REPUBLIC OF PARAGUAY
PRESIDENCIA DE LA REPUBLICA
SECRETARIA TECNICA DE PLANIFICACION

# THE STUDY ON WATER POLLUTION CONTROL PLAN FOR THE LAKE YPACARAI AND ITS BASIN

## VOLUME 4
## SUPPORTING REPORT VI, VII, VIII, IX

AUGUST 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

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# SUPPORTING REPORT VI

# POLLUTION STATUS OF THE LAKE AND ITS MAIN RIVERS

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## ABBREVIATION

| | | |
|---|---|---|
| DO | : | Dissolved Oxygen |
| EC | : | Electric Conductivity |
| SD | : | Secchi Disk Reading |
| Chl-a | : | Chlorophyll-a |
| TCOD | : | Total Chemical Oxygen Demand |
| PCOD | : | Particulate Chemical Oxygen Demand |
| DCOD | : | Dissolved Chemical Oxygen Demand |
| BOD | : | Biochemical Oxygen Demand |
| TP | : | Total Phosphours |
| PP | : | Particulate Phosphours |
| DOP | : | Dissolved Organic Phosphorus |
| DTP | : | Dissolved Total Phosphorus |
| IP | : | Inorganic Phosphorus |
| TN | : | Total Nitrogen |
| TNK | : | Total Nitrogen, Kjeldahl |
| TON | : | Total Organic Nitrogen |
| DON | : | Dissolved Organic Nitrogen |
| DTNK | : | Dissolved Total Nitrogen, Kjeldahl |
| TIN | : | Total Inorganic Nitrogen |
| TR | : | Total Residue |
| LL · TR | : | Ignition Loss of Total Residue |
| SS | : | Suspended Solid |
| IL · SS | : | Ignition Loss of Suspended Solid |

# POLLUTION STATUS OF THE LAKE AND ITS MAIN RIVERS

## CHAPTER I

## INTRODUCTION

Lake Ypacarai water is brown in color and always turbid. The transparency (Secchi Disk Reading) before 1987 is reported to have been 7 ~ 15cm throughout the year (ICB, 1985). It is said that the water color turns black in summer and people suffer skin irritation during bathing.

As the water temperature is high in summer, blue-green algae water bloom appears, giving the water surface a vivid green color.

Many rivers, the main tributaries being the Yuquyry and the Pirayu and flow into Lake Ypararai. Domestic miscellaneous effluents, effluent from butchery, factory effluent, and effluent from farmland and pasture, which are produced in the catchment area, are discharged without treatment into these rivers and finally pass into the lake.

The water quality and flow rate of inflow rivers govern directly the degree of pollution and eutrophication in the lake. High phosphorous or nitrogen content in the river water accelerates phytoplankton production resulting in an increase of internal production in the lake.

The amount of phytoplankton in the lake can be judged from the transparency, tubidity, particulate organic nitrogen and carbon, and amount of chlorophyll. These factors can thus be used to know the degree of eutrophication or the amount of internal production.

The lake bottom is considered a place for the accumulation for the nutrient salts. For a shallow lake, in particular, lake bottom mud contributes greatly to the behavior of the materials in the lake water (e.g., the elution of nutrient salts in bottom mud, increase in turbidity by the stirring of bottom mud, etc.).

SENASA, in 1982, and ICB, in 1983 and 1984, undertook, respectively, the survey on the inflow rivers and the lake.

This study was made from Feb. 1988 to Mar. 1989 on the inflow rivers and the lake (including the swamp for which a purification effect is expected), concerning the monthly variation of the water quality, for the purpose of obtaining fundamental knowledge necessary to clarify the pollution mechanism in the lake. The result of this study is summarized in the subsequent pages.

# CHAPTER II

# WATER QUALITY OF THE RIVERS

## 2.1 Materials and Methods

### 2.1.1 Sampling Stations and Dates

1) Sampling stations and dates

Regular sampling stations include Y6 and Y7 along Yuquyry River, P11 along Yagua-Resa-u River, and P12 along Ypucu River (Fig. S6.2.1).

Sampling at Y6 was started in June, 1988.

Table S6.2.1 shows the sampling dates and meteorological conditions.

2) Sampling on small rivers flowing into the three rivers

Sampling stations for both surveys are shown in Fig. S6.2.1.

Survey on the water quality of small rivers of the Yuquyry water system was made in July. 1, 1988.

Survey on the water quality of small rivers of the Pirayu water system was made in July. 5, 1988.

3) Sampling on the days after rainfall

Survey on the water quality of rivers on the days after rainfall was made from Oct. 31 to Nov. 3, 1988.

Sampling stations are the regular stations: Y7, P11 and P12.

The sampled water each time was frozen and stored at -20°C, and all sampled water was analyzed simultaneously by the regular methods.

### 2.1.2 Analytical Method, Observation Items and Analysis

1) Field observation

Items for measurement in field observation were the transparency, temperature, EC, DO, pH, water velocity, and flowing water volume.

The equipment used was a portable type with long cord (US Series, Central Kagaku).

2) Items for water quality analysis

Items of water quality analysis in the laboratory are listed below: TP, DTP, $PO_4$-P, TNK, DTNK, $NH_4$-N, $NO_3$-N, TCOD, DCOD, BOD, TR, IL of TR, SS, IL of SS, $Cl^-$, TFe, Alkalinity, Fecal coliform bacteria, POC, PON, Diameter of particles.

Note that analyses were not always made on all of these items.

3) Handling of samplings and the analytical methods

The sampled water for analysis was stored and maintained at low temperature in an ice-packed box and brought back to the laboratory.

A GF/C glass fiber filter (1μm pore) was used for filtration. Any residue on the filter was handled as particulate forms while in the fltered water as dissolved forms.

A small quantity of acid was added to the raw or filtered water when it was stored in refrigerator. When the water was to be stored over a long period, it was frozen.

The analytical method was mainly based on the "Standard Methods for the Examination of Water and Waste Water".

For PON and POC analysis, the filtered paper was dried and brought back to Japan for analysis with a CN analyzer.

A small quantity of formaldehyde was added the water for diameter measurement of particles sampled on the same date as in the PON and POC analysis, and measured with a coulter counter in Japan.

Certain calculations were made using following equations:

$$PP = TP - DTP \qquad DOP = DTP - PO_4\text{-}P$$
$$TN = TNK + NO_3\text{-}N \qquad TON = TNK - DTNK$$
$$DON = DTNK - NH_4\text{-}N \qquad PCOD = TCOD - DCOD$$

## 2.2 Results and Discussions

### 2.2.1 Water Quality of the Yuquyry River

1) Field observation record

The Yuquyry River is usually turbid and brown in color.

The color turns to red-brown when the inflowing volume increases, indicating an increase in the inflowing sand.

In this river, DO is low at all times and its saturation degree is at an average of 48%, indicating existence of large quantity of organic pollutants.

Another feature of this river is an extremely high EC.
During rainfall, in particular, a high EC was observed (April. 13, 1988).

EC at Y6 downstream of Y7 is slightly higher than that at Y7, but its variation pattern is similar to that at Y7 (Figs. S6.2.2 ~ 6 ).

2) Phosphorus

TP:
The Concentration varies greatly from month to month, (195 ~ 1,090μg/ℓ), regardless of the season and rainfall.

$PO_4$-P:
The $PO_4$-P concentration is high, at about 50% of the TP.
The variation pattern is similar to that of the TP. (Fig. S6.2.7).
At Y6, the TP concentration is slightly higher than that at Y7, but the $PO_4$-P concentration is nearly equal.

3) Nitrogen

TN:
Nearly constant from summer to winter. But this value varies greatly and is extremely high from spring to summer in the following year (Fig. S6.2.8).

$NH_4$-N:
Generally of high concentration with substantial variation.
$NH_4$-N occupies rather a high percentage (35%) of the TN, alternately with DON.

$NO_3$-N:
Low in concentration. Its percentage of the TN is a maximum 30% and generally below 1/10.
The nitrogen concentration at Y6 is generally higher than that at Y7, but the variation pattern is similar.

4) Chemical oxygen demand (COD)

TCOD is high at an average 32mg/ℓ and tends to show slightly higher concentration when the flow rate increases (April 13 and 19, August 18) (Fig. S6.2.9).

The concentration and variation patterns at Y6 are similar to those at Y7.

5) Biochemical oxygen demand (BOD)

BOD value is low as compared with the concentration of other items. This may be due to a large content of organic materials (nitrogen compounds, etc.) which are not decomposed during the five-day-test period.

There is a butchery upstream of Y7 on Yuquyry River, which discharges effluent without treatment which causes a large inflow of these nitrogen compounds.

BOD value at Y6 is slightly lower than that at Y7.

This may mean that self-purification is in effect between Y7 and Y6 inspite of the existence of the inflow rivers.

6) Suspended solids (SS) and total residue (TR)

SS:
The SS concentration increases with the increased load, after rainfall (Fig. S6.2.10).
The value varies substantially even at normal water level conditions.
The content of particulate organic materials is considered almost constant (53%) when the SS concentration is low.

TR:
Considerably constant value was obtained

The difference between the SS value (dissolved materials) is 73% of the TR and its ratio is extremely high.
The diameter ratio, as measured with a coulter counter, shows 73% for 1μm or less. This result also shows the high ratio of dissolved materials in the water.

The TR value at Y6 is higher than that at Y7, but the lack of monthly difference and IL of TR at Y6 are similar to those at Y7.

7) $Cl^-$

The $Cl^-$ concentration is substantially high (mean: 47mg/ℓ) and varies greatly from 3 to 82 mg/ℓ for the Yuquyry River.

Since the background $Cl^-$ may be estimated at 3 ~ 4mg/ℓ from the $Cl^-$ of inflow rivers, the above-mentioned high concentration indicates inflow of considerable polutants (Fig. S6.2.11).

The concentration at Y6 is slightly higher than that at Y7.

8) Fecal coliform number

This number varies greatly and tends to increase with rising water temperature.

This indicates a considerable inflow of human waste (Fig. S6.2.12).

### 2.2.2 Water Quality of the Yagua Resa-u River

1) Field observation record

The transparency is substantially high throughout the year.
DO is high both in concentration and saturation degree (93%), and inflow of organic pollutants is not considered to be large.
EC is low and tends to decrease further (though small in quantity) on days with a high flow rate (Figs. S6.2.2 ~ 6).

2) Phosphorus

TP:
At an average 91µg/ℓ, with small monthly variation. The value tends to increase after rainfall, indicating a high ratio from non-point sources (April 13). (Fig. S6.2.14)

$PO_4$-P:
Generally low and at 0µg/ℓ on certain days (Sept. 26 and Oct. 24).
The concentration tends to become high after rainfall (April 19), *and its percentage of the TP is about 30%.*

3) Nitrogen

TN:
The concentration varies substantially from month to month (Fig. *S6.2.15). As observed in Apr. 13 and 19, the concentration* increased after rainfall, indicating inflow of the TN from the basin (Fig. S6.2.15).

DON:
High percentage of the TN (ca. 50%)

$NH_4$-N:
Low concentration (0 ~ 224μg/ℓ, meam : 78μg/ℓ)

$NO_3$-N:
Low concentration (20 ~ 554μg/ℓ). The concentration showed a peak value on Apr. 13 after rainfall.

4) COD

TCOD:
Substantial monthly variation ranging at 2 ~ 39mg/ℓ (Fig. S6.2.16), indicating a variation of the inflowing organic pollutants.

DCOD:
0 ~ 31mg/ℓ with substantial variation.

5) BOD

Low in concentration (1 ~ 2.0mg/ℓ). The amount of organic materials which can be decomposed by organisms is extremely small. But, judging from a high ignition loss of TR or COD, there may exist a large quantity of organic materials (nitrogen compounds, etc.) which cannot be decomposed during the five-day BOD-test.

6) SS and TR

SS:
The value was high in April 19, which may be due to a large amount of sand inflow after rainfall (Fig. S6.2.10). SS was low on other days.
Generally, SS showed a small peak after rainfall.

TR:
The value shows small monthly variation, but the values of ignition loss of TR varies.
The particles of size 1 μm or less occupy 80 ~ 90% of TR, which corresponds with the value of 84.3% for the size of 1 μm or less determined by the particle diameter measurement.

7) $Cl^-$

It is normally extremely low in concentration. However, high concentration is sometimes associated with a high TP concentration (Mar. 15) or a high TN concentration and alkalinity (Sep. 26).

8) Fecal coliform number

424-950 No./100mℓ and not such a high variation.

### 2.2.3 Water Quality of the Ypucu River

1) Field observation record

The transparency is generally not high, but is slightly higher in winter.
The saturation degree of DO never exceeds 100% (generally 49 ~ 98%) (Fig. S6.2.3).

The pH tends to lower after rainfall (Apr. 13 and 19) while EC tends to increase when the flow rate is low (Apr. 6, May 4 and Jun. 14, Figs. S6.2.4 ~ 6).

2) Phosphorous

TP:
Increase in TP, possibly due to inflow from non-point sources, is observed after rainfall (Apr. 13).
The concentration in other months was 103 ~ 272μg/ℓ.
The TOP is high when the TP is high.

$PO_4$-P:
$PO_4$-P is low when the TP is high, and high when TP is low.
The average is 84μg/ℓ and its percentage of the TP is around 45%.
The concentration varies from month to month, and inflow of $PO_4$-P is high after rainfall.

3) Nitrogen

TN:
In addition to the peak value found after rainfall, on Apr. 13 and 19, an extremely high value (3,916μg/ℓ) was observed on Sept. 26 (Fig. S6.2.17).
In other months, the values were from 588 to 3,258 μg/ℓ.

TON:
The concentration is high almost constantly and the percentage of the TN is about 75%.

$NH_4$-N:
The value varies greatly from 0 ~ 547μg/ℓ.
The percentage of the TN is extremely low at 10% or less.

$NO_3$-N:
The concentration is almost twice that of $NH_4$-N, but shows no

peak after rainfall.
The percentage of the TN is around 20%.

4) COD

TCOD:
The concentration varies from 5 to 41mg/ℓ.
An effect from rainfall is also visible, as more or less an increase in the concentration (Fig. S6.2.16).

DCOD:
Rainfall causes the high value.
The concentration varies from 0 to 38mg/ℓ.

5) BOD

The concentration ranges 1.0 ~ 6.9mg/ℓ and tends to show the high value in winter.
The ratio to TCOD is low at BOD/TCOD ≒ 1/7.

6) SS and TR

SS:
The value shows substantial monthly variation (8.8 ~ 301.5 mg/ℓ (Fig. S6.2.10).
Though the value reaches a peak after rainfall, it is not so high.
The value was extremely high on Mar. 15, 1988, but the cause is not known because it is at times of normal water level conditions.

TR:
167 ~ 224mg/ℓ.
The percentage of SS to the TR is about 20%.

7) $Cl^-$

The variation of the concentrations is large (3 ~ 54mg/ℓ) (Fig. S6.2.11) and a correlation between Cl- and other water qualities and the flow rate is not observed.

### 2.2.4 Water Quality in the Small Rivers Flowing into the Yuquyry Water System

1) Sampling stations

Yuquyry River has many tributaries and even around the smallest of these, there are human habitations.
Since tributaries are subject to the effect of these human habitations, observation and sampling were made at stations (including stations considered to be less polluted and those already considerably polluted) which were expected to facilitate understanding of the Yuquyry Water System (Fig. S6.2.1, Sts. Y1 ~ Y8).

2) Results

It was observed that DO was extremely low at all stations and EC increased suddenly in the main stream of Yuquyry River.

① Sts. $Y4_1 \sim Y4_3$

There is an oil factory immediately upstream of the station, and this factory discharge effluent make substantial effect.

The value at $Y4_3$ was obtained at a discharge outlet.
The amount of effluent was 2,450$m^3$/day, which was only about 6% of the flow rate of the river water at that time. Though effluent was thus not large, P and N concentrations were extremely high. Consequently, the discharge load rises, indicating that this is a large pollution source.

② Other stations

Except for rivers at St. Y3, other rivers are considered to be polluted.

St. Y3 is located along a small river running through dry fields. It was characteristic for the $NO_3$-N to be slightly high and the ratio of dissolved organic materials to the total dissolved materials to be quite high (84%).

### 2.2.5 Water Quality of the Small Rivers Flowing into the Pirayu Water System

1) Sampling stations

Sampling stations enabling the understanding of the whole of Pirayu water system were chosen (Fig. S6.2.1, Sts. P1 ~ P12).

2) Polluted rivers

St. P1 is located on a small river in a pasture which hardly flows. The DO value was extremely low while that at EC, TP, TN, TR, SS, $Cl^-$, and alkalinity were high, indicating that the river is polluted. P and N were observed mostly in a particulate forms.
The high percentage of SS (65%), when compared with TR and the low ignition loss of SS (23%), indicate there are many inorganic particulate materials.

As for St.4 (Zanjamoroti River), there are two alcohol factories upstream of the sampling points. Because of discharge of untreated effluent, this river is heavily polluted.
The water in this river is a thick black color and has an offensive odor. The analytical results show extremely high $PO_4$-P (559μg/ℓ) and a high nitrogen content. For nitrogen, the DON value is high, but the $NH_4$-N value is extremely low.
Judging from the high TCOD (and particularly DCOD) and high TR (and particularly the ignition loss of TR) when compared with SS, it is known that large quantity of organic materials with fine particles (1 μm or less) are discharged.

3) Other rivers

Results of water quality analysis are considered to indicate that the water at stations P2 (Pirayu River), P3, P5 (Mbatovi River), P6 (Cardena River), and P7 (Paso Vera River) has not been so polluted.

Among the five rivers, Pirayu River is considered rather large with a large flow rate in comparison to other small rivers.

The water quality of the Pirayu water system, as determined from observation results concerning the five rivers and P11 and P12, are shown below.

| DO | | EC | pH | TP | $PO_4$-P | TN | $NH_4$-N | $NO_3$-N |
|---|---|---|---|---|---|---|---|---|
| mg/ℓ | % | μS/cm | | μg/ℓ | | | | |
| 8.9 | 93 | 60 | 6.6 | 77 | 50 | 993 | 44 | 262 |

St. P2 (Pirayu River) has polluted rivers (St. P4) on its upstream side, but self-purification may be in effect down to St. P2.

There was scant human habitation only around St. P3.

The high TN value at St. P3 may be due to the effect of the surrounding human habitation.

The Yagua Resa-u River is not polluted, possibly due to lack of inflow of small rivers.

The values concerning the water quality of Ypucu River are higher than the average, which may be attributed to many inflow rivers and the associated inflow of pollutants exceeding the capacity for self-purification.

In the Pirayu water system, the percentage of non-point sources (dry fields, pasture) is high (Supporting Report V). Inflow of pollutants is expected to increase during seasons with heavy rainfall.

### 2.2.6 Water Quality of the Three Rivers on the Day after Rainfall

Surveys were carried out from Oct. 31 to Nov. 3, 1988 and the precipitation during the period was 93mm.
Observation and sampling were started in about half hour after rainfall.

Figs. S6.2.18 ~ 21 show the above results.
These results on the three rivers may be roughly summarized as follows:

* TON and $NH_4$-N values of the three rivers show no variation during the survey period.

* The $NO_3$-N concentration is extremely high.

* The PP or DOP concentration is high, but the $PO_4$-P value is low.

* The SS concentration is particularly high for the three rivers, which is more than twice that during the normal water level conditions.

Though the concentrations concerning water quality are not high, the flow rate is high after rainfall and thus the load amount increases.
Here, the load amount during the survey period is compared with the load amount on Oct. 24, 1988.

Ratio of Discharge Load after Rainfall to that on Oct. 24 '88

| Times | TP | TN | TCOD | SS |
|---|---|---|---|---|
| Yuquyry R. | 6.9 | 9.2 | 6.3 | 28 |
| Yagua Resa-u R. | 110 | 60 | 28 | 181 |
| Ypucu R. | 21 | 12 | 12 | 38 |

The ratio of load amount in the Yuquyry River after rainfall and that during normal water level conditions is considerably small when compared with the case in the other two rivers. It is supposed that the percentage of non-point sources is low for Yuquyry River, and there is not such a large temporary increase in the inflow load after rainfall.

On the other hand, the above load ratio for Yagua Resa-u River is particularly high, which indicates considerable inflow from non-point sources.

The SS ratio is high for the three rivers comparing this to other ratios. This may be attributed to erosion in the basin.

### 2.2.7 Comparison among the Three Rivers' Water Qualities

1) Comparison of water quality values of the three rivers on clear day

In the Yuquyry River basin, there are more point-pollution sources (factories, urban districts) than non-point sources. It is evident that there is inflow of pollutants into small rivers even during the normal water level period.

The degree of pollution thus caused varies from river to river, but, in any case, there exists a considerable amount of pollutant inflow.

Normally, self-purification is in effect on the downstream side of rivers. For Yuquyry River, however, no results proving an overwhelming self-purification effect have been obtained, even at Y7 (Y6), possibly because of a high level of pollution from small rivers flowing into this river.

Consequently, characteristics of water quality are observed to be of a higher order at St. Y7 and downstream St. Y6 than those on the small rivers.

On the other hand, for the Pirayu water system comprised by Yuquyry Resa-u River and Ypucu River, some of small inflow rivers (Pland P4) are polluted. But self-purification can be seen in effect on the downstream (P2).

Yagua Resa-u River has few inflow rivers and is considered to be less polluted.

But the water quality values at St. P12 of Ypucu River are higher than the average for less-polluted small inflow rivers, indicating that inflow and accumulation of pollutants are under way.

Contrary to the case of the Yuquyry River, the percentage of non-point sources is high in the Pirayu River basin. Accordingly, the amount of inflow pollutants to the river while the water level is normal, is estimated to be smaller than that after rainfall.

Analytical values at the representative stations, Y7, P11, and P12 of Yuquyry River, Yagua Resa-u River, and Ypucu River, including inflow from small rivers, show the following relative trends.

* The DO value at St. Y7 on Yuquyry River is extremely low, which is a reflection of the fact that the amount of organic pollutants here is the largest among the three rivers.
  However, the concentration of other water quality characteristics is the highest among the three rivers.

* The TP concentration is 195 ~ 1,090µg/ℓ at Y7, and 1/5 ~ 1/6 of these values at P11, and about 70% at P12 were found.

* The $PO_4$-P ratio to the TP is highest at 50% at Y7, 30% at P11, and 45% at P12.

* The TN value is high at 1.6 ~ 5.6mg/ℓ at Y7, 1/2 of this level at P11, and around 2/3 at P12.

* The $NH_4$-N value is normally high (35% of the TN) at Y7, which is different from the 10% or less at P11 and P12.

* The $NO_3$-N value is rather low (10% of the TN) at Y7. At P11 $NO_3$-N is 40% of Y7 value, at P12 it is slightly lower than that at Y7. The ratio of $NO_3$-N to the TN at P12 is high at 20% and the ratio of TON to the TN is also high.

* The COD value is 11 ~ 57mg/ℓ at Y7 and increases after rainfall. The value at P11 is 2/3 of the value at Y7 while the value at P12 is slightly higher than that at P11. The effect of rainfall are observed at both stations.

* The BOD values for the three stations are considerably smaller than the amount of organic materials as determined from COD or ignition loss of TR. However, the BOD/COD value is 1/4.6 at Y7, 1/13 at P11, and 1/7 at P12.
  This means that the inflow of COD from point sources is lower in Y. Resa-u River and Ypucu River than in Yuquyry River.

* The SS value is highest at 26.0 ~ 108mg/ℓ at Y7 and may present a high value of 268µg/ℓ after rainfall. At P11, the value is lowest and the rainfall effect at P12 is not so critical. The ignition loss of SS is about 50% for the three rivers and particulate materials occupy about 20% of the total.

* The diameter of particles in river water is the largest (max. 10μm) in Yuquyry River, followed by that in Ypucu River (8μm). The particle diameter is the smallest (5μm) in Yagua Resa-u River.

* The amount of flowing water is the largest in Yuquyry River and so is the load amount.
The examples of load amount at the three stations are calculated below for the normal water level.

Table Comparison among Discharge Load of the Three Rivers on a Clear Day

Sep. 26 '88

| | TN | $NH_4$-N+$NO_3$-N | TP | $PO_4$-P | TCOD | SS |
|---|---|---|---|---|---|---|
| | kg/day | | | | | |
| Y7 | 630.2 | 471.3 | 84.6 | 61.5 | 1,473 | 5,022 |
| P11 | 80.8 | 43.1 | 2.4 | 0 | 91 | 1,772 |
| P12 | 111.7 | 21.0 | 7.1 | 2.9 | 627 | 1,334 |

The above ratio is not always obtained because of variation in the flow rate and the concentration of water quality, even at times of normal water level. In particular, the N concentration was high on Sep. 26, 1988 and the $NH_4$-N value was extremely high at Y7 on the date. Accordingly, the load amount of nitrogen at Y7 was high.

The concentrations concerning the water quality at P11 are normally lower than those at P12, but the load amount at the former point is occasionally higher than at the latter point because of a high flow rate.

The total load amount at P11 and P12 flows into the lake, however, the inflow load from Yuquyry River is considerably larger than the total of the other two rivers. This means there is a larger contribution from the Yuquryr River in to the lake as a pollutant carrier.

2) Comparison of discharge load of the three rivers after rainfall

The discharge loads of the three rivers after rainfall are compared here.

Calculation based on the tables in sections 2.2.6 and 2.2.7, leads to the following results.

Table Comparison of Discharge Loads of the Three Rivers after Rainfall

| | TN | TP | TCOD | SS |
|---|---|---|---|---|
| | ×$10^3$kg/day | | | |
| Y7 | 5.8 | 0.6 | 9.3 | 140.6 |
| P11 | 4.8 | 0.3 | 2.5 | 320.7 |
| P12 | 1.3 | 0.15 | 7.5 | 50.7 |

The values shown above were calculated on the basis of the load amount for the normal water level on Sep. 26 and on the load ratio after rainfall to that for the normal water level.

During times of normal water level, the load amount of Yuquyry River was extremely large concerning on the items. The inflow load from non-point sources after rainfall, being large for Yagua Resa-u River and Ypucu River may be responsible for obtaining the above result.

Remarkable increase in the load amount from non-point sources was observed after rainfall in Yagua Resa-u River.
Increase in TP load is particularly great, which was about 1/35 of the level at Y7 on a clear day, and was 1/2 of that at Y7 after rainfall.

It is not clear such increase occurs at all times, and such increase is considered to vary depending on the precipitation.
The precipitation was 93mm on Oct. 31, but such precipitation is observed quite frequently in Paraguay. In such an event, the load amount to the lake from Yuquyry River is nearly equal to that from Pirayu River. In particular, the SS inflow load amount is extremely large from Pirayu River.

## 2.3 Comparison with the Past Data

Table Water Quality of Yuquyry River Analyzed by SENASA

| mg/ℓ | Y6 | | Y7 | | |
|---|---|---|---|---|---|
| | May 7, '82 | Sep. 7, '82 | Mar. 9, '82 | May 7, '82 | Sep. 7, '82 |
| $NO_3$-N | 0.53 | 3.13 | 0.43 | 1.07 | 3.62 |
| $NH_4$-N | 0.75 | 1.33 | 0.32 | — | 0.98 |
| $PO_4$-P | 0.20 | 0.24 | — | 0.30 | 0.28 |
| BOD | 16 | 8.82 | — | 16 | 1.74 |
| TR | — | 609 | 422 | — | 541 |

The table above shows the result of analysis performed by SENASA at stations Y6 and Y7 in 1982.

When compared with data in 1988, the above result shows that the $NO_3$-N concentration is higher than that of $NH_4$-N and that the TIN concentration, in 1982, is as high as that in 1988.

The $PO_4$-P concentration is slightly higher in 1988 than in 1982.

Both BOD and TR concentrations are higher in 1982.

Judging from data, though limited, inflow of human waste into Yuquyry River is larger in 1988, (as is evident from the increase in $NH_4$-N) this may be possibly due to growth of the population in the basin. On the whole, however, the degree of pollution has not changed and this fact may indicate that Yuquyry River has been heavily polluted for many years.

Similar comparisons of water qualities with past data are made for Ypucu River and Yagua Resa-u River.

| mg/ℓ | P11 | | | P12 | | |
|---|---|---|---|---|---|---|
| | Oct. 6, '81 | Apr. 23, '82 | Sep. 9, '82 | Oct. 6, '81 | Apr. 23, '82 | Sep. 9, '82 |
| $NO_3$-N | 0.03 | 0.23 | 0.21 | 0.39 | 0.26 | 0.38 |
| $NH_4$-N | 0.07 | 0.07 | 0.05 | 0.29 | 0.16 | 0.09 |
| $PO_4$-P | 0.24 | 0.04 | 0.07 | 0.23 | 0.04 | 0.03 |
| BOD | — | 1.06 | 7.33 | — | — | 9.75 |
| TR | 273 | 142 | 186 | 265 | 146 | 156 |

For the Yagua Resa-u River, the TIN values are nearly at the same level in 1981, 1982 and 1988. $PO_4$-P concentrations in 1981 and 1982 are higher, and BOD and TR concentrations in 1981 and 1982 are slightly higher than those in 1988.

In the case of Ypucu River, $PO_4$-P, $NO_3$-N, and $NH_4$-N concentrations are slightly higher in 1988 than in 1981 and 1982. The BOD value is slightly higher in 1982 while the TR is nearly at the same level for the three years.

Though comparison of the degree of pollution cannot be based solely on the concentration, and such degree should be in any case, considered as a gross quantity including the flow rate, low precipitation in consecutive months in 1982 and 1988 may lead to an assumption that Ypucu River was slightly more polluted in 1988 than in 1982.

# CHAPTER III

# SEDIMENT OF THE RIVERS

## 3.1 Materials and Methods

The surface sediment was sampled at regular stations (Y6, Y7, P11, and P12) on the three rivers and at P2 on Pirayu River on Jul. 9, 1988 for measurement and analysis (See Fig. S6.2.1).

Organic carbon and organic nitrogen were analyzed with a CN analyzer after the dried samples were brought back to Japan.

For the grain diameter measurement, the dried samples were brought back to Japan and measurement was made by means of wet screening and a coulter counter.

## 3.2 Results and Discussions

### 3.2.1 Grain Diameter of the sediment in the Three Rivers

Table S6.3.1 shows the grain diameter of sediment and its ratio, and Fig. S6.3.1 shows the size distribution.

The sediment is sandy in the three rivers and shows no specific difference in appearance.

The diameter of sediment of Yuquyry River ranges at considerably larger sizes than that of other two rivers. This may be due to the difference in production of the bottom materials.

That is to say, the grain size of phenocryst in the parent rock on the upstream of Yuqury River is smaller than that of Pirayu River. But , the parent rock of Yuqury river is more friable than that of Pirayu River, thus the phenocryst of Yuqury River flows down to the lake together with smaller-sized matrix which are a component of the parent rock.

On the other hand, though the grain size of phenocryst of Pirayu River is larger than that of Yuqury River, only the smaller-sized matrix in this river flows down to the lake and phenocryst is left upstream.

In this sense, the distribution range of diameter in Yuqury River is wider than that in Pirayu River.

### 3.2.2 Physical and Chemical Characteristics of Sediment

Table S6.3.2 shows physical and chemical characteristics of sediment.

Characteristics found at P2 of Pirayu River differ greatly from those found at the four other stations. In other words, at P2, the density is small, while the ignition loss and C, N, and water contents are high. In other words, the sediment at this station is less sandy.

The sediment at the four other stations differs in diameter, but is quite similar in physical and chemical characteristics.

Though a considerable amount of organic materials flows into the lake from the three rivers, the organic content in sediment is small. It is considered that inflow organic materials are washed downstream without settling, precipitation, and adsorption by sediment.

# CHAPTER IV

# WATER QUALITY IN LAKE YPACARAI

## 4.1 Materials and Methods

### 4.1.1 Sampling Stations and Dates

1) Sampling stations

Fig. S6.4.1 shows the sampling stations in the lake. Field observation and sampling for water quality analysis were made at each station. Though observation and water sampling were not made at every station every day, we attempted to concentrate observation and water sampling at St.0 and St.4 which are considered to be representative inflow points of Pirayu River, at St.25, St.49, and St.57 in the middle of the lake, at Yuquyry Boca and Riacho Negro at the inflow of Yuquyry River, and at Salado Boca at the outlet.

2) Dates

The survey was started on Feb. 16, 1988, and was carried out approximately once a month up to Mar. 14, 1989. Table S6.4.1 shows the observation dates and meteorological conditions of the surveying days.

### 4.1.2 Analytical Methods, Observation items and Analysis

1) Field observation

Observation items at each station are the depth, transparency, Secchi Disk Reading, temperature, pH, DO, EC, and color.

The temperature, pH, DO, and EC were measured in the surface and the bottom (about 10 cm above the lake bottom) layers.

Measurements on the turbidity and underwater light intensity were also made several times.

The equipment used for observation of the rivers (portable US Series, Central Kagaku) was used also for observation of the lake. The water for water quality analysis was sampled from the surface layer, and also from the bottom layer, using a Van Dohrn sampler as required.

The methods to transport, stock, and filter the sampled water are the same as those for the river water.

2) Analytical items

Items for water quality analysis are the same as those for river water, with the additional measurement of Chl-a concentration.

The analytical method is also the same as that for river water.

PON and POC of the surface water sampled at Sts.4, 25, and 49 on Jul. 8, 1988, were analyzed with a CN analyzer in Japan.

Surface water particle diameters and ratios, sampled on the same date as the PON and POC sampling at Sts.0, 4, 25, and 49 and at Yuquyry Boca were analyzed with a coulter counter in Japan.

## 4.2 Results and Discussions

### 4.2.1 Horizontal Distribution of EC Values

The EC value each month at Sts.4, 25, 49, and 57 (considered representative of the lake), is shown in Table S6.4.2. Though the value varies from month to month at each station, the monthly variation pattern appears similar.

It is evident that the Pirayu River water with a low EC value, is present at the surface layer at St.4 (Jun. 21 and Jan. 10). On the other hand, the high EC value of Yuquyry River is often visible at the bottom layer at St.49.

Apart from the months when the effect of both rivers are apparent, the number of months with minimum values is large at St.4 while that with maximum values at St.49. As regards the EC value at both stations, there is no significant difference between surface and bottom layers (95% probability). The EC in the lake is considered to be kept nearly uniform through advection and diffusion.

The EC distributions in the surface layer in March and December are shown as an example (Figs. S6.4.2. and 3).

### 4.2.2 Vertical Distributions of Selected Items of Water Quality

1) EC and $Cl^-$ at the surface and the bottom layers

Lake Ypacarai is extremely shallow (average 2.0 m) and surface and bottom layers are mixed with each other by wind. As a result, the difference in physical characteristics is small between surface and bottom layers.

The degree of vertical mixing as determined from the EC ratio between surface and bottom layers is described below.

The EC value is slightly higher in the bottom layer than in the surface layer, but the difference is negligible.

*Table* *Mixing Degree of Water on the Surface and the Bottom Showed by EC in the Lake*

| St. | *EC (μS/cm) |
|---|---|
| 4 | 1.00±0.03 |
| 25 | 0.99±0.02 |
| 49 | 0.98±0.02 |
| 57 | 1.00±0.01 |

* Mean value for Apr. 20 '88 ~ Mar. 3 '89
* Surface value /Bottom value

The vertical distribution of $Cl^-$ determined similarly is 1.02±0.22 (0.67 ~ 2.08), thus, Lake Ypacarai presents good vertical mixing.

2) Vertical distribution of other elements

The vertical distribution of some elements in the lake water in the summer of 1989 is shown in Figs. S6.6.4 ~ 6.

The water temperature of the surface layer frequently exceeds 30°C in the summer and , in this event, a layer 25 ~ 50 cm below the surface of the water may often show a temperature of 2 ~ 3 °C or lower. However, this difference in temperature does not last for long (Figs. S6.6.4-A and S6.6.5-A, F).

For a shallow lake sucha as the Ypacarai, there exist no thermoclines even in the summer.

The vertical profiles of DO and pH, which is closely related to the bioproductivity in the water, show a difference in the DO and the pH between the surface and the bottom layers as a result of rapid phytoplankton production in the summer, particularly in the surface layer.

Besides this, DO at the bottom layer is consumed by decomposition of organic materials, thus the DO difference between surface and bottom layers is also found, in particular in the high temperature condition.

In February and March, 1989, waterbloom appeared in the southern part of the lake. As shown in Fig. S6.4.4-B, C the difference in DO and pH between surface and bottom layers at St.4 is larger than that at St.25 and St.49.

In February and March, 1989, there existed almost no vertical difference in all elements in places other than the one with the bloom. The vertical distribution of biological elements is also uniform (Fig. S6.4.5-B, C).

But, the Chl-a concentration of the surface layer is extremely high at St.0 and St.4, with corresponding vertical distributions of DO and pH (Fig. S6.6.5-G, H). Fig. S6.6.6-A, B shows the same trend.

The strong effect of river water is occasionally exerted on the vertical profile (Fig. S6.4.6-D, E, F-St.4).

St.4 sometimes shows characteristics reflecting the effect of the inflow of the Pirayu River, as is known from the information of the temperature, pH, and EC on March 14, 1989.

### 4.2.3 Data Handling Methods

As described in 1) and 2), the lake is handled as one water area, with a thorough mixture of surface and bottom layers. The average of the values of the surface layer at various stations was used here, is the same as the daily average for the lake.

However, St.0 which is an inflow point of Pirayu River, was not included in the average. For St.4 and St.52, the values obtained there were not included when the effects of Pirayu River and Yuquyry River were apparent.

### 4.2.4 Comparison among Water Quality of the Lake, its Inflowing and Outflowing Rivers

Wide swamps exist in the south and north of Lake Ypacarai, and Yuquyry River and Pirayu River flow through the swamps into the lake. In particular, the swamp through which Yuquyry River flows is large, and the river water spreads over the swamp and branches into small rivers to flow into the lake. Principal small rivers include mainly Riacho Negro and Rio Colorado. Both these rivers show nearly similar flow rate and level of water quality.

Ypucu River and Yagua Resa-u River merge within the swamp to form a wide inflow area.

1) Purification effect

At present, Yuquyry River, Ypucu River, and Yagua Resa-u River are heavily polluted, with high concentrations of TN, TP, or COD. The pollution of Yuquyry River is particularly remarkable. Since these concentrations are rather lower at the estuery than at the upstream, it is evident that the river waters are purified while passing through the swamps.

The velocity of river water slows down rapidly as it passed through the swamp and is considered to be purified as follows:

① SS and turbidity

Adhesion to root hair, filtration with hydrophyte, and settling.

② Organic materials

Decomposition and purification caused by microorganisms around hydrophyte.

③ Purification of N

Denitrification and gasification of $NO_3$-N.

④ Purification of P

Removal mainly of particulate P through actions similar to those for SS and turbidity.

Figs. S6.4.7 ~ 17 show some chemical characteristics of the rivers, at the inflow and outflow points, and in the lake.

To obtain the definite purification rate, the survey considering the retention time of river water in the swamp area will be necessary.

The purification rate is different at the normal water level from that after rainfall.

The effect of river water on the lake water and the relationship between the inflow and the lake water quality characteristics are discussed here through comparison of river water, inflow water, and the lake's interior characteristics.

2) Relationship of quality characteristics among the river, the inflow and the lake waters

The above relationship is summarized below.

① The difference of water quality characteristics between river and inflow waters on each item is equivalent to the amount purified within the swamp.

The purification effect is estimated to be higher in the Yuquyry swamp than in the Pirayu swamp.

② Both swamps' ability to purify varies (not constant) on clear days and on days after rainfall.

③ The inflow values of $NH_4$-N, SS, TP, and $PO_4$-P are normally low.

④ The TN value differs substantially between the river water and the inflow water.

⑤ The difference in TN between the lake water and the inflow water may be attributed to phytoplankton production in the lake.

⑥ As regards $NO_3$-N, the inflow value varies due to purification and denitrification; and in the lake it varies due to oxidation from $NH_4$-N and utilization by phytoplankton.
The difference of $NO_3$-N, therefore, between inflow and lake waters is not constant.

⑦ The $PO_4$-P concentration of the lake water is substantially lower than the inflow value. This is due to the utilization of phytoplankton and elimination through absorption and settling from the lake water. As a result, the TP value in the lake water is lower than that of the inflow value in spite of production in the lake.

⑧ TCOD and DCOD flow into the lake almost without purification, and the DCOD of inflowing water is nearly equal to the lake water value.
This is so because decomposition of DCOD is slow, resulting in its continued stay in the lake's water. It is considered, on the other hand, that the TCOD concentration is higher in the lake water than in the inflowing water because of production in the lake.

⑨ SS is removed in an extremely high percentage. Though the inflow value slightly increases after rainfall, particles exceeding 1μm are mostly removed in the swamp.

The above description applies to the year 1988. Almost all of inflow values (TN, TP, etc.) increased after January, 1989 and these values were equivalent to or more than the average in the lake.

In 1988, the purification effect was considerable regardless of the precipitation, or river water quality values. It is presumed, however, that the purification capacity of the swamp was not infinite and the inflow load from the river exceeded this capcity in the beginning of 1989, resulting in deterioration of the effect and inflow of high concentration of pollutants.

As will be described later (4.2.6 - 6), inflow of organic materials of 1μm or less increased in 1989, and, as a result, the main substance of pollution in the lake in 1989 is presumed to have been changed from that in 1988.

### 4.2.5 Monthly Variations of the Field Observation Records of the Lake

1) Secchi Disk Reading (SD)

SD shows a considerably wide horizontal range even on the same sampling dates (Tables S6.4.3, S6.4.4 (1)-(15)). When each station shows lower SD value, (as in Apr. and Oct. 1988, and Feb. and Mar. 1989) than other months, SD are within narrower ranges than druing other months.

The mean SD value of each month varies from 18 to 81 cm during this survey period (Figs. S6.4.18 and 19). The months Apr. and Oct. 1988 and Feb. and Mar. 1989 show a lower mean SD than other months. In particular, in Oct., the mean SD was extremely low at 18cm.

The correlation between the SD and Ch1-a is not so high ($\gamma = -0.55$, see 4.2.7-1) in this lake, indicating that SD is not dependent solely on the amount of phytoplankton. In 1988, however, SD is considered to have been dependent mainly on phytoplankton (see 4.2.7-9) with several exceptions.

Compared to the average SD of 39~81cm, the SD on Oct. 27 was low at 18cm. In this case, the SD has been offset to the lower left of the correlation curve; and was extremely low for the Ch1-a amount. Such a situation may have been caused principally by sediments: the stirring of sediments by strong wind for three days before Oct. 27 caused darkening of the water color and the high mixing rate of sediments into SS lowered the ignition loss of SS below the level of other days.

SD in Feb. and Mar. 1989 were 25cm and 23cm. A similar shift to the lower left of the SD-Ch1-a curve was shown in these months. And since the ignition loss of SS was low, the sediment mixing ratio was also low; and the percentage of particles less than 1μm in size was extremely high in these months. The low SD may not be due to the amount of phytoplankton or residual bottom mud. Rather, the dark water color caused by the inflow of difficult-to-be-decomposed dissolved organic materials is considered responsible for the decrease in the SD.

2) Water temperature

The temperature of the surface water of the lake corresponds well with the air temperature, and its seasonal fluctuation ranges from 15.3 to 32.0°C (Figs. S6.4.21).

For the period from January to September when the water temperature is low, the Chl-a amount is also low. This indicates that the production activity of phytoplankton is inactive.

The vertical distribution of water temperature in the summer of 1989 shows almost no difference between the upper and the lower layers. This occurs due to the constant mixing of the upper and the lower water layers in the shallowness of the lake. Thermocline, therefore, is not found even in the summer (Figs. S6.4.4~6).

3) DO

The mean DO on the surface was very high in 1988, although on the first four sampling dates there were wide horizontal ranges.

In winter, DO were hardly lower than in summer.

The staturation degree of the mean DO was always over 100% until Dec. 1988. The value dropped to 7.3 mg/ℓ (96%) in Jan. 1989, then it decreased gradually to 6.3 mg/ℓ (82%) in Mar. 1989.

DO on the bottom layer were always, at all the stations, quite lower than at the surface, and only on a few occasions they were saturated.

The mean DO, although low as stated above, are higher than 4.5 mg/ℓ (58%) and, thus, even on the bottom of the lake there is no case of complete anaerobic conditions.

The DO variation pattern was similar to the monthly variation of Ch1-a in the surface layer. The DO concentration was low for a period from January to September when the Ch1-a concentration was low (Figs. S6.4.7~9).

In 1989, however, the DO concentration was considerably low (and thus not saturated) in spite of the Ch1-a concentration which was more than equal to that of winter.

The SS content of water in this case was high , but SS is considered to consist of organic materials other than phytoplankton (see Art.

4.2.7-9). The low DO concentration in these months may be due to the DO consumption for decomposition of organic materials which was larger than the DO production through photosynthesis, as is known from extremely high TR, prevailing particles of 1μm or less, high ignition loss, and high DON and DOP concentrations.

The difference in the DO concentration between surface and bottom layers was occasionally extremely large. Such increased difference is attributed to a fact that the movement of plankton was not always in line with the water flow and moreover rapid photosynthesis occurred in the surface layer.

Actually the Ch1-a concentration of the surface layer was considerably high at the station where the above difference was large, and the difference reduced in winter.

4) pH

The pH in the surface layer shows a considerably high value, and with quite a wide range on the sampling dates from Feb. until Oct.1988 and Jan. 1989 (Figs. S6.4.10 and 11). In particular, pH was higher than 9.0 at all stations with means of 9.4 and 9.6, respectively, on Mar. 2 and 22, 1988.

pH on the bottom layer is slightly lower than on the surface. Only one case in Sept. 1988, however, is found that the mean pH on the bottom is the same as on the surface but it has a higher minimum pH than that on the surface.

It is known that the high pH value of the surface layer from summer to spring in 1988, corresponded well with the high Ch1-a and DO concentrations of the surface layer, as a result of high-level photosynthesis in the surface layer.

The low pH in Feb. and Mar. 1989 is considered to be due to reduction of photosynthetic activity.

5) EC

On a given sampling date, the EC in the lake was horizontally and vertically homogeneous. Accordingly, uniformity of physical characteristics is considered to be high due to thorough advection and diffusion (Figs. S6.4.12 and 13).

The EC value in the lake fluctuates in satisfactory coincidence with the EC value at Yuquyry Boca. Since the EC value at Yuquyry Boca fluctuates under the effect of the EC value of Yuquyry River,