records of the Navy and compared with monthly precipitation average, and it was found that the correlation between the lakewater level and the precipitation every month was low. This fact suggests that the lakewater level is not decided only by the inflow amount, but is affected by the status of the Salado egress.

In this study, self-registering water gauges (two locations) and water gauge staffs (two locations) were installed at the lake and rivers. The records from these and the lakewater level record were compared, and it was found that the lakewater level begins to rise almost at the same time, as the inflow river water level goes up, but once risen, the level does not go down easily even after the inflow river water level goes down (Fig. M3151).

It is believed that the aquatic vegetation drifting in floods choke the egress of the Salado and block the outflow of lake water.

The water level fluctuation pattern of the Yagua-Resa-u River and the Yuquyry River are similar. The time lag between the peak rainfall at flooding and the peak river water level is 1.5 to 2 days at the Yagua-Resa-u and 0.5 to 1 day at the Yuquyry; the latter is shorter. This can be considered due to the high ratio of urban area in the Yuquyry basin.

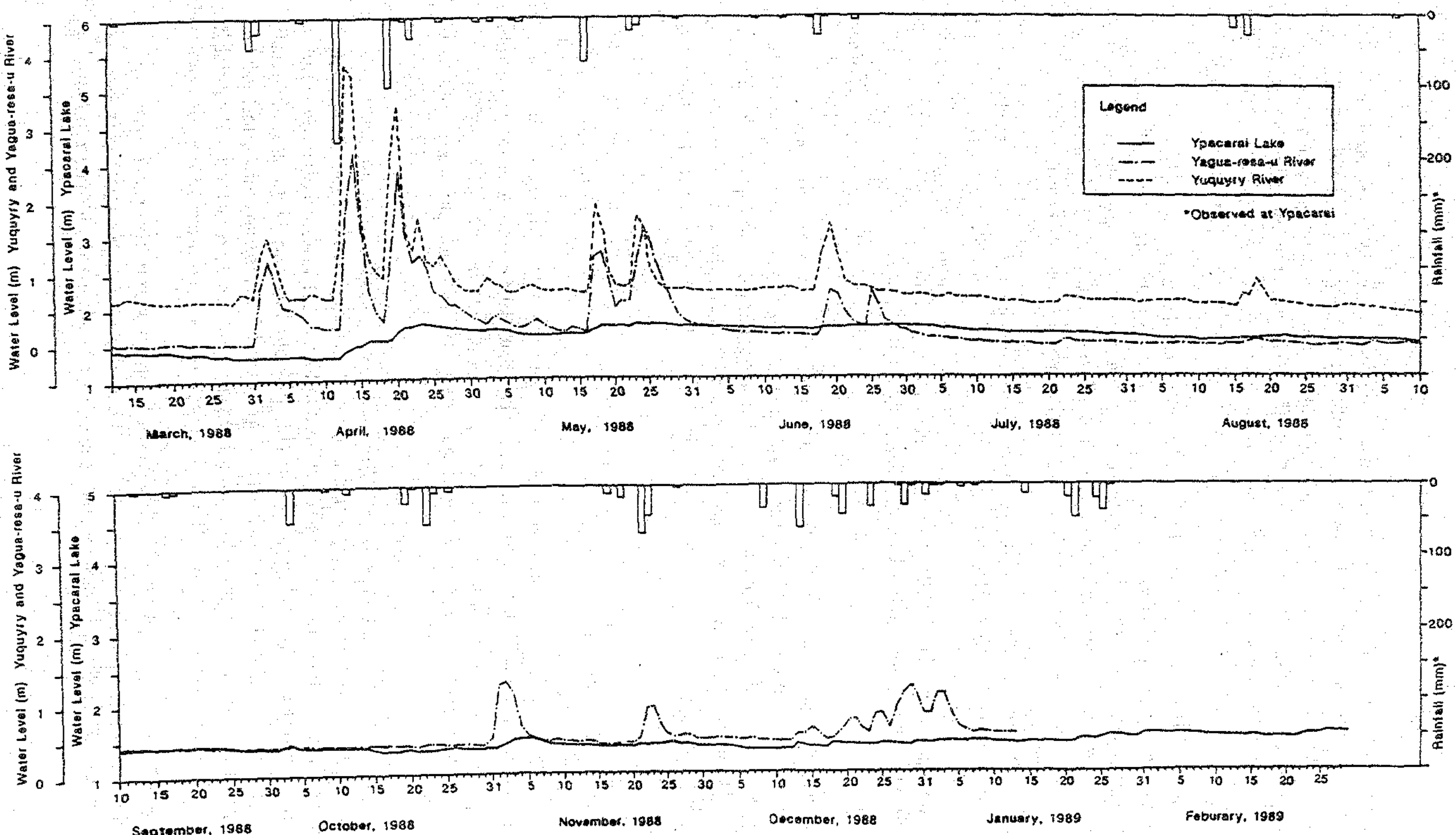

Fig. M3151 Water Level of the Lake and the Rivers during the Study Period

The water level vs. quantity of flow curves (H-Q diagram) are shown in Fig. M3152 for the Pirayu (Yagua-Resa-u River + Y-Pucu River) and the Yuquyry, according to the observation records during this study. From this curve, the formulae $Q=6.76\ (H-0.04)^2$ for the Pirayu River and, $Q=3.76\ (H-0.32)^2$ for the Yuquyry River, were obtained. By these formulae the quantity of flow can be directly calculated from the measured water level value.

Attention is drawn to the heavy rainfall in January 1988, and the subsequent rise in the level of the lake water ; this causing clarity of the water not seen in a normal year. However, accurate data regarding the amount of rainfall and the change in the water level during this period does not exist because the meteorological observation in this study had not yet begun at that time.

This rainfall occured concentratedly during the period of four days from the 13th to the 16th January 1988. Amounts of rainfall recorded were Asuncion 111mm, Caacupe 226mm, and Carapegua 92mm. From the big differences between the districts, a possibility of much more rainfall in the basin cannot be denied, and according to past data from three observatories, this does not seem so unusual.

From Navy records, the lake water level which was 1.68 m before the rainfall, rose rapidly from January 14th, and from the 16th to the 18th it reached the past high of 2.6 m. The reason was that the egress of the Salado was blocked by water plants, and after they were removed on the 20th, the water level went down very quickly.

3.1.6 Vegetation

It is convenient to classify the basin vegetation, by its location and relation to land use, into five categories : mountain forest, riverside forest, palm community, meadow and hydrophyte community. The distribution of mountain forest and riverside forest interpreted on the aerial photos taken in 1988 is shown in Fig. M3161.

The mountain forest is vegetation which develops on the western slopes of the Los Altos mountains and the mountains from Paraguari to Aregua; it includes various kinds of trees and is dense. What is considered natural forest is observed on steep slopes, but most of this is secondary forest. Judging from the distribution, this mountain forest may be the vestige of the forest once spread widely in the basin and transformed into bush due to repeated felling and natural renovation, rather than particular vegetation in the mountain environment.

The riverside forest is vegetation which develops alongside the water course of the Yuquyry, the Pirayu and their tributaries, and is composed of shrub and bush of hygrobic or submersible species. The development of riverside bush is

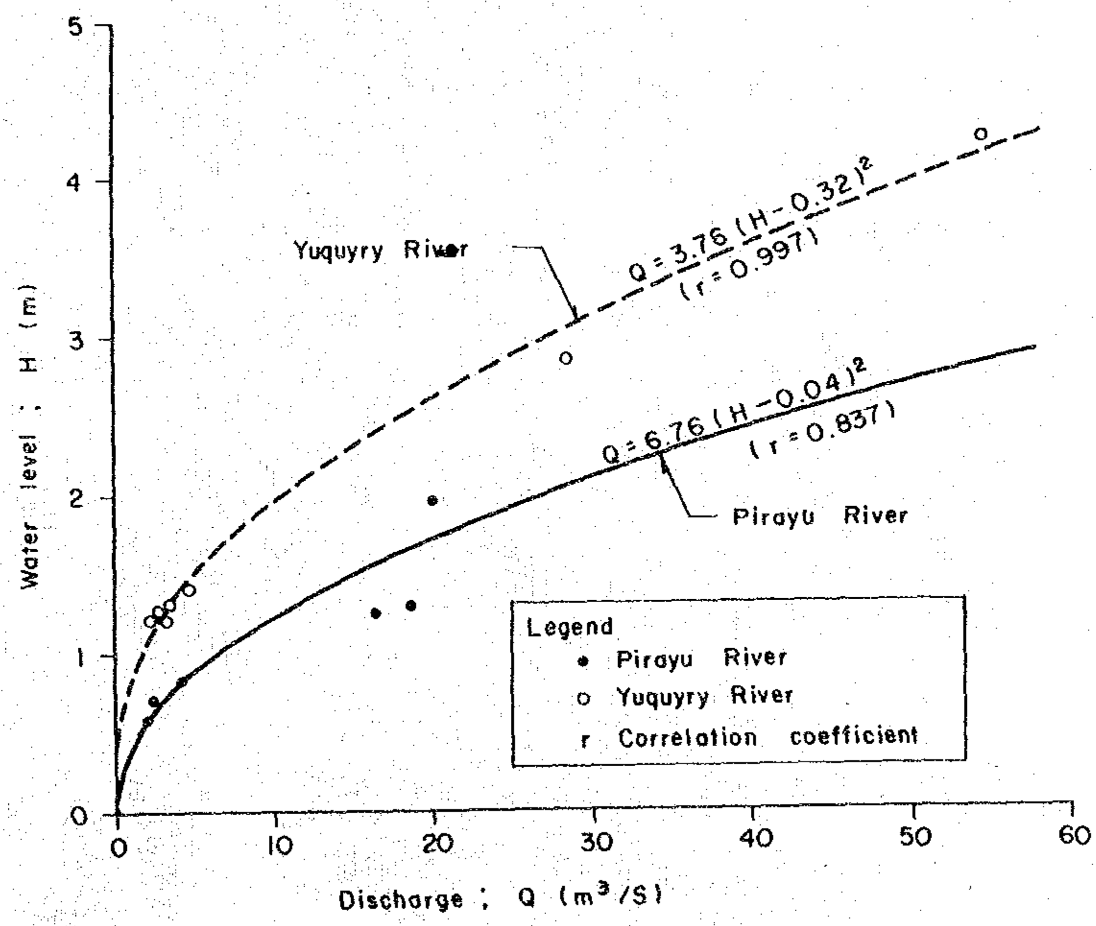

Fig. M3152 **H-Q Curves of Pirayu River and Yuquyry River**

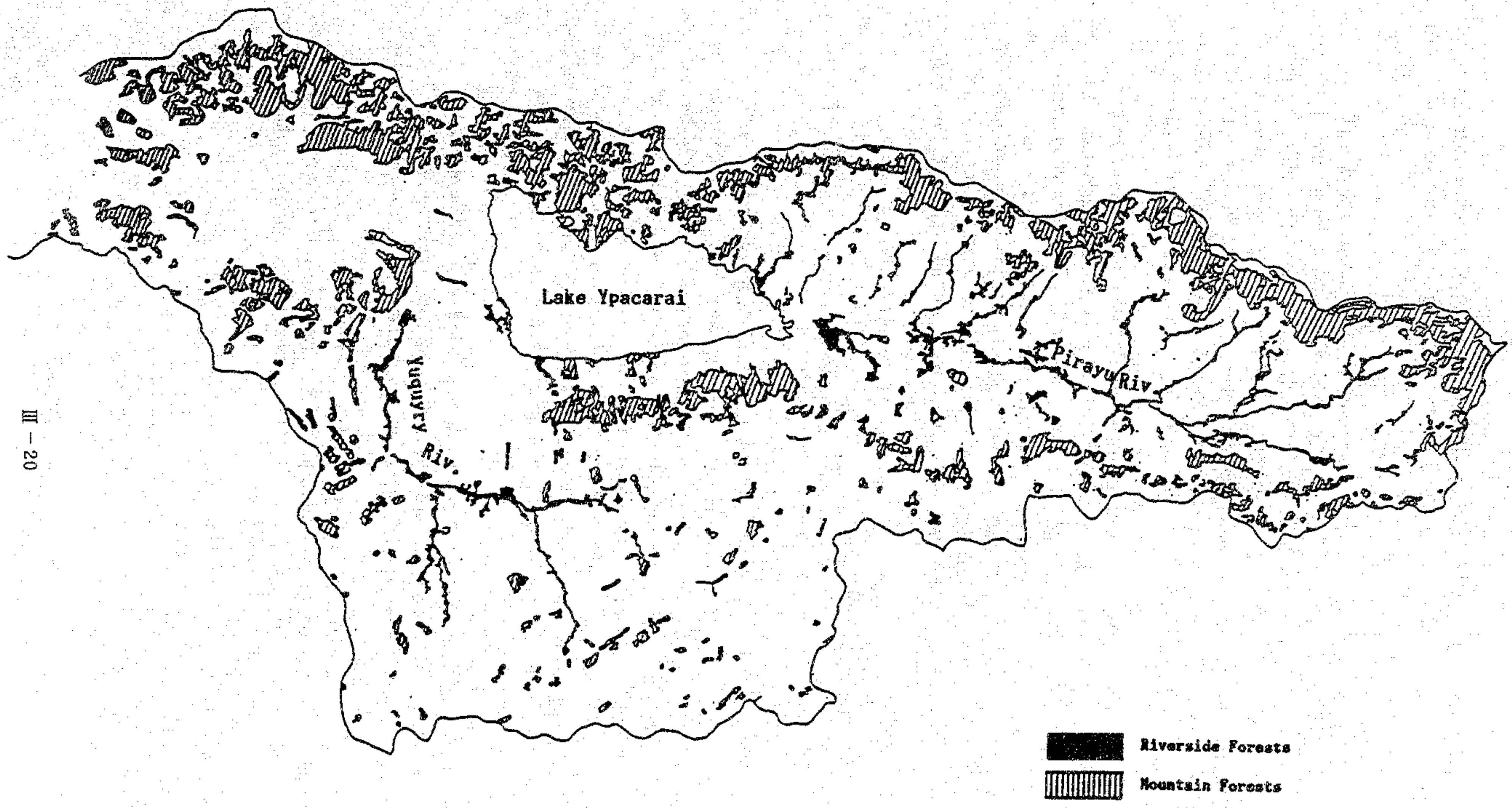

Fig. M3161　　Distribution of Mountain-Forest and Riverside-Forest

reason seems to be that the valley width is narrower at the Yuquyry River and the chance of felling is greater because of the fact that the valley is densely inhabited.

The palm community is vegetation in which palm trees and bush are scattered over meadows. This is principally Karanday palm which grows in clayey soil of low permeability and Paraguay coco palm which grows in sandy soil of high permeability. In Paraguay, the Karanday palm community is widely distributed in the Chaco area, and there also seems to be natural coppice within the study area. The Paraguay coco palm community seems artificial, because it is mixed with the mountain forest and its value in use is very high.

The meadow is vegetation mainly composed of grasses, and classified by the configuration of the land into marsh, low meadow, and flat meadow ; each of which are composed of different species. Marsh is a natural meadow that develops where there is an excess of water and trees have difficulty in growing. The formation process of low meadow and flat meadow is unknown. The meadows have been used as pasture since long ago, and burned and renovated where the grass becomes too tall and/or hard because of insufficient pasturing.

The hydrophyte community develops in and/or around the water, and is found in the vicinity of the Pirayu estuary, in creeks of the lake and in deeper ponds among the many small-scale ponds distributed along the Salado and in the Pirayu lowland.

The hydrophyte distributed in the lakeshore is classified by life style and development place into five groups: emerged plant, floating-leaved plant, submerged-leaved plant, submerged plant and floating plant; all of these five groups are growing together in the northern half of the eastern shore and at the southern end near the estuary of the Pirayu where the effect of wind and waves is not so strong. On the contrary, the hydrophyte community is scarcely observed on the west shore of the lake, where the effects of wind and waves are severe and the topography of the lake bottom is steep dropping to the bottom in 1m at 2 to 3m from the water front.

At the southern part of the eastern shore too, the hydrophyte community does not develop, because, in addition to the fact that the slope of lake bottom is steep and the bottom material is sandy, effects of the south winds are strong.

Among these hydrophyte, the floating plant in particular, floats from the lakeshore by the wind and/or waves, drifts ashore near the egress of the Salado and blocks the lake water outflow.

3.1.7 Aquatic Lives and Ecosystem

The phytoplankton of the Lake shows characteristics of a eutrophic lake, in which the ratio of cyanophyta is high throughout the year (Fig. M3171).

The cell density during the study period was in the order of 10^4 cells/mℓ, and the cyanophyta production determined the total density. The prominent species among cyanophyta changed depending on conditions, such as water temperature.

According to the survey of 1984, ICB concluded that there is little phytoplankton in Lake Ypacarai. Therefore, the state during this study period seems to have resulted from an increase in the lake transparency in January followed by phytoplankton production owing to the existent abundant nutrient salts.

In February and March 1988, water bloom was observed, but changed locations from time to time. It is believed that the cyanophyta contains gas sporangium and gathers near the surface due to its buoyancy and then is affected by the surface current.

The zooplankton is mainly rotifer, cladocera and copepoda, and shows the species composition particular of eutrophic lakes. From the results of visual observation, the existing amount also seems to be large. The ICB survey results also show little zooplankton, but during this study period the zooplankton is thought to have increased as a result of highly phytoplankton production.

The benthos is mainly *Chironomidae* larvae, and was mostly found at the point near north-west shore. The existing amount is 88 to 1,320 No./m^3, and is lower than that of a temperate zone eutrophic lake. The reason for this is unknown.

In this study, 10 new species of fish were caught, which brings the total to 22 families, 45 genera and 50 species, when combining all the records. Judging from the feeding habits of these fish, which are the main component of the lake's high order production, they seem to form a food chain with the hydrophyte community near the lakeshore, and algae clinging to them and to the micro-organisms, crustacean, periwinkle and hydroinsecta.

3.1.8 Succession of the Lake's Natural Environment

It is assumed that the present central lowland was once a continuous lake which was reduced to the present lake through time, from the fact that many small-scale ponds are distributed at the foot of the mountain 80 to 200m above sea level on the Pirayu right bank where a trace of a river course is observed; the gleizationed soil formed underwater (planosol) is distributed widely in the central

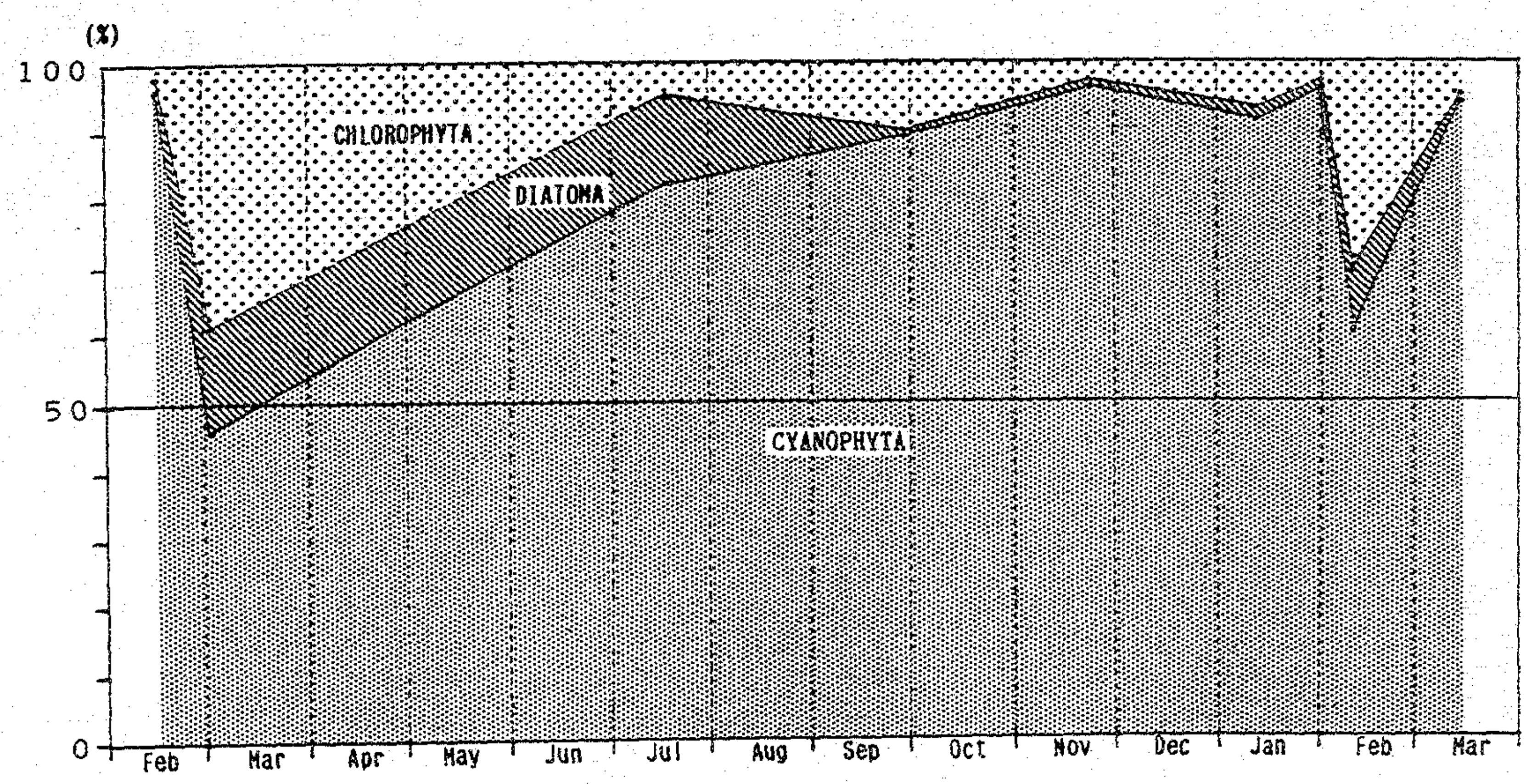

Fig. M3171 Variation of Phytoplankton Species Composition during the Study Period

lowland ; surrounding the marsh, natural grassland, of different vegetation is zonaly distributed in accordance with the topography. The succession of this lake is shown in Fig. M3181.

Ⓐ is Lake Ypacarai at young stage. There is no evidence showing how far back it goes, but it is surely after the Quaternary period, due to the Planosol formation. Judging from the results of geological surveys, the central lowland seems to form a tectonic valley originating from a fault along its western edge. Topographically, it is assumed that this valley was connected with the lowland on the Paraguari side, but then was separated from it by upheaval of the ground.

Ⓑ is Lake Ypacarai at prime stage. As the result of upheaval of surrounding mountains, erosion of rivers was activated and many small scale alluvial fans were formed at the foot of the mountains. It seems that the main stream Yuquyry flowed into the north of the present estuary, and as a result of alluvial fan formation, was bent to the south. This alluvial fan determines the northern edge of the present lake.

Ⓒ is Lake Ypacarai at early old stage. The wide water area spread in the valley of the Pirayu has almost vanished and been transformed to low meadow. The Yuquyry valley is completely transformed into a marsh and clay layer rich in humus was formed.

Ⓓ is Lake Ypacarai at present which corresponds to the middle old age of human life. The water area spread along the Salado has been transformed into marshes, and the lake water area is completely separated from the Paraguay River. It is in between Ⓒ and Ⓓ when humans have started various activities in this basin. The primary forest, spread over the entire basin except for the central lowland, has been rapidly felled and only the secondary forests are left at present in the area as shown in the figure.

Ⓔ is the final stage in life of Lake Ypacarai. The water area is far removed from the present lakeshore and rotten organic substances produce foul odors. How far we postpone this period depends on the degree of environment conservation of the basin.

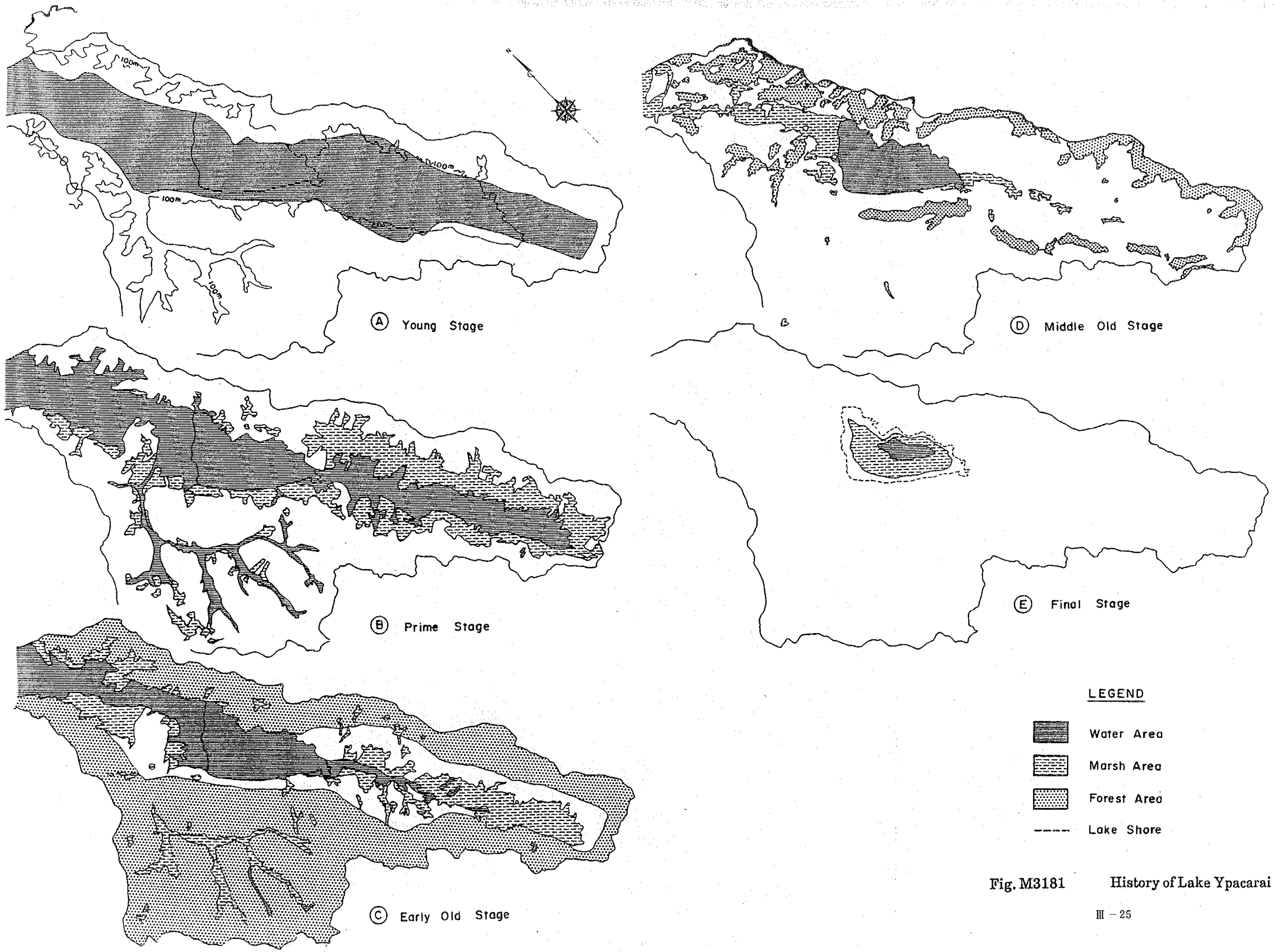

Fig. M3181 History of Lake Ypacarai