the monthly variation of the EC value in the lake reflects strong influence from the EC value of rivers.

4.2.6 Monthly Variations of Chemical and Biological Characteristics

1) Phosphorous

① TP

The TP concentration tends to be high in summer and low in winter. The concentration in the summer of 1989 was substantially higher than that in the summer of 1988 (Figs. S6.4.14 ~ 16). This may be partially due to the reduction of the purification capacity of the swamp. The factor that is considered more important is the inflow value, which was high in spite of the low TP concentration in the river (resulting in the effect on the TP concentration in the lake), plus elution of PO_4-P from bottom mud along with a rise in temperature.

The TP concentration showed, occasionally an extremely high value, and the reason differs for each case. For instance, the peak on Apr. 20, 1988 may be due to inflow from rivers after considerable precipitation on Apr. 12 and 19. This inference is based on the high TP concentrations that were recorded in inflowing rivers, at Yuquyry Boca and St. O after the rainfall, taking also into account taht the river flow rate was large.

② PP

The TP concentration was high on Oct. 27 and, particularly, the particulate P was extremely high on that date. This was completely different from the case of other months. This exceptionally high PP concentration is considered to be a result of strong wind blowing for two days before the observation date: i. e., the wind stirred up bottom mud, causing PP absorbed and settled at the bottom to return to and remain in the water.

The PP value in sediments of the lake is shown below:

Table PP of Sediment (mg/g. dwt)

	Oct. 27 '88	Mar. 3 '89
St.25	0.618	6.34
St.49	0.480	3.84
Mean	0.549	5.09

The difference in PP between Oct. 27, 1988 and Mar. 3,1989 may be equivalent to the amount of bottom mud stirred and returned to the water.

The PP concentrations were also high when the Chl-a concentrations were relatively high (Feb. 16, Apr. 20, and Oct. 27, 1988). PP in these cases are presumed to be mostly phytoplankton-P.

The high concentration on Oct. 27 may include mostly PP from the bottom mud plus phytoplankton-P.

The fact that the PP consists mostly of phytoplankton production in the lake is also supported by the PP concentration which tends to be lower during winter (Jun. to Aug., 1988) when phyttoplankton production is limited.

In Feb. 1989, the PP concentration was high and its percentage in TP extremely high (77~49%) at Sts. 0, 3/4, and 4 where blooming occurred. Most PP in this case is considered to be phytoplankton-P.

③ PO_4-P

PO_4-P concentration show low values with an occasional zero at all stations from the beginning of the survey period until Jan. 1989 (Figs. S6.4.30 and 31).

In contrast to the values before Jan. 1989, extremely higher values at all stations are found in Feb. and Mar. 1989 but these lie within a limited range.

PO4-Pconcentrations in the lake up to Jan. 1989, were always lower than the inflow value. These differences may indicate the utilization by phytoplankton production in summer, for Ch1-a concentrations are also high during this period.

But, in winter, PO_4-P concentrations in the lake were low at 0~15 μg/ℓ. The difference from the inflow values during this period is considered to be due to absorption or settling without being used for phytoplankton production, since Ch1-a concentrations are also low.

After December, the inflow values became quite higher than those before in spite of the values of the Yuquyuy River not being so high. This fact may be a reflection of the reduction of the purification capacity of the swamp.

In Feb. and Mar. 1989, actually, low uptake of PO_4-P by phytoplankton production, in spite of a continuation of high-level inflow, plus elution from bottom mud along with a rise in temperature, contributed to extremely high PO_4-P concentratin in the water layer.

Such high PO_4-P concentration is nearly equivalent to the average of 113 µg/ℓ which is an observation result of ICB in 1984. The result of SENASA for 1981 to 1982 was 0 ~ 510 µg/ℓ and the PO_4-P concentration is considered to increase further after March, 1989.

2) Nitrogen

① TN

TN is distributed horizontally with a considerably wide range. In particular, the difference between the maximum and the minimum values is very big of 3,721 µg/ℓ as in Sep. 1988, when the maximum mean value, which was extremely high, was found during this survey period (Fig. S6.4.33).

The monthly variation of TN concentration in the lake can evidently be divided to a period up to December, 1988 and to three months of 1989 in view of difference in the concentration and proportion of nitrogen of various forms in TN.

The TN value of the lake of 1988 was slightly higher than the inflow value at Yuquyry Boca and varied in satisfactory correspondence to the latter.

On Sep. 27, when the exceptionally high TN value was observed in Yuquyry River, the value was also high at Yuquyry Boca and the average in the lake high coincidently. Extremely high TP was found on Oct. 27, mainly because of stirred mud from the bottom, and phytoplankton production. In the case of TN, TN values higher on Oct. 27 than in other months are found on some stations, but the effect of the exceptionally high inflow of TN on Sep. 27 on the high value in the lake was stronger than on Oct. 27.

In 1989, the TN value, though showing satisfactory correspondence to the inflow value, tended to increase along with time as the inflow value rose. The value was extremely high, particularly in March, 1989.

During this period, PON was low and DON showed a downward trend in winter when the plankton production was small.

② NH_4-N

The monthly variation of NH_4-N can be divided into 1988 and 1989 as in the case of TN.

This value showed a slight downward trend, but not so remarkable, in winter of 1988. The concentration and variation pattern are on the same level.

In January, 1989, however, NH_4-N concentration rose abruptly, for many presumed reasons. For example, the inflow value of NH_4-N increased, NH_4-N decomposition from a high DON value accelerated with the rise in temperature, and there was a low uptake of NH_4-N by phytoplankton. This is presumed to back up the low uptake of IP, thus phytoplankton production was conceivably limited during this period

③ NO_3-N

The concentration was several times larger than that of NH_4-N from summer to spring in 1988, then lowered gradually to a value nearly equivalent to that of NH_4-N during August to December. The NO_3-N concentration became zero in December.

On Sep. 27, however, values of NO_3-N and other N forms were exceptionally high in the rivers and the lake.

In 1989, the NO_3-N concentration rose rapidly along with other nitrogen forms to return to the level in the summer of 1988.

Increase/decrease of NO_3-N follows a complicated pattern due to oxidation from NO_2-N and denitrification, and its utilization as a N-source for phytoplankton production.

But the NO_3-N variation pattern in the lake is similar to that of the inflowing NO_3-N.

3) COD

① TCOD

The TCOD concentration decreased from summer to winter in 1988 and then leveled off (Figs. S6.4.37 and 38).

The value in the lake is higher than the inflow value, which is due to the production in the lake (in the form of mainly phytoplankton or a return from the bottom mud).

Extremely high TCOD value was observed on Oct. 27, 1988, which may be attributed to the addition of TCOD by the stirring up of the bottom mud.

② PCOD

The PCOD concentration varied over a range of 3~16 mg/ℓ and was normally 1~10 mg/ℓ higher than that inflowing, except on a few occasions.

PCOD was mostly made from phytoplankton production in the lake, and apart form the addition by the stirring up of the bottom mud on Oct. 27, 1989, does, however, not show satisfactory correspondence with the variation of Chl-a.

③ DCOD

The DCOD value in the lake is slightly lower than that flowing into the lake almost without purification in the swamp. The difference between both values may be due to decomposition of DCOD, yet, such decomposition is very limited and the DCOD decomposition coefficient is small ($k = 0.16$/day, $Ct = Co \cdot e^{-k}$). Such difficult-to-be-decomposed dissolved organic materials mainly include humin.

The DCOD value was extremely high on Oct. 27, 1988, which may be attributed to addition by the stirring of bottom mud.

Values of COD in the pore fluid of bottom mud and in the water at the time are shown below.

Table COD in the Pore Fluid and in the Water Layer of the Lake
Oct. 27, '88

(mg/ℓ)	St.25		St.49		Boca Salado	
	a	b	a	b	a	b
TCOD	121	39	299	56	3,099	78
PCOD	37	14	159	28	224	43
DCOD	84	25	140	28	2,875	35

a: pore fluid b: mean of the upper and the bottom water layers

The COD concentration in the pore fluid of bottom mud was higher than that in the water layer and such COD may have been stirred up together with bottom mud to push up the COD concentration in the water. This can be known from the fact that the ratios of each COD form in the pore fluid and that in the water layer were nearly equal.

The TCOD value remained the same in February and March, 1989, but the DCOD concentration at that time increased. This indicates that the content of difficult-to-be-decomposed dissolved organic materials increased. Such increase may be a principal reason for the darkening of the water color in February and March, 1989.

This is backed up by the fact that the values obtained by deducting SS-IL from TR-IL in the inflowing water (i.e., 1μm or less organic materials) and in the lake water were high.

4) BOD

The BOD measurement was not frequently carried out.

The average in the lake was 2.5 ~ 4.3mg/ℓ, which was normally higher than the value (1.7 ~ 3.3mg/ℓ) at Yuquyry Boca and the value (1.1 ~ 2.7mg/ℓ) at St. 0. The difference may be attributed to production of organic materials.

The inflow value and the value in the lake appear to be lower than that in the organic materials estimated from other analytical values. The BOD value remains low possibly because a large quantity of nitrogen compounds inflowing over the Ypacarai basin have difficulty decomposing within five days of BOD test.

5) Chl-a

In 1988, the Chl-a concentration was high in summer but low in winter (Figs. S6.4.23 and 24). This trend corresponds well with the variation pattern of DO, pH, PP, and PON. However, in the summer of 1989, the Chl-a concentration remained on a level with the winter of 1988 in spite of sufficient PO_4-P, IN quantities, and high water temperature. This fact, plus the low DO concentration and pH value, may lead to an assumption that the production activity of phytoplankton during this summer was low. (Figs. S6.4.39 and 40)

Responsible factors may be as follows: Inflow of humin and other difficult-to-be-decomposed dissolved organic materials resulted in their accumulation after a continuation throughout the year, and the proportion of 1μm or less of organic materials increased with the inflowing water. Besides, though not so heavy as in the spring season when the wind is strong, the bottom mud was stirred up and remained in the water. These causes changed the water's color to blackish grey, resulting in the reduction of the efficiency of light utilization and, thus, decline of production activity.

Since there existed IN and IP in sufficient quantities even in this situation, blooming occurred in a limited surface portion in part of the lake. Extremely high Chl-a concentration was observed in such a portion (example: Sts. 0, 3/4, and 4 on Feb. 15, 1989).

Pollution inside the lake may be caused by ① high phytoplankton production and dead plankton, ② residue of stirred bottom mud, and ③ inflow and residue of difficult-to-be-decomposed dissolved organic materials (humin, etc.). It is conceivable that ① was a major factor in 1988 and ③ in 1989.

Organic pollution by phytoplankton is included in the SS content in the lake. Since SS contains bottom mud and organic particles other than phytoplankton, the correlation between Chl-a and SS in the lake is not definite. A high Chl-a concentration, however, was observed in Feb. and on Mar. 2, 1988 and showed a definite correlation with SS (4.2.6-3). This indicates that SS was mostly phytoplankton. The SS-Chl-a ratio of phytoplankton (mainly blue-green algae) was Chl-a/SS = 15.1μg/mg. (February, 1989).

It is not clear that the lake's inner state will return to its state in 1988 nor to its state in February and March, 1989. As long as the water color in 1989 persists, the low Chl-a concentration (low plankton production) is considered to continue and the pollution of the lake governed by the factor of above ③ will continue.

6) SS and TR

① SS

SS concentration varies from station to station and from season to season (Figs. 6.4.41 and 42). But the tendency found was that higher SS values were in the north east part of the lake in the beginning of the survey period. Then, the higher values shifted to the south west side in the lake at nearly the end of the survey period. Those areas where higher SS was found more or less associated with the blooming areas in the lake, although the correlation of SS values to Chl-a concentrations is not so high.

SS inside the lake is considered to include the inflow components from rivers, plankton, non-living plankton, and residue of bottom mud stirred up by wind.

Inflowing SS from rivers is mostly removed in the swamps except for in periods of heavy rainfall (October to November, 1988) and the summer of 1989. Difference between the values in the lake and in the inflowing water may be due to production in the lake (Fig. S6.4.17).

Fig. S6.4.45 shows the relationship between SS and Chl-a average values in each month. A bottom line shows the SS and Chl-a relationship of phytoplankton (mainly blue-green algae, Chl-a/SS = 15.1μg/mg February, 1989). As is evident from the figure, the SS each month was comprised not solely of plankton. In particular, the SS concentration on Oct. 27 was higher than the Chl-a concentration.

Water bloom was observed in February, March, and April, 1988. This evidently indicates that SS contained a large quantity of phytoplankton.

② Mixing ratio of sediment into SS

The lake is extremely shallow, with an average depth of about 2.0m and the sediments may be stirred up by a wind of about 3m/s. The high SS value on Oct. 27 evidently includes mixing of sediments.

The ratio of mixing sediment into SS is calculated.

Assuming that the ignition loss of sediment is 20% and the organic part (assumed to be totally phytoplankton) determined from the ignition loss of SS is 80% (Table S6.4.3), the mixed ratio on Oct. 27 is represented as follows, with xmg/ℓ for mixed sediment and ymg/ℓ for SS other than sediment:

$$x+y=59.6 \qquad x=34.6\text{mg}/\ell$$
$$0.2x+0.8y=26.9 \qquad y=25.0\text{mg}/\ell$$

<Accordingly, the mixed ratio of sediment into SS is 58%. >

Similarly, the mixed ratio on Jun. 21 is 2.2mg/ℓ (34% of SS) while that on Aug. 18 is 8.7mg/ℓ (40% of SS).

The above calculated value may be a considerable overestimation because the ignition loss of SS was assumed to be totally phytoplankton (Table S6.4.4).

③ TR

The TR concentration in the lake rose gradually from Jun. 21. 1988 (107 mg/ℓ) and reached 245mg/ℓ on Mar. 3, 1989.

Differing from SS which shows the localized distribution, TR shows uniform distribution.

The inflow concentration of TR from the rivers remains almost constant throughout the year and the average in the lake was slightly lower than that in 1988. In 1989, however, the value inside the lake rose to the approximate level of that of the inflow.

The TR concentration decreased in 1988 as a result of decomposition of the organic part in the lake water, while, in 1989, the decomposed part decreased considerably and an organic materials of 1μm or less size remained in high concentration in the lake.

The inflow TR and IL in 1989 were different from those in 1988. The TR value in the lake also differed as shown in the table.

It is evident that the inflow value of difficult-to-be-decomposed dissolved organic materials increased and the remaining period of the organic materials in the lake water extended. This is supported by the following facts: a high TR concentration in the lake, a large amount of organic materials, an increase in the amount of 1μm or less particles in 1989 (average at 109mg/ℓ in 1988), and a high content of organic part of 1μm or less particles (average at 54.6mg/ℓ in 1988, 116.0gm/ℓ in March, 1989). This is considered a cause for the blackening of the lake water color in the summer of 1989, and, thus, one cause of pollution in the Lake.

Table TR, IL and SS in the Lake

	Jun 21	Aug. 18	Oct. 27	Feb. 15. 1989	Mar. 3. 1989
TR (mg/ℓ)	107±8	137±8	171±36	223±16	245±22
IL (mg/ℓ)	62	76	69	95	139
% to TS	58	55	40	43	57
SS (mg/ℓ)	6.5	21.9	59.6	23.7	37.0
% to TS	6	16	35	11	15
TR-SS (mg/ℓ)	100.5	115.1	111.4	199.3	208.0

④ Particle diameter and ratio in the lake water

The particle diameter and ratio in the lake water in 1988, when the SS concentration was low in winter is as follows. The particle size at Yuquyry Boca was smaller than that in the lake, which indicates that particles in the lake originate mostly in the lake (Table S6.4.5).

At St. 0 to St.49, there was no blooming during this period and nearly even particle size distribution could be observed.

7) Cl^-

The inflow value from Yuquyry Boca is normally high, however the concentration in the lake is extremely low because of dilution. The distribution pattern shows satisfactory coincidence between these two places (Fig. S6.4.44).

The value at Yuquyry Boca is higher than that of Yuquyry River, however, it reflects variation of the latter value, except for the considerable fluctuation observed in Yuquyry River which is alleviated by a stabilization in the swamp.

The vertical distribution of Cl^-, which does not contribute to the production activity in the lake, shows only a slightly higher Cl^- concentration on the upper layer.

This fact indicates that satisfactory vertical mixing has occurred in the lake.

8) Fecal coliform number

Fecal coliform bacteria was found in high concentration (40 ~ 84/100mℓ) in the estuaries of the Yuquyry River and the Pirayu River when compared with the concentration in the lake (Fig. S6.2.12).

The coliform concentration levels of three inflow rivers are considerably high than that of the lake and the high coliform concentration at a river mouth indicates that residue of coliform bacteria is in large quantity in the river water.

4.2.7 Relationships between Selected Characteristics of Water Quality

Various combinations of the many factors of algal production due to eutrophication, stirring of bottom mud by wind, residue of difficult-to-be-decomposed organic materials, etc. result in the pollution of the lake.

Several relationships of these factors observed in the lake are described below.

1) SD and Chl-a

The SD is dependent not only on Chl-a, but also on stirred bottom mud and others (SS or dissolved substances). The SD and Chl-a showed a srong correlation on Feb. 16, 1988 ($\gamma = -0.90$) (Fig. S6.4.46). On Feb. 16, 1988, there was no stirring of bottom mud and it was presumed that the level of phytoplankton production occurred over a wide range of concentration in the lake.

In other months, the relationship between averages through the year, was extremely poor: ($\gamma = -0.12$). For example, there was bottom mud apparently mixed into the water on Oct. 27 or the SD was low due to dark water color in February and March, 1989. Except for the value on Oct. 27, in February and March, 1989: $\gamma = -0.55$ (Fig. S6.4.46).

2) SD and SS, TR

The SD can be correlated to the SS and TR in the lake. What is remarkable concerning the correlation is that TR is low in spite of SS being quite high in Oct. 1988 (Fig. S6.4.47).

In Feb. and Mar. 1989, SS levels are low in comparison with the high TR values.

3) SS and Chl-a

The lake is shallow, therefore, the stirring of bottom mud by wind of about 3m/s occurs (Supporting Report VII): SS is considered to contain a considerable amount of stirred bottom mud.

As described in 4.2.4 (6), the correlation between SS and Chl-a is low. In any case, the correlation could be observed on Feb. 16 and Mar. 2, 1988 (Fig. S6.4.48).

An alternate long and short dash line shows the relationship between SS and Chl-a of phytoplankton (mainly, blue-green algae) in February, 1989 for the lake.

4) POP and Chl-a

The relationship between POP and Chl-a unsatisfactory ($\gamma = 0.54$), which indicates a considerable amount of POP other than plankton (Fig. S6.4.49).

POP of phytoplankton (mainly, blue-green algae) was 0.9 Chl-a (Table S6.4.7). The line in the figure is considered to be lower than 0.9 because of the use of a mixed plankton sample (diatom, etc.).

5) TN and TP

Monthly average of TN and TP appear to show strong correlation ($\gamma = 0.75$), except for the values of April and March, 1988.

The inflow value of nitrogen was high on Sep. 27 and an exceptionally high nitrogen value was observed in the lake, while on Apr. 20, the P inflow value was high after heavy rainfall. In both months, no correlation could be observed between TN and TP in the lake (Fig. S6.4.50).

When compared with previous years, the phosphorus concentration in 1988 was low (over-nitrogen state).

The N/P by weight was 15.4 (9.9 ~ 24.2), which was 6.8 (over-P) on Apr. 20 and 42.3 (over-N) on Sep. 27.

6) pH and Chl-a

The pH value was substantially high on the surface layer evidently as a result of active photosynthesis in the summer of 1988. But its correlation to the Chl-a concentration was poor (Fig. S6.4.51).

The correlations were rather good on Mar. 22 and Oct. 27, 1988. The pH value was constant at around 7, regardless of the Chl-a concentration in February, 1989, which was greatly different from other months (Fig. A). Overall distribution is shown in Fig. B

7) Light intensity and SS, depth

The light attenuation state of the lake water is shown in Fig. S6.4.52. The light intensity was high at the surface on Feb. 27, 1989, but suddenly attenuated to a level 1% that of the surface at an extremely shallow depth (40cm at St. 25 and 43m at St. 49). The Secchi Disk reading in this case was 15cm (St. 25) and 20cm (St. 49), and the relationship between the depth at which the light intensity becomes 1% and the SD, is as generally stated.

The relationship between the SS concentration at the surface and the depth at which the light intensity becomes 1% of that at the surface is shown in Fig. S6.4.53-A. But the value (✖) at St. 49 was exceptional on Feb. 27, 1989.

The correlation between the light intensity at the surface and the depth at which the said intensity becomes 1% of that at the surface (Fig. B) in February, 1989 was different from other cases both at St. 25 (■) and St. 49 (✖).

The relationship on Feb. 15, 1989 (◎) agrees with that of another month (July, 1988). In February and March, 1989, however, the situation was different from that in 1988: dark water color and an obviously different lake state, with an extremely high attenuation coefficient.

8) Turbidity and SD

The relationship between the turbidity and SD is shown in Fig. S6.4.54. The measurement on Feb. 15 and 16, 1989 is shown in the lower left (⊗) of a curve: different form other months, the SD was low in spite of low turbidity.

9) Sediment mixing ratio and SD, SS, and Chl-a

As described in 4.2.4 - 6, the sediment mixing ratio was calculated (Table S6.4.9) for Jun. 21, Aug. 18, Oct. 27, and Mar. 3, 1989 and Oct. 19, 1988 (one sample from Aregua). The mixing ratio of sediment into TR was calculated by assuming that the percentage of sediment of 1μm or more diameter is 70%, on average.

The SD, sediment mixing ratio into SS, and sediment content in SS can be coordinated, except for March, 1989.

The low SD in March, 1989 can be less related to the mixing of sediment into SS.

The relationship between 80% of the SS content (from which the calculated sediment amount was deducted) and Chl-a was investigated. "(SS-sediment)×0.8" is equivalent to the organic part of SS. Except for March, 1989, the correlation between the above value and Chl-a is rather high at 0.83. The organic part of SS, other than sediment, may, thus, be said to consist mainly of phytoplankton.

4.2.8 Water Quality Comparison between 1988 data and 1989 data

The survey of the lake was made from February, 1988 to the middle of March, 1989. The lake state in 1988 was different from the previous state in that the water color was not dark, the transparency high, and the amount of phytoplankton large. Besides, the N concentration was higher and the P concentration lower than the previous level.

In February, 1989, the lake state changed (from the 1988 state) as the water color became dark and the P concentration increased extremely (the N concentration remained the same).

The lake state for 1988 and 1989 (February and March) is summarized in Table S6.4.6.

Factors responsible for lake water pollution are considered to include the following three factors:

① High phytoplankton production due to eutrophication and dead plankton

② Residue of bottom mud stirred by wind in the lake water

③ Inflow and residue of difficult-to-be-decomposed organic materials (humin, etc.) in the lake

Judging from the above description and summary in the table, the main factor for pollution of the lake in 1988 is considered to be ① high phytoplankton production due to eutrophication and dead plankton.

The effect of ② residue of bottom mud stirred by wind exists in a limited degree at all times. When the wind is strong, the stirring of bottom mud may become more critical than phytoplankton (October, 1988).

The factor ③ of residue of difficult-to-be-decomposde organic materials (humin, etc.) exists at all times, but was not so critical in 1988.

As long as the two-month state in 1989 is concerned, the purification effect of the swamp degraded, allowing an increase in the inflow of difficult-to-be-decomposed organic materials and other nutrient salts. As a result, the lake water color changed and photosynthesis was restricted to the shallow layer only. Consequently, the phytoplankton production was low in spite of high N and P concentrations. Besides, the wind velocity was low and caused less residue of stirred bottom mud. In this sense, pollution in 1989 (Feb. and Mar.) may have been due to ③.

Though it is not known if this situation continued after March, 1989, the situation as observed this time is expected to occur any time that the inflow of pollutants from rivers increases to exceed the purification capacity of the swamp.

4.3 Comparison with the Past Data

The survey result of SENASA for the 1981 ~ 1982 period of the lake, that of ICB in 1984, and 1988 and 1989 data of this survey are compared here.

Table Water Quality Comparison

	1988	1989	1981-82	1984
SD (cm)	39-81	23-25	—	7-15
DO (%)	72-127	67-76	6.8-9.4 (mg/ℓ)	58-98
pH	6.9-9.6	7.0-7.6	6.8-7.6	6.8-7.9
TP (μg/ℓ)	73-166	203-228	—	200-400‘
PO_4-P (μg/ℓ)	0-56	116-134	0-510	40-150
TN (mg/ℓ)	0.72-3.34	2.01-3.28	—	0.65-1.00
NH_4-N (mg/ℓ)	0-0.07	0.11-0.13	0.00-1.40	0.02-0.04
NO_3-N (mg/ℓ)	0-1.41	0.38-0.59	0.03-1.00	0.08-0.30
BOD (mg/ℓ)	1.5-6.4	1.5-4.0	0.7-1.7	—
TN/TP	6.8-42.2	10-14.4	—	3.3-4.4 * (0.7-6.1)

* rare cases

As is shown in the above table, the water quality in 1988 appears to be different from that of other years. It is known that DO and pH values were high and the phytoplankton production active while TP and PO_4-P values were extremely low. The TN value was not so low, but the NH_4-N value was lower in 1988.

The BOD values in 1988 and 1989 were higher than the level in 1981 ~ 1982.

In 1989, the N value increased slightly above the 1988 level while TP and PO_4-P values were also extremely high.

This means that the lake state in 1989 was nearly equal to the lake state before 1988.

CHAPTER V

SEDIMENT ON THE LAKE BOTTOM

5.1 Materials and Methods

1) Sampling stations and dates

Fig. S5.5.1 shows stations of bottom sampling.

Sts. E-a ~ E-e : Feb. 17, 1988 core sampling.

Sts. A0 ~ A1
B1 ~ B3
C1, C'1
D1 ~ D5
F1 ~ F3
G1 ~ G3
H1 , H2
X1
} Feb. 17, 1988
Surface mud sampling with Ekman-Birge.

Sts. 0, 4, 27, 30, 49
Yuquyry Boca
} Jul. 9, 1988
Surface mud sampling with Ekman-Birge.

St. 25 : Jul. 9, 1988 core sampling.

2) Analytical items and methods

The sample was stored at a low temperature and brought back to the laboratory for measurement of the following items:

Water content, ignition loss, organic N, organic C, diameter and its ratio, organic P and COD.

The core sample was cut every 2.5 cm or 5 cm and ananalysis and measurement were made on each of these cut pieces.
The water content of samples at Sts. E-a ~ E-e, Sts. 0~49, and Yuquyry Boca were measured after centrifuging at 4,000 rpm for 20 minutes.
The analyses of organic N and C were made with a CN analyzer of

the dried sample brought back to Japan.

The diameter and its ratio (Jul. 9 sample) was analyzed with a coulter counter in Japan after screening.

5.2 Results and Discussions

1) Horizontal distribution

Organic N, organic C, water content, and ignition loss of sediment at various points in the lake do not show any seasonal difference. But the values at St. E-a and St. 4 are comparatively lower than those at other stations (Table S6.5.1). St. E-a located on a lake shore near Aregua has sandy sediment while the value at St. 4 is an intermediate value between Ypucu River and Yagua Resa-u River and considered to be influenced by both rivers.

The water content at St. 30 (a lake-shore station similar to E-a) is comparatively higher than that at St. E-a. Because of a lack of other items, a comparison between these stations cannot be made. Therefore, it is not known if the sediment at all stations on the lake shore nearer to Aregua is similar to that at St. E-a.

Except for St. E-a and St. 4, the water content and ignition loss show a horizontal difference (water content:170 ~ 223%, ignition loss: 8.9 ~ 34.3%) while the organic N, organic C and C/N do not.

The horizontal distribution of the water content and ignition loss of bottom mud sampled with an Ekman-Birge sampler is shown in Figs. S6.5.2 and 3.

The water content of these samples were measured without centrifuging and thus cannot be compared directly with the water content for Sts. E-a ~ E-e and Sts. 4 ~ 49.

2) Vertical distribution

The vertical profiles of organic N, organic C, and C/N (though the measurement was limited) show the difference that is dependent on the station rather than the seasonal difference (Fig. S6.5.4).
St. E-c annd St. 25 weere located at the middle of the south to north line in the lake, though more or less at a distance. Both the quantity and profile of quality characteristics of those stations are similar until the depth of 17.5~20m.

The water content and ignition loss up to the depth of 15cm at St.25 are almost similar to those in the surface mud. The N, C content is also not estimated to decrease so much from 12.5cm to this depth.

The C/N value either decreases little along with the depth or remains the same at each station. At Sts. E-a ~ E-e and St.25, nitrogen compounds (particularly, organic compounds accumulated once in the soil) remain longer than carbon.

The grain size of bottom mud at St. 4 is larger than that at Sts.25 and 49 due to the effect of the Pirayu River, with the diameter reaching a peak at 74 ~ 5μm. At Sts. 25 and 49, the diameter ratio are almost the same up to 74μm ~ 1μm> (Table S6.5.4, Fig. 6.5.5). The size distribution ranges roughly from 105μm to 1μm or less at stations without an effect on the river. Particles less than 1μm size are readily stirred in the water to cause turbidity.

3) Geological survey result

According to the geological survey, the sediment of the lake may be summarized as follows (Supporting Report Ⅰ): The sediment in the lake bottom consists mainly of muddy suspended particles in colors of black to black grey and the well-sorted quartz sand is distributed on the lake shore. The origin of quartz sand can be easily identified, but the origin and generation of black micro suspending matter (a cause of pollution or degradation of the water quality of the Lake) are not yet fully known.

The X-ray analysis shows that the black micro matter is the clay mineral of micro quartz particles, smaller than the silt size kaolinite, montmorillonite, etc. Origins of these inorganic fine particles include the following:

① Dissolution and out flowing from the Kaolin strata during geological time

② Washing out of the present open pit during rainfall

③ Dissolution and out flowing of interstitially packed clay minerals, altered minerals, and iron oxide of the quartz and feldspar grains which compose the arenitic red sandstone and arkose sandstone beds, which are the geological components of the basin

④ Secondary fine particles produced through the re-dissection of the alluvial deposits on the plain

As for the blackish color may be it is due to gleyzation of remains under carburization, or to reducing conditions; this is not entirely clear.

CHAPTER VI

WATER POLLUTION MECHANISM

6.1 Water Pollution Mechanism and Factors

6.1.1 Features of Water Pollution of Lake Ypacarai

① Lake Ypacarai is a dish-shaped shallow lake with a mean depth of about 2m.

② This water area is stagnant having a water exchange rate of about two to three times a year.

③ There is a wide swamp of $15.7km^2$ at an estuary of Yuquyry River (the largest inflow river).

④ The mean water temperature is 23°C over the course of a year.

⑤ The nutrient salt concentration of inflow rivers is about $0.5 \sim 3mg/\ell$ in TN and $0.05 \sim 1mg/\ell$ in TP.

⑥ Accordingly, there exists a high potential of algal production.

⑦ Because of the shallow depth, the water quality is sensitive to elution and the stirring of bottom mud.

6.1.2 Mechanism and Modelling of Water Pollution

Water pollution of Lake Ypacarai is governed by the following three factors.

① Residue of inflow load from rivers

- Inflow load from pollution sources in the basin is partially settled or decomposed in the course of slowing down.
- Load is purified in the swamp at estuary.
- Particulate materials are settled at estuary during flood.

② Production of phytoplankton in the lake

- Production of phytoplankton on the basis of light and nutrient salt an causes increase in the concentration of particulate organic materials in the lake.

- Dead phytoplankton is either settled or decomposed by bacteria.

③ Effect of bottom mud

- Pollutants in bottom mud are emitted from the gap water into the lake water.
- The bottom mud surface layer is stirred by the action of wind and convection.

These factors can be modelled as shown in the following Figure.

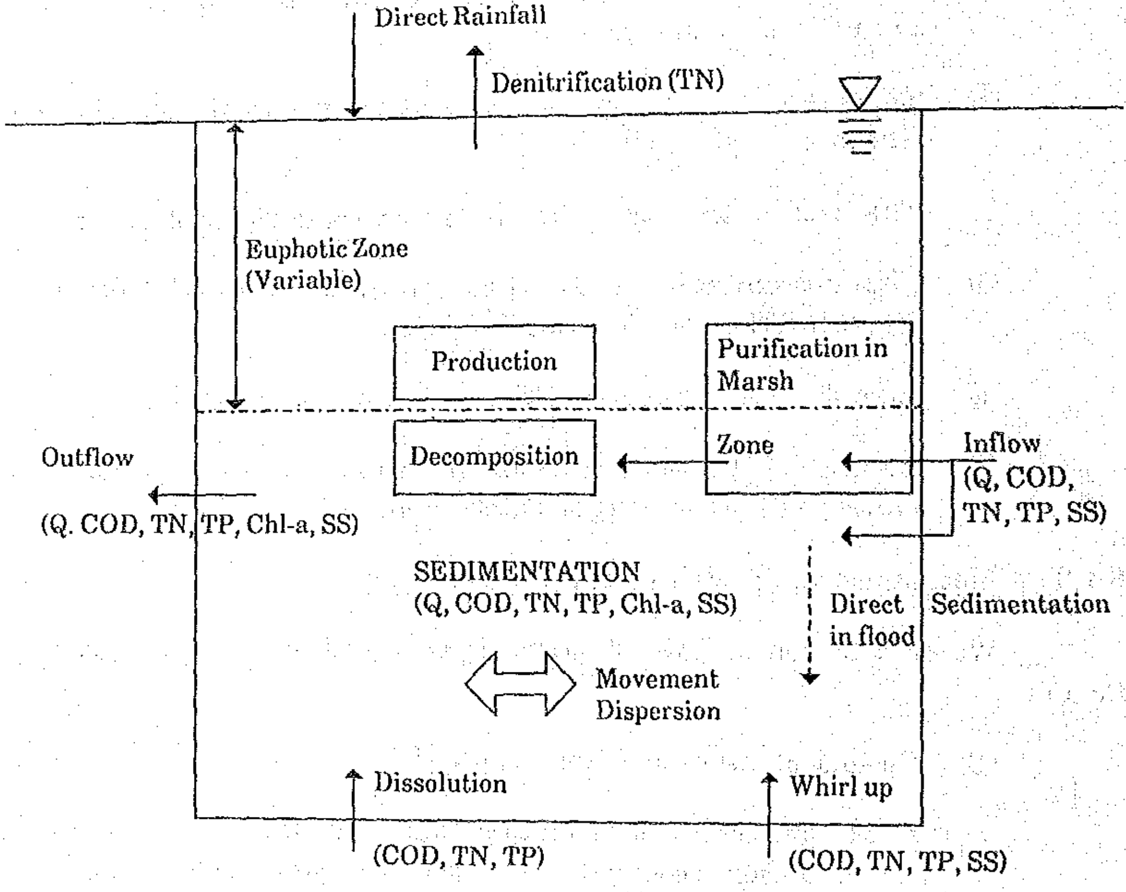


Fig. Pollution Mechanism in Lake

6.1.3 Survey and Experiment to clarify the Pollution Mechanism

The survey and experiment on each factor to clarify the pollution mechanism were made on the basis of the following concept.

① Purification of the swamp

The field survey of the water quality at inflow and outflow points of the swamp by season was assumed to help understand the purification effect of the swamp.

② Precipitation at estuary

Generally, some particulate materials flowing in during flood are known to settle in the estuary, without affecting directly lake water quality.

To understand this, the water and the bottom mud were sampled from inflowing rivers and the lake for the laboratory settling experiment using the measuring cylinder.

③ Production of phytoplankton

Though it would be best to perform the experiment to determine the production rate, the highly sophisticated technique necessitates the control of experimental conditions and it would be difficult to obtain highly reliable data.

Therefore, this survey involves the field O_2 method and algae cultivation (AGP) test to obtain data to be referenced for the estimation of the production rate.

Since the production is also governed by light, the luminous attenuation in water was measured in the field.

④ Decomposition of organic materials into inorganic materials

Organic materials in the lake water are decomposed into inorganic ones by bacteria. The lake water was sampled and the decomposition rate experiment was made to determine this rate.

⑤ Settling of particulate materials

The settled material amount was measured on-site to determine the settling rate of particulate materials in the lake.

⑥ Elution from bottom mud

Pollutants in the bottom mud are emitted gradually into the pore fluid, then into the lake water. The bottom mud surface layer was sampled in the center of the lake and the laboratory elution experiment was made to determine this phenomena.

⑦ Stirring of bottom mud

Bottom mud at the surface layer is expected to be stirred by wind and waves. The on-site survey was made in winter when the wind was strongest.

⑧ Direct rainfall

Since pollution loads during rainfall could not be ignored, rainwater was sampled in San Lorenzo and analyzed.

⑨ Denitrification

The N content of NO_2-N and NO_3-N is gasified by bacteria under anaerobic conditions and dissipated into air. No survey on denitrification has been made because there is not a good method to determine this phenomenon directly and the anaerobic condition never happens in the lake.

6.2 Analysis of Factors causing Water Pollution in the Lake (Semi-quantitative analysis)

As described previously, water pollution of Lake Ypacarai may basically be attributed to three factors: ① Residual inflow load, ② Eutrophication in the lake, and ③ Effect of bottom mud.

Related phenomenal factors are listed below:

① Purification in the swamp

② Settling at estuary during flood

③ Production of phytoplankton

④ Decomposition (decomposition of organic materials into inorganic ones)

⑤ Settling (Settling of suspended particles)

⑥ Elusion from bottom mud

⑦ Stirring of bottom mud

⑧ Denitrification

Analysis and review are made here on these factors to determine the water pollution phenomena in Lake Ypacarai and to provide fundamental data for selection of the simulation model constant.

6.2.1 Purification in the Swamp

(1) Distribution and features of swamps

There is the swamp area at the estuary of the Yuquyry River and the Pirayu River. Technical data on these swamps are shown in the table below.

Table Outline of Swamps at the Estuary of Inflow Rivers

Classification	Area (km^2)	Flowrate at normal water level (m^3/d)	Water area load at normal water level ($m^3/d/m^2$)
Yuquyry River	15.7	About 2.5×10^5	About 0.02
Pirayu River	1.83	About 1.5×10^5	About 0.08

*Note The water area load means the flow volume per unit area of the swamp.

The swamp covers a particularly wide area in the case of Yuquyry River. The river passes through the swamp and branches into four channels to flow into the lake. The channels are intricate and are presumed to flood nearly the entire swamp area when the water level rises.
On the other hand, the Pirayu River has a small swamp area and the channels are definitely there.

The swamp of the Yuquyry River may be subject to the effect of back-flow of the lake water. But, judging from the survey result of EC as described in 6.1.3, the river may be considered to flow in a normal direction.

(2) Purification mechanism in the swamp

It is presumed that the water is purified in the swamp according to the mechanism described below:

① SS

Adhesion to root hair of hydrophyte and filtration by hydrophyte.

② Organic materials (COD)

Purification by decomposition by bacteria around hydrophyte.

③ Purification of N

Denitrification for gasification and dissipation into air.

④ Purification of P

Removal mainly of particulate P through action similar to that for SS.

(3) Purification (or purification residue) ratio and water area load

The purification ratio in the swamp is considered to bear a relationship to the water area load (the flow volume per unit area: $m^3/d/m^2$).

Namely, the purification ratio is considered to become higher with an increasing period of time required for the water to pass through the swamp.

The relationship between the five-day mean water area load and the purification ratio of COD, SS, TN, and TP for the Yuquyry River is shown in Fig. S6.6.1.

This figure shows that the purification ratio approaches a certain saturation value when the water area load increases.

On the other hand, for the Pirayu River, the swamp area is small and the purification ratio is extremely small (except for SS).

Table Trial Calculation of Water Purification of the Swamp

Item (mg/ℓ)	Pirayu estuary are (average) (A) *1)	Pirayu River inflow load (average) *2)		Remarks
		Measured value (B)	Purification ratio (1-A/B)	
T-P	0.079	0.0844	0.063	
T-N	0.956	0.726	—	
COD	14	18.2	1.231	
SS	3.0	5.7	0.474	

6.2.2 Settling at Estuary during Flood

Large quantity of particulate materials flow into the lake during flood. The SS component with relatively large grain size is considered to settle at the estuary area, thus not effecting the lake water quality.

The laboratory experiment using measuring cylinder was made.

The water and bottom mud of inflow rivers and the lake were sampled and the SS concentrations were observed in one hour, and 24 hours, for two cases:

with mixed bottom mud and without mud. Generally, the water turbidity and concentration tend to decrease exponentially in the course of settlement of particles, and the result was indicated on a single exponent chart.

The result show that the SS settling attenuation ratio of SS in water is 0.0001 ~ 0.02 ℓ/hr and as high as 0.07 ℓ/hr for the water with mixed bottom mud. For inflow rivers, the water without bottom mud may be assumed to have the water quality and settling state of that at normal water level while the water with mixed bottom has the quality of that during flood (Fig. S6.6.2).

It is evident from the above result that the settling of particulate materials occur in the estuary area during flood.

6.2.3 Production

1) Outline of the production phenomena

The primary production consists of the production of organic materials from iorganic materials through photosynthesis, mainly by phytoplankton. A large quant hydrophyte and algae naturally carry out the primary production near the shore, but the scale of primary production is extremely smaller that further into the lake itself. Production of zooplankton, benthos, and fish is also dependent on the production of phytoplankton, directly and indirectly, via the food chain.

There are many methods to determine the primary production, as shown in Table in the next page.

Relevant production factors are light, water temperature and nutrient salt (inorganic N and P).

Assuming that the production is dependent on all these factors in Lake Ypacarai, the production rate can be expressed as a Micaeles-Menden type equation.

Table Primary Production Measuring Method

Measuring method	Description
Field O_2 method	Measurement of the photosynthesis amount of phytoplankton on the basis of change of DO. The measurement is made in the field.
Field CO_2 method	Measurement of the photosynthesis amount of phytoplankton on the basis of change of CO_2. The measurement is made in the field.
^{14}C method	Measurement of the radioactivity of phytoplankton after application of $HaH^{14}CO_3$ with known radioactivity in a certain amount.
Pseudo-field method	Method of applying the temperature and light conditons artificially to a certain amount of sample. O_2 and CO_2 are measured.
Estimation of the primary production amount from chlorophyll amount	Estimation of the production amount by alloying the water temperature, quantity of solar radiation, and light conditions while assuming that the maximum production per unit chlorophyll amount is known.
pH method	Measurement based on change in the photosynthesis amount pH of phytoplankton.
Method considering uptake of nutrient salt	Method assuming that the production quantity varies depending on variation of nutrient salt because the primary production is dependent on the nutrient salt quantity. In this survey, the production quantity was assumed to be expressed by the following equation and the experiment made to determine the Micaeles constant for IN and IP. $Kp=\mu(T)\cdot\frac{f}{Kmf+f}\cdot\frac{IN}{KmIN+IN}\cdot\frac{IP}{KmIP+IP}$ where KP : Production quantity μ : Max. propagation rate T : Water temperature f : Solar radiation quantity IN : Inorganic nitrogen concentration IP : Inorganic phosphorus concentration Kmf : Micaeles constant of the solar radiation KmIN : Micaeles constant of nitrogen KmIP : Micaeles constant of phosphorus

2) Survey on the production

The simple field O_2 method and AGP test were made to determine the production (For the AGP test, refer to the separate report).

① Production measurement result according to the simple field O_2 method.

Date of survey: Feb. 27, 1989

Table Condition in the Lake and Result of Measurement

		St. 25	St. 49
Light intensity at the surface(lux)		30,000	32,000
Euphotic depth (cm)		40	43
Temp (°C)	At the surface	28.3	29.1
D.O (mg/ℓ) (%)		7.1 (92)	7.1 (93)
Chl-a (μg/ℓ)		307.3	34.7
SS (mg/ℓ)		72.0	18.3
Photosynthetic Activity (Om) (mgC/m^3. h)		373	101
Photosynthesis (mgC/m^3. day)		774	226
Respiration (mgC/m^3. day)		639	218

② Light intensity attenuation in water

The production rate in the lake is governed by the thickness of the euphotic zone and the vertical light distribution.

The result of the survey on light intensity attenuation with an underwater illuminometer is shown in Fig. S6.6.3.

The thickness of the euphotic zone in terms of transparency is normally about two times the degree of transparency. The thickness is also assumed to be have a depth of 1% attenuation when viewed in terms of light intensity in water.

6.2.4 Decomposition

Organic materials are decomposed by bacteria and decrease under the aerobic conditions.

Since organic materials flow in from rivers they are mostly decomposed in the course of flowing downstream; most of the residual organic materials are considered to be difficult to decompose (k_A).

On the other hand, there are living and dead photoplankton (k_B) and organic materials due to elution and stirring of bottom mud (k_C). These are finally decomposed to inorganic materials (CO_2 and H_2O) by bacteria.

When comparing the scales of k_A, k_B, and k_C it follows that k_A (k_C (k_B . However, measuring these items separately is difficult. In practice, these are understood as a mixture.

Generally, decomposition is considered a primary reaction and expressed as follows:

$$\frac{dc}{dt} = -Kd \cdot C$$

$$Kd = Kd_{20} \cdot \theta^{t-20}$$

Where K_d : Decomposition rate constant (1/day)
C : Concentration of the material to be decomposed
C_1 : Decomposition rate factor
t : Water temperature (°C)
θ : Water temperature coefficient
K_{d20} : Decomposition rate constant at 20°C (1/day)

The surface water around San Bernardino was sampled in October, 1988 and the sample was stored at 20°C in a dark place for the measurement of COD, Chl-a, and SS concentrations from time to time (Oct. 19 ~ Nov. 3, 1988).

The decomposition rate as calculated from the result of the laboratory decomposition experiment is $k_{COD}=0.036$ and $k_{Chl\text{-}a}=0.054$ as shown in Fig. S6.6.4.

The SS concentration is considerably smaller than the COD (COD is decomposed while shifting to the dissolved phase while SS is particulate and contains a sandy component.).

6.2.5 Settling

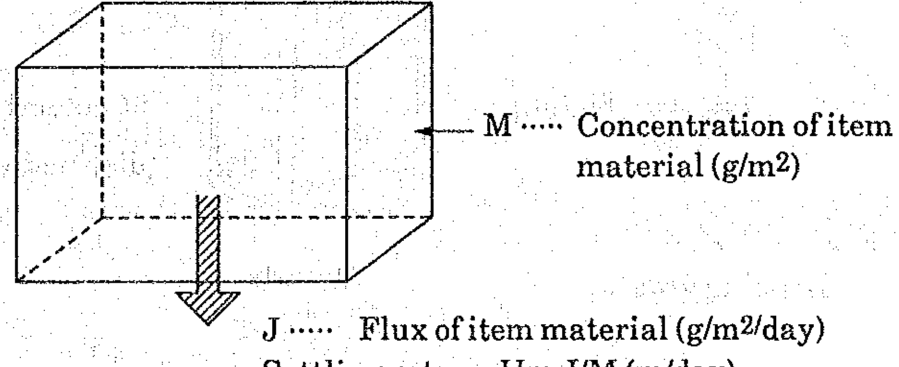
1) Outline of the settling phenomenon

Particles floating in the lake water consist of algae of small specific gravity and bottom mud or materials originating from rivers during flood (which have large specific gravity). These settle and disappear as time passes. Both components settle naturally at different speeds. Besides, particles not only settle, but also accumulate in the bottom mud only to be stirred and moved in the water by wind. Along with the migration of particles, the materials (nutrient salt, etc.) also move.

Since through the screening of algae and sandy material it is difficult to measure their actual settling speed, the settling mass and physical composition are first determined, for the calculation.

2) Modelling of the settling phenomenon

The settling phenomenon can be expressed as shown in the following Fig.
The material specified may be an aggregate of materials with different settling rates when viewed microscopically. The settling rate defined in the figure represents the mean settling rate of the whole item. Modelling of the settling phenomenon can be roughly classified as follows:



Settling rate: Um J/M (m/day)

Fig. Definition of Settling Rate

3) Observation of the settling rate

① Method

To observe settling materials, a ø24 cm collector was set at a depth of 2.0 m at St 25 (the full depth 2.9 m) and changed every 24 hours. (The survey period was from Jul. 12 to 21, 1988.)

After measuring of the water level in the collector, an analysis on SS, COD, D-COD, K-N, D-K-N, T-P, and D-TP was made. A calculation on P-COD, P-K-N, and P-T-P was made from the analysis' result.

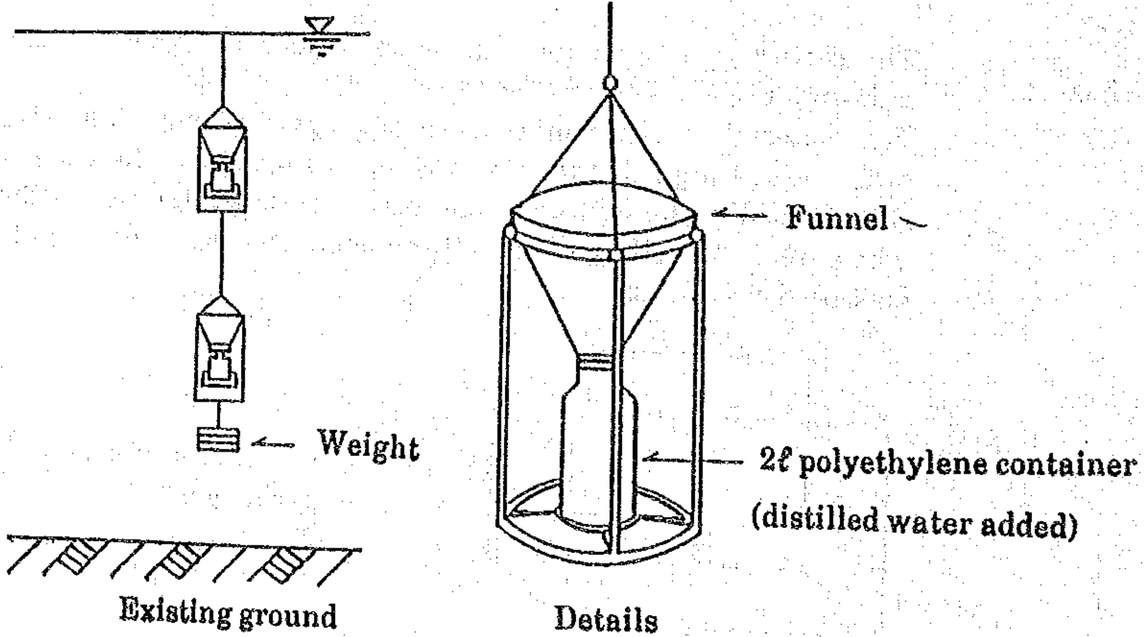


Fig. Settling Collector and Installation Method

② Result

The settling mass was calculated as follows on the basis of the test result for the particulate:

$$M = Ca \times \frac{V}{1000} \times \frac{1}{A} \times \frac{1440}{T}$$

Where
M : Settling mass (mg/m^2/day)
C_a : Water quality concentration in collector(mg/ℓ)
V : Water quantity in collector (mℓ)
A : Collector area (m^2) $A = 0.0452$
T : Collection time (min)

Table Sedimentation materials (mg/m^2/day)

Term / Ikem	7/12 ~ 7/13	7/13 ~ 7/14	7/14 ~ 7/15	7/15 ~ 7/18	7/18 ~ 7/19	7/19 ~ 7/20	7/20 ~ 7/21	Min ~ Max AVE
SS	3237	3434	8850	2421	2156	2194	2119	(2119 ~ 8850) 3487
P-COD	1804	1280	1211	665	363	2018	1695	(363 ~ 2018) 1291
P-ON	16.2	10.8	54.0	14.9	6.8	45.7	10.1	(6.8 ~ 54.0) 22.6
PTP	6.0	2.5	4.3	1.9	3.5	4.1	4.1	(1.9 ~ 6.0) 3.8

③ Calculation of the settling rate

The settling ratio and rate per day of SS was calculated as follows:

$$Ur = \frac{M}{Cs \cdot H \cdot 1000}, \qquad U = Ur \cdot H$$

where Ur : Settling ratio (1/d)
U : Settling rate (m/d)
H : Collector installation depth (m) $H = 2.0$
M : Settling mass (mg/m^2/d)

Table Settling Rate Calculation Result (SS)

Observation period Item	7/12 ~ 13	7/13 ~ 14	7/14 ~ 15	7/15 ~ 18	7/18 ~ 19	7/19 ~ 20	7/20 ~ 21	Min ~ Max	AVE
Lake water SS (mg/ℓ)	8.2	10.5	10.5	10.5	14.2	12.5	7.0	—	—
SS quantity on collector (mg/m^2)	16400	21000	21000	21000	28400	25000	14000	—	—
SS settling mass (mg/m^2/d)	3237	3434	8850	2421	2156	2194	2119	—	—
Daily settling ratio (1/d)	0.197	0.164	0.421	0.115	0.076	0.088	0.151	0.076 ~ 0.421	0.173
Settling rate (m/d)	0.39	0.33	0.84	0.23	0.15	0.18	0.30	0.15 ~ 0.84	0.35

Since, by the nature of the experiment, the stirred SS may be mixed, it should be noted that the numerical figure thus obtained could possibly contain a positive error.

On the basis of the concept similar to SS, the settling rate of COD, N, and P can be determined as follows:

Table Settling Rate Calculation Result

Observation period Settling rate	7/12 ~ 13	7/13 ~ 14	7/14 ~ 15	7/15 ~ 18	7/18 ~ 19	7/19 ~ 20	7/20 ~ 21	Min ~ Max (Ave)
P. COD	0.24	0.17	0.16	0.09	0.05	0.27	0.23	0.05 ~ 0.27 (0.17)
P. ON	0.044	0.030	0.146	0.040	0.018	0.124	0.028	0.018 ~ 0.146 (0.061)
P. TP	0.158	0.066	0.114	0.050	0.092	0.108	0.108	0.050 ~ 0.158 (0.099)

6.2.6 Elution from Bottom Mud

1) Outline of Elution

Elution means the return of nutrient salt from the lake's bottom mud to the lake water. The elution rate is expressed as a flux of nutrient salt per unit area of bottom mud going from the bottom mud to the lake water. Elution is also referred to as an internal load because it gives the nutrient salt loads (P, N) to the lake water, but not through inflow. This is said to contribute greatly to the physical circulation, particularly in the shallow lake.

There are two elution rate measuring methods: an actual measuring method to determine the change of material concentrations in the water of the lake water - bottom mud system by making measurements in the field or laboratory; and a method with a theoretical model in which a dissipation model is applied to this system.

In this survey, the pseudo-field type laboratory test was made in the stationary state.

The elution rate in the stationary state can be expressed as follows:

$$K_R = k_{R20} \cdot \theta^{t-20}$$

where K_R : Stationary elution rate (mg/m2/d)
K_{R20} : Stationary elution rate at 2°C (mg/m2/d)
θ : Water temperature coefficient (1/d)
t : Water temperature (°C)

2) N, P, COD elution test from bottom mud

The elution rate of N, P, and COD from bottom mud was determined by the laboratory experiment (July 9 ~ 19, 1988)

① Experimental method

Bottom mud was sampled by the Ekman-Birge Sampler at St. 25. The sample was laid in the bottom of a bucket and distilled water was poured over the mud.

In this way, the elution experiment was made in aerobic conditions.

Two temperatures were used: 20°C and 30°C

② Analysis

The sample was analyzed in terms of the dissolved state of COD, N, and P.

③ Elution rate calculation method and result

The equation (1) was used for N and P and the equation (2) for COD.

$$KR=(C_n-C_0)\times V_n\times \frac{1000}{A}\times\frac{1}{n} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad \begin{matrix}(1)\\ \text{N, P}\end{matrix}$$

$$KR=(C_n-C_0 10^{-kn})\times V_n\times \frac{1000}{A}\times\frac{1}{n} \quad \cdots\cdots\cdots\cdots \quad \begin{matrix}(2)\\ \text{COD}\end{matrix}$$

* Note: COD decomposition factor of $k=0.03$ was assumed for calculation.

where KR : Elution rate per day ($mg/m^2/d$)
C_o : Initail (0 day) concentration
C_n, C_{n+1} : n, n + 1 day concentration
V_n, V_{n+1} : V, V_{n+1} water quantity
A : Area of the experiment device
n, (n + 1) − (n) : Period covered by calculation

Table Elution Rate of Lake Bottom Materials

Item	Elution Rate ($mg/m^2 \cdot day$)		Observation
	20°C	30°C	
D. COD	226	238	Condition
IN	1.14	—	Condition
D. PO_4-P	0.104	0.423	Condition

6.2.7 Survey on the Stirring of Bottom Mud

In the shallow lake, the bottom mud itself is stirred by the wind. Bottom mud thus stirred is re-settled when the wind stops and causes pollution only while the wind is blowing. Part of the mud, however, becomes dissolvable while floating in the lake water. The stirring by wind may be expressed as follows:

$$Kv=f(F)$$
$$Kz=f(Kv)$$

where Kv : Quantity of bottom mud stirred
F : Wind strength
Kz : Shift of the amount of component which becomes dissolvable in water

The observation of the stirring of bottom mud by wind in Lake Ypacarai was made on July, 1988. The result is shown in Fig. S6.6.5.

The turbidity increased substantially at St. 30 during July 18 ~ 19. Accidentally, the observation period coincided with the time of the year when the wind was strongest.

Accordingly, the stirring of mud by wind may be considered less extreme.

There may be other factors, such as convection due to temperature difference between day and night, but details are not clear.

CHAPTER VII

CONCLUSIONS

Following conclusions may be drawn from the survey on rivers and the lake for one year.

1. The Yuquyry River, which is one of main rivers follwoing into the lake, and almost all of small inflowing rivers, are polluted while some are heavily affected by the factories.

   The inflow of pollutants exceeds the water's capacity for self-purification.

2. On the other hand, small rivers of the Pirayu Water system, which is one of the main water sources flowing into the lake, are generally less polluted. In some sections, self-purification is active.

   Pollution of Yagua Resa-u River, which is one of rivers of the Pirayu River system, is extremely low.

3. There is no given tendency in the monthly pattern of water quality variation at four stations of the two river systems.

4. The inflow of pollutants increases, resulting in a clear increase in concentrations in the three rivers after rainfall.

   Reflecting the high percentage of contamination from the non-point pollution source, the load quantity in the Pirayu River system increases more substantially after rainfall than at the normal level. About 10 ~ 40 times at Ypucu River, about 60 ~ 180 times at Yagua Resa-u River.

5. The load increase after rainfall in Yuquyry River is not so high, which is a reflection of the high percentage of point sources in the basin. About 6~28 times at this river.

6. In the three rivers, erosion of river banks is heavy and the SS increase after rainfall is high.

7. Even while considering of the load increase after rainfall, the discharge load from the Yuquyry River is much larger than from the Pirayu River system.

8. The three rivers pass through swamps before flowing into the lake, and these swamps remove pollutants. The swamp of Yuquyry River is particularly wide with a large purification capacity.

   The purification of pollutants of large grain size is high.

9. River water flows into the lake after purification in the swamps. It appears that the inflow value is governed greatly by the concentration of elements which determine river water quality. In particular, the N variation in the lake corresponds well to that of the inflow value.

10. Organic pollutants in the lake may be attributed to the inflow of the residue of dissolved organic material (difficult-to-be decomposed) and, mainly, living and dead phytoplankton produced with high N and P concentrations brought from rivers.

11. Another factor of lake pollution is residual bottom mud that is readily stirred because the lake is very shallow.

    Stirring occurs frequently in spring when the wind is strong.

12. The lake is mixed well vertically and horizontally.

    Biologically, however, the lake shows localization (for example, Chℓ-a distribution).

13. The lake's state in 1988 was different from its previous states in terms of high SD, brown and transparent water, large quantities of phytoplankton and zooplankton and low TP and PO_4-P. This may be attributed to the flush-out of water due to heavy rainfall in January, 1988.

14. In 1989, the lake's state apparently differed from that in 1988 in terms of dark water color and a drop in phytoplankton production, low SD, extremely high TP and PO_4-P. The lake's state in 1989 may be considered to be similar to that in 1987 and before, though the survey period was limited to less than three months only.

15. In the 1989 state, the swamp purification capacity exceeded its limit and the inflow value of each water quality item has increased since the beginning of 1989. Particularly, the inflow quantity of 1μm or less of organic materials increased to cause increased concentration of difficult-to-be-decomposed organic materials (humine, etc.) responsible for pollution in the lake. These factors plus dead phytoplankton and residual mud changed the water color to black.

An increase in TP and PO_4-P may be due to elution from the lake bottom and a temperature rise, in addition to an increase in the inflow values.

The above conditions can readily occur in the lake.

CHAPTER Ⅷ

FURTHER STUDIES

A basic survey on the lake pollution mechanism was made for nearly one year starting in February, 1988. In a district with summer and winter seasons, the one-year survey on the water area containing organisms was not enough. Further studies mentioned below are necessary to make clear the pollution mechanism of the lake.

1. A rough pattern of the monthly variation in water quality could be understood, but the survey frequency must be increased further to determine the correct variation over a long period.

2. Concerning three major factors for lake pollution;

① High phytoplankton production by eutrophication and its decomposition.

② Residue of stirred bottom mud, and
③ Residue of difficult-to-be-decomposed organic materials (humin, etc.)

An in-depth study must be made on the extent and manner of mixing these factors to cause pollution.

3. In particular, concerning factor ③ which is considered responsible for blackening the water in February and March, 1989, a further study is necessary concerning the inflow source, generation source, and water blackening mechanism.

4. If the pollution mechanism is to be clarified in more detail, the study must be continued on the load circulation mechanism in the lake, and the swamp purification mechanism, and its relationship with the inflowing river water.

TABLES

Table S6.2.1 (1) Sampling Dates and Meteorological Conditions

Date	Station	Weather	Air Temp(°C)	Wind Velocity (m/s)	Wind Direction	Precipitation (mm)	Remarks
Feb. 24, '88	A°-s (Y7, P11, P12)	Clear					
Mar. 15, '88	A°-s (Y7, P11, P12)	Clear	27.2	0.75	SSW	0	Rainfall Mar. 13 : 3.0~3.5mm
Apr. 6, '88	A°-s (Y7, P11, P12)		24.6	0.35	SW	0	
Apr. 13, '88	A°-s (Y7, P11, P12)		19.4	2.3	SSW	0	Rainfall Apr. 12 : 149mm
Apr. 19, '88	A°-s (Y7, P11, P12)		20.6	0.8	ENE	93.0mm	
May. 4, '88	A°-s (Y7, P11, P12)	Clear	12.3	1.4	S	0	Rainfall May. 3 : 7mm
May. 19, '88	A°-s (Y7, P11, P12)	Cloudy	18.0	0.73	S	0	Rainfall May. 16 : 62.2mm
Jun. 1, '88	A°-s (Y7, P11, P12)	Clear	6.8	0.4	ENE	0	
Jun. 14, '88	A°-s (Y7, P11, P12)	Cloudy, little rainfall	10.5	0.4	SSW	0	
Jun. 23, '88	A°-s (Y6~BOCA)	Cloudy, later little rainfall	22.1	0.8	NNE	7.3mm	
Jul. 1, '88	A°-s (Y1~Y8)	Clear	21.3	0.4	ENE	4.9mm	
Jul. 5, '88	A°-s (P1~P7)	Cloudy, little rainfall					
Jul. 6, '88	A°-s (P8~P12)	Cloudy, little rainfall	10.3	0.5	SSW	0	
Jul. 9, '88	A°-s (Y6~P12)	Clear	12.1	1.2	S	0	

Table S6.2.1 (2) Sampling Dates and Meteorological Conditions

Date	Station	Weather	Air Temp(°C)	Wind Velocity (m/s)	Wind Direction	Precipitation (mm)	Remarks
Aug. 17, '88	A°-s (Y6~P12)	Clear	16.1	0.8	WNW	16.7mm	Rainfall Aug. 15 : 12.5mm Aug. 16 : 2.1mm
Aug. 18, '88	A°-s (Y6~P12)		20.2	1.23	SW	0	
Sep. 26, '88	A°-s (Y6~P12)	Slightly cloudy	25.7	1.6	SSW	0	
Oct. 24, '88	A°-s (Y6~P12)	Clear		0.9	ENE	0	
Dec. 10, '88	A°-s (Y6~P12)	Clear, hot	25.9	0.4	W		
Jan. 11, '89	A°-s (Y6~P12)	Clear	20.8	0.6	WSW		
Feb. 14, '89	A°-s (Y6~P12)	Clear	25.3		WSW	0	
Mar. 2, '89	A°-s (Y6~P12)	Clear	24.8	0.3		0	
Oct. 31, '89	A°-s (Y7, P11, P12)	Rain and cloudy		1.5	W	93.0mm	
Nov.3, '89	A°-s (Y7, P11, P12)	Clear		1.0	SSW	0	

Table S6.3.1 Grain Diameter of Sediment in the Rivers

Sampling date: July. 9,'88

Name of River	Max. Size (mm)	Size of 60%(mm)	Size of 30%(mm)	Size of 10%(mm)	Size Ratio (%)						
					>4.76 mm	4.76~ 2.0	2~ 0.42	0.42~ 0.074	0.074~ 0.057	0.057~ 0.02	0.02> mm
Yuguyry	9.52	2.15	0.35	0.051	24.5	17.5	27.3	18.2	2.3	3.9	6.3
Ypucu	4.76	0.75	0.17	0.027	0	6.0	48.5	24.5	3.0	9.8	8.2
Yagua-Resa-u	4.76	0.59	0.14	0.030	0	6.6	41.9	31.7	3.8	9.5	6.5

Table S6.3.2 Physical and Chemical Characteristics of Sediment in the Rivers

Item / Name	Density (mg/cm³)	Water Content (%)	Ignition Loss (%)	Organic N (mg/g-dw)	Organic C (mg/g-dw)	C/N
Yuquyry River St. Y7	-	24.9	0.7	0.11	1.07	9.7
Yuquyry River St. Y6	1.97	22.3	0.4	0.07	1.32	18.9
Ypucu River St. P12	1.99	23.7	0.6	0.14	1.55	11.1
Yagua resa-u River St. P11	1.88	23.4	0.9	0.10	1.00	10.0
* Pirayu River St. P2	1.36	98.9	12.8	2.18	21.36	9.8
Mean	1.95	23.8	0.7	0.11	1.24	12.4

* *Values taken at the Pirayu River, St. P2, were not used for mean values.*

Table S6.4.1 (1) Sampling Dates and Meteorological Conditions

Date	Station	Weather	Air Temp (℃)	Wind Velocity (m^3/s)	Wind Direction	Precipitation (mm)	Others
Feb. 16, '88	Lake	Clear		weak	S	0	
Mar. 2, '88	Lake	Clear	26.9	0.8	SW	0	Rainfall Mar. 1 : 1.5mm
Mar. 22, '88	Lake	Clear, hot	30.6	1.3	NE	0	
Apr. 13, '88	Y. BOCA		19.4	2.3	SSW	0	Rainfall Apr. 12 : 149.0
Apr. 15, '88	Y. BOCA		19.9	0.7	ENE	0	
Apr. 20, '88	Lake	Cloudy	22.8	0.6	ENE	1.5	Rainfall Apr. 19 : 97.8mm
May. 31, '88	Lake	Clear	5.7	0.73	SSW	0	
Jun. 21, '88	Lake	Cloudy, later clear	19.7	0.6	SSW	0	Rainfall Jun. 18 : 40.1mm
Jul. 8, '88	Lake	Clear	7.2	0.4	SSW	0	
Aug. 18, '88	Lake	Clear	20.2	1.2	SW	0	Rainfall Aug. 17 : 16.7mm
Sep. 27, '88	Lake	Cloudy	27.8	2.6	SSW	0	
Oct. 27, '88	Lake	Clear, not hot	23.5	0.8	SSW	0	Wind Velocity Oct. 25 : 2.1m/s Oct. 26 : 1.9m/s
Dec. 6, '88	Lake	Clear, dry		0.5	NE	0	
Jan. 10, '89	Lake	Clear, warm	25.4	0.8	SSW	0	

Table S6.4.1 (2) Sampling Dates and Meteorological Conditions

Date	Station	Weather	Air Temp (℃)	Wind Velocity (m^3/s)	Wind Direction	Precipitation (mm)	Others
Feb. 10, '89	Lake (Plankton Sampling)	Clear	26.4	0.3	W	0	
Feb. 15, '89	Lake	Slightly cloudy	25.6	0.3	WSW	0	Feb. 14 : 3.4
Feb. 16, '89	Lake	Slightly cloudy	23.0	0.4	SW	0	
Feb. 27, '89	Lake (Plankton Sampling)	Clear	22.5	0.2	SSW	0	
Mar. 3, '89	Lake	Clear	27.0			0	
Mar. 14, '89	Plankton Sampling	Clear	28.3			0	

Table S6.4.2 <u>Distribution of EC in the Lake</u>

Date st.	Feb. 16, '88	Mar. 2	Mar.22	Apr. 20	May.31	Jun, 21	Jul. 8	Aug.18	Sep. 27	Oct. 27	Dec. 6	Jan. 10 '89	Feb.16,	Mar. 3	Mean ±S.D.
4 s	107	152	159	141	145	*123	154	157	179	182	184	*150	165	167	158±20
b	–	–	–	*88	140	154	159	–	179	186	–	–	164	170	165±14
25 s	108	163	172	148	150	156	157	155	182	175	196	180	168	166	162±20
b	–	–	–	145	156	152	160	–	181	181	–	–	178	167	165±13
49 s	113	168	164	159	150	154	164	158	172	188	209	187	177	176	167±21
b	–	–	–	162	158	*194	168	–	172	192	–	–	182	176	173±11
57 s	109	166	150	157	145	162	–	154	–	–	208	188	177	175	163±24
b	–	–	–	160	145	–	–	–	–	–	–	–	177	175	164±13

* These values clearly show the effect of Pirayu River and Yuquyry River water, therefore these were not used for mean values.

Table S6.4.3 <u>Phytoplankton Characteristics within Lake Ypacarai</u>

Dominant group : Blue-green Algae
Sampling date : Feb. 16, '89
Sampling point : between St. 3 and St. 4

$\frac{\text{Chl-a}}{\text{SS}}$ (µg/mg)	$\frac{\text{Chl-a}}{\text{COD}}$ (µg/mg)	P (µg/mg-dwt)	N (µg/mg-dwt)	N/P by wt.	Ignition Loss (%)
16.4 14.9 14.0 Mean 15.1	5.6	9.6 17.6 Mean 13.6	307 354 Mean 331	24.7	83.6