LIMNOLOGICAL STUDIES IN LAKE YANAKA

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As part of a major effort to understand and quantify the eutrophication process in Lake Yanaka, characterization of the lake is carried out by combining extensive survey and analysis of existing data with field measurement of both flow and water quality parameters in Lake Yanaka.

Peak concentrations of chlorophyll a and its relation with phosphorus, oxygen, inflow and outflow, and the observed flow patterns are the main focus of this paper. Various features of water quality conditions in the lake are elucidated, and particularly, the mechanism of phytoplankton blooms in Lake Yanaka is explained with supporting evidence.

Key Words : *Lake Yanaka, eutrophication,* chlorophyll a, *oxygen, phosphorus, flow, filed measurement, ADCP.*

1. INTRODUCTION

Lake Yanaka is part of the Watarase retarding basin, north of Tokyo, 36°13' N in latitude and 139°40' in longitude. Its main purpose is three-fold: flood protection, drinking water supply to Tokyo area and maintenance water supply for downstream rivers. It has a surface area of 4.5 km^2 and an average depth of six meters with seasonal changes of about three meters for flood control. The lake is divided into three blocks by levees and connected by gaps as depicted in Fig.1. Inflow and outflow are regulated at the pumping station which is located in South Block. The water is taken from the Yata river (80%) and Watarase river (20%).

In recent years, the eutrophication problem has surfaced up in Lake Yanaka. High inputs of nutrients led to excessive growth of phytoplankton. For example, the concentration of chlorophyll a ranges between 50 μg/l and 150 μg/l with peaks of up to more than 250 μg/l as shown in Fig.2. To improve water quality in lake Yanaka, some initiatives have been taken. For instance, a project of using a reed-wetland as filter to remove nutrients is now progressing. In this study, first of all, existing field data are reviewed and analyzed for the characterization of the water quality conditions in Lake Yanaka. Previous studies have suggested that in shallow eutrophic lakes significant amounts of phosphorus may be released form the sediments under anaerobic condition. As the fall overturn starts, the regenerated phosphorus can be transported from the hypolimnion to epilimnion and result in autumn algal bloom (Alexander[3]). However, the situation in Lake Yanaka is different. The thermal stratification is virtually non-existent during the summer months. Therefore, the autumn bloom in Lake Yanaka must be caused by a mechanism other than the fall overturn. In this study, efforts are made to explain the possible mechanism behind the spring and autumn bloom in Lake Yanaka. The hypothesis suggested in the present work concerning the algal growth in autumn may contribute to the implementation of better management strategies for Lake Yanaka.

To investigate the lake dynamics and the spatial variation of water quality parameters in Lake Yanaka, field observations of flow and water quality were carried out from December 3rd to 5th, 1997 and from October 5th to 7th, 1998. The present paper is also aimed to report some of the filed results and to shed some new light on the difference of water quality between the three blocks in Lake Yanaka. And the observed flow patterns may help better understanding the nutrients transport processes in Lake Yanaka.

2. CHARACTERISTICS OF WATER QUALITY IN LAKE YANAKA

Characterization of water quality in lake Yanaka is based on continuous monitoring data obtained from the Tone River Upstream Work Office. The field measurement was done at one point in each block at two different depths, namely 50cm below the surface and 1m above the bottom. Measured Quantities are: water level, air temperature, water temperature, transparency, odor, color of the water, wind direction and speed, pH, DO, BOD, COD, suspended solids, Colon bacillus, turbidity, EC, total phosphorus, PO_4-P, dissolved total phosphorus, total nitrogen, NH_4-N, NO_2-N, NO_3-N, organic nitrogen, dissolved total nitrogen, dissolved organic nitrogen, total organic carbon, total chlorophyll, chlorophyll a, chlorophyll b, chlorophyll c, organic phosphorus and various toxic substances. Since some analyses such as water temperature distribution and yearly variation of nutrients have already been presented by Huang[1,2], and Amitabh[4], the attention here is focused on peak concentrations of Chlorophyll a.

Figure 2 shows the variation of Chlorophyll a concentration in three blocks. As can be seen from the figure, there were a spring bloom and an autumn bloom. The peak value of Chlorophyll a could be as high as 300 μg/l.

The spring peak may be attributed to the inflow load of nutrients and the rise of water temperature due to season change. Water intake usually started from April to June as can be seen from Fig.3. Figure 4 shows that the concentrations of TP and PO_4-P in the Yata river during spring could be as high as 1mg/l and 0.6mg/l, respectively. Besides, as indicated in Fig.5, the water temperature in May varies in the range of 18-22^{0}C, which is optimal for algal growth such as diatoms.

The autumn bloom in many lakes is driven by progressive break-down in stratification occurring towards the end of the summer. However, the autumn assemblage in Lake Yanaka must be caused by a different mechanism because the stratification in the lake during summer is very weak, as can be seen from Fig.6. The driving force for the autumn bloom is considered to be the water release from the lake. For the purpose of flood control, water was being gradually pumped out from July to August. This outflow may promote the release of nutrients from anoxic sediment. Besides, near the boundary of the lake, the bottom is concrete. The nutrients settled there in preceding months could not be decomposed. As the water level dropping, those nutrients would be transported to the pelagic region of the lake where they are taken up by phytoplankton.

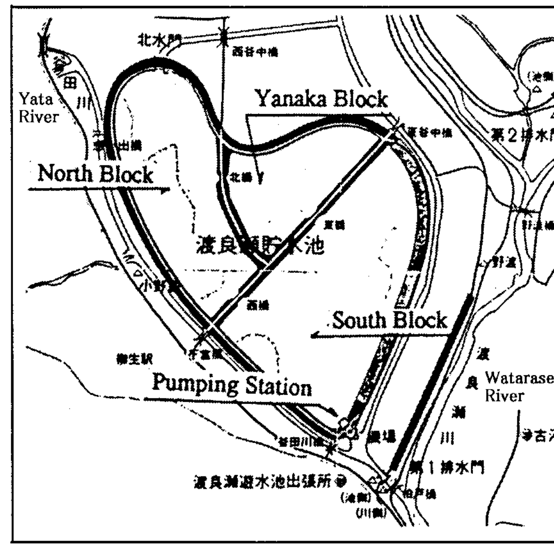

Fig. 1 Lake Yanaka

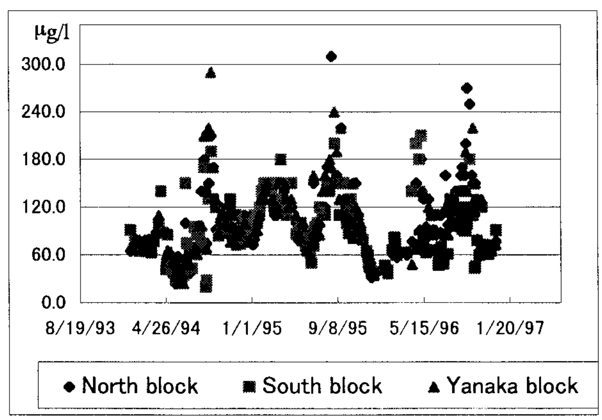

Fig. 2 Chlorophyll-a (μg/l) in three blocks

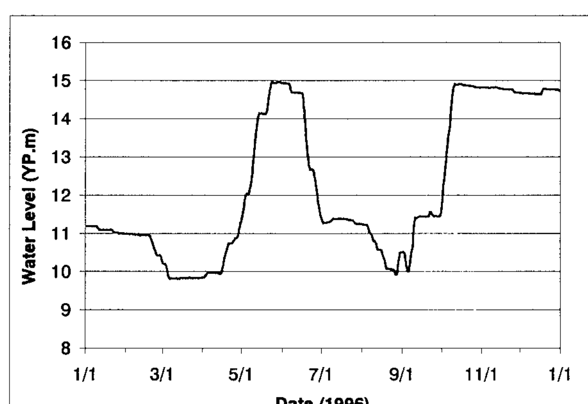

Fig. 3 Water level variation in Lake Yanaka

Examination of variation in suspended solids supports the above reasoning. Since it is found that the peak of suspended solids occurred about one month earlier than the autumn bloom (Figure 7).

Then, regression analysis was made between Chlorophyll a and total phosphorus under different

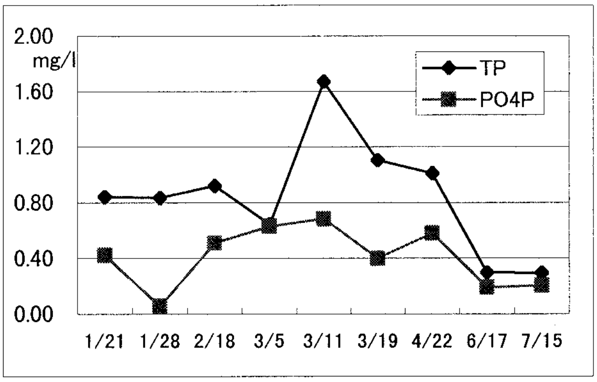

Fig. 4 Nutrients level (mg/l) in the Yata river

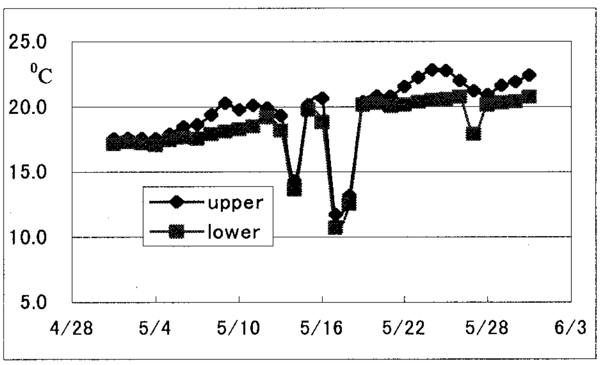

Fig. 5 Water temperature (°C) variation in spring

water levels. It is revealed that the correlation between Chl-a and TP changes significantly with depth. The lower the water depth, the stronger is the correlation between Chl-a and TP as shown in Fig.8. This finding is in support of our argument on the autumn bloom.

In addition, by using the recorded data of water release rate and assuming North wind at 1m/s speed, the flow patter was numerically simulated as shown in Fig.9. According to this flow pattern, it is clear that the nutrients settled near the bank of the North Block may be transported to the middle part of the South Block where they became available for phytoplankton growth.

Figure 10 shows the seasonal cycle of DO in 1996 one meter above the bottom. Dissolved oxygen at the bottom were almost depleted in June 1996 with concentrations below 2 mg/l. The minimum DO level recorded in summer was o.6 mg/l. Such a low concentration of dissolved oxygen may have been harmful to the aquatic lives and may have induced a higher release rate of inorganic phosphorus from the sediments. The nutrients released from the sediment under anaerobic condition may stay over the bed in early summer since there is almost no flow during that period of time. Then, as water release starts, those nutrients will be transported upward by shear stress, which can contribute to the autumn phytoplankton bloom.

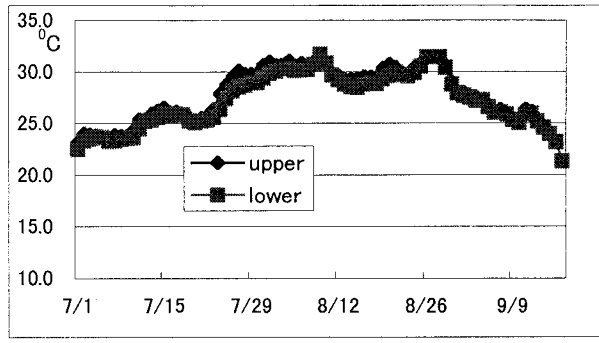

Fig. 6 Water temperature (°C) variation in summer

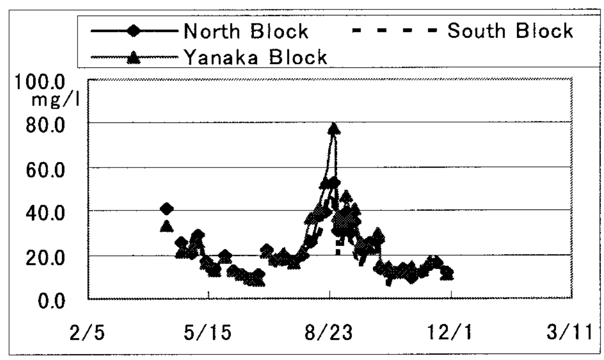

Fig. 7 Suspended solids in three Blocks in 1996

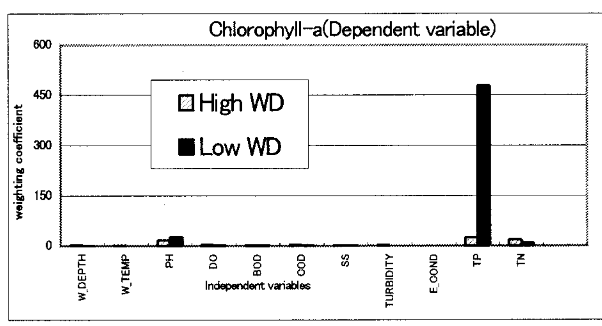

Fig. 8 Water depth influence

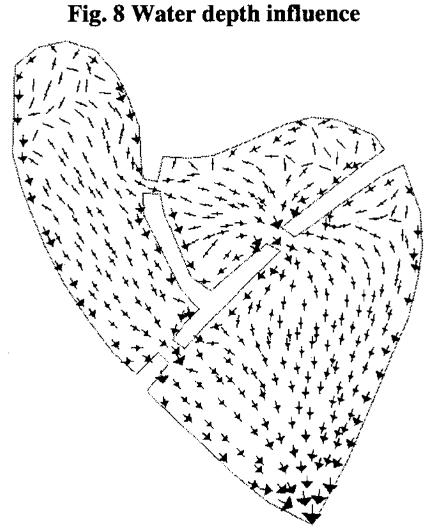

Fig. 9 Flow patter induced by water release

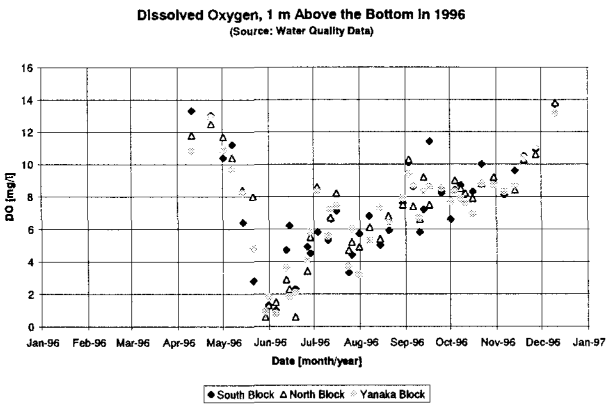

Fig. 10 Dissolve oxygen, 1m above bottom, 1996

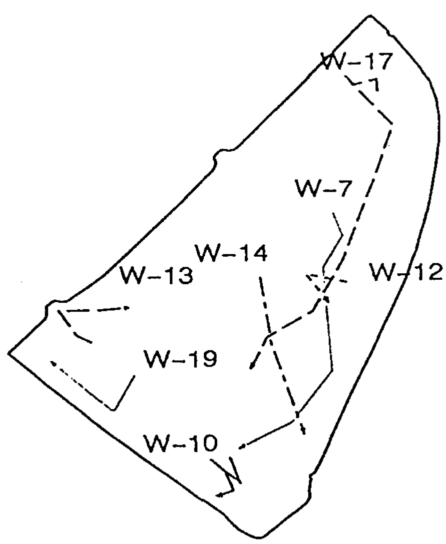

Fig. 11 Observed flow pattern in South block

3. OUTLINE OF FIELD OBSERVATION

To investigate the hydrodynamic behavior of Lake Yanaka, and the spatial variation of water quality parameters, filed observations were conducted from December 3rd to 5th, 1997 and from October 5th to 7th, 1998. In 1997's observation, a number of drifters were released into the lake. The drifters were designed after Bhowmik and Stall(1979), who tested the cross-vane movement with the average velocity of the surrounding water in a flume and described the correlation to be "excellent". After the drifter were released into the lake, photographs were taken hourly from an airplane at a height of approximately 700m. Then, by applying aerial photo processing technique, the movements of the drifters were traced. Because of overcast weather during the time of observation, a large number of photos were too dim to trace the movement of drifters, a successful portion was shown in Fig.11.

In the middle part of the south block, the drifters moved toward the southwest, following the recorded wind direction. And near the opening between the south and north block, a small scale circulation was observed. Water quality parameters such as water temperature, dissolved oxygen, turbidity, EC were measured at five points in each block every three hours. The data suggested that the water quality indexes do not change significantly through space during the period of field measurement. However, it should be mentioned that there were some occasions when the temperature difference between blocks were appreciable.

In 1998, the flow measurement was done with ADCP(Acoustic Doppler Current Profiler). The frequency was 1200KHz. The sampling points are horizontally five points at each block, and vertically nine to thirteen layers according to the local depth. In this way, 3-D structure of the flow field was obtained. The velocities both its magnitude and direction at all sites were recorded every three hours for two days. The water depth at the time of measurement is approximately 5m on average, and 7m as maximum. The meteorological conditions including wind speed and direction were also measured continuously.

Fig. 12-13 show the changes of horizontal velocity components u, v along the depth at S-1 station at the time of 17:00,October 5, and 9:00, October 6, respectively. S-1 denotes the number 1 station in south block which is located near the inlet of the lake. As can be noticed from these figures that around the inlet flow is toward south near the surface while it takes the opposite direction at some depth, and again reverses its direction near the bottom. During the field measurement, water was being taken into the lake from the Yata River and the Watarase River, therefore the vertical profile of flow at S-1 might be caused be the difference in water temperature between lake and river.

Flow structures at Y-1, N-1 station at the time of 17:00, October 5 are depicted in Fig.14-15. They are also characterized by the change in flow direction at different layer. It is then concluded that for the numerical simulation of flow in Lake Yanaka, a multi-layer model might be needed although the lake is shallow.

Figure 16 and 17 demonstrate the horizontal flow vector field at the surface and at the depth of 3m at the time of 11:30, Oct. 6th. It is clear that flow at the depth of 3m was almost in opposite direction to the surface flow. Around that time, the wind speed was weak, approximately 1m/s, toward south. And the pumping station was in operation to take water into the lake. Since the inflow water was colder than that of lake water, we believe that observed flow pattern were probably caused by water temperature

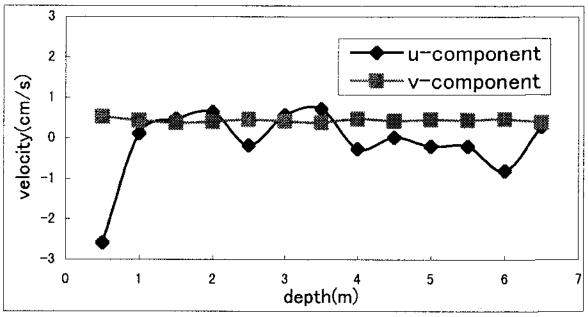

Fig. 12 Velocity at S-1 station (10/5, 17:00)

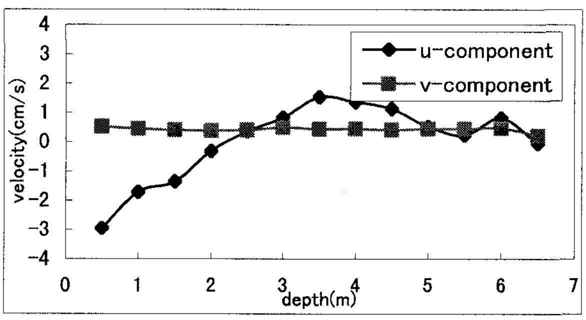

Fig. 13 Velocity at S-1 station (10/6, 9:00)

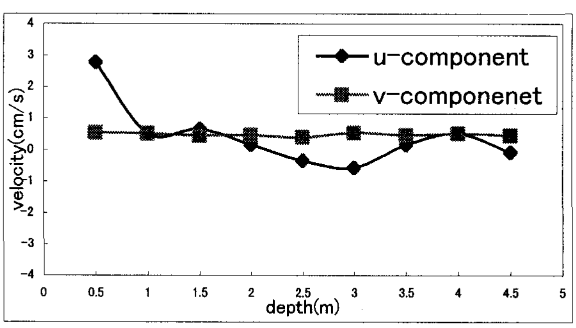

Fig. 14 Velocity at Y-1 station (10/5, 17:00)

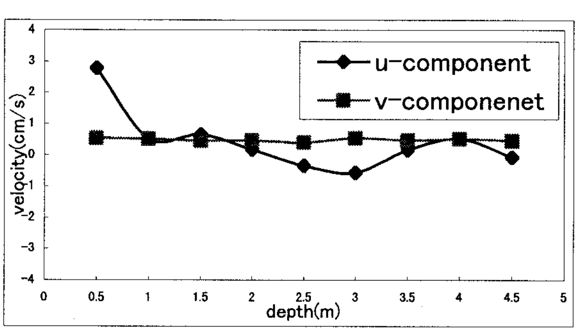

Fig. 14 Velocity at N-1 station (10/5, 17:00)

difference. The cold inflow entered the lake as a plunging flow, and penetrated into the whole lake although the temperature difference was small (probably, <2^{0}C). Such a flow pattern could have wide-ranging implications in the eutrophication process.

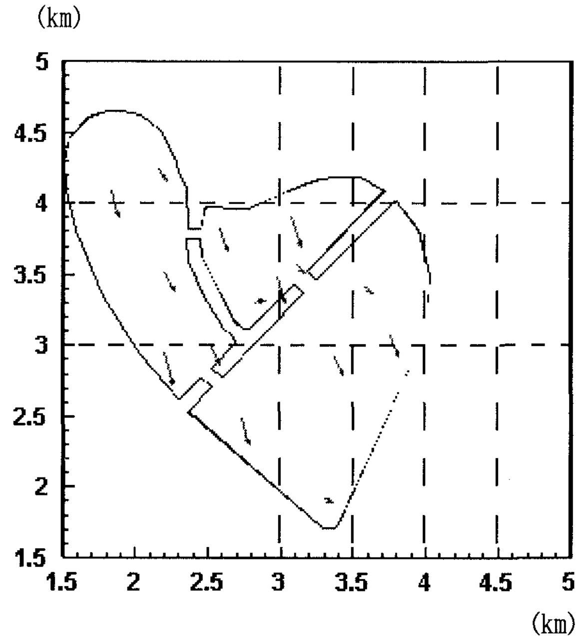

Fig. 16 Observed surface flow pattern

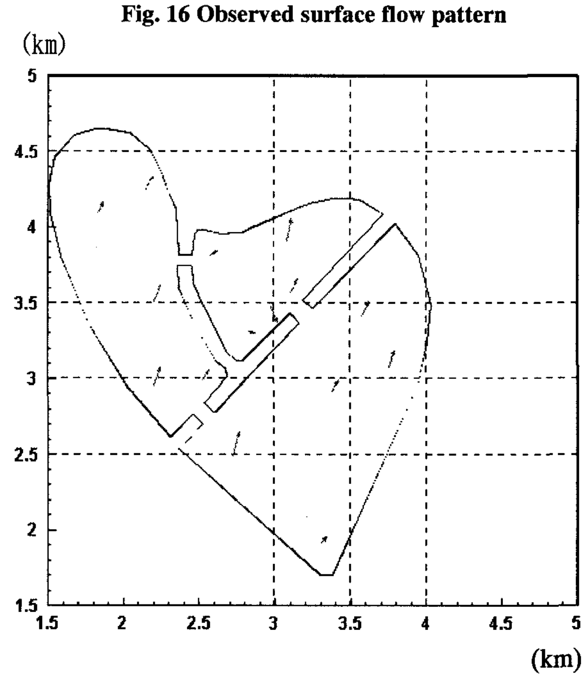

Fig. 17 Observed flow pattern at the depth of 3m

The measured concentrations of total phosphorus in the three blocks are shown in Fig.18-20. The maximum and minimum values are close to each other among blocks. The time and depth averaged concentrations in South, North, and Yanaka block are 0.72mg/l, 0.73mg/l, and 0.749mg/l, almost the same. However, the diurnal variation pattern is different between blocks. It is a common view that TP is a conservative quantity and does not change significantly on daily basis, so that the observed diurnal variation and the difference between blocks implies that bottom release rate of nutrients varies diurnally and has a remarkable degree of spatial heterogeneity. Such features were not reflected in the existing data of nutrients concentrations because they were taken on daily basis.

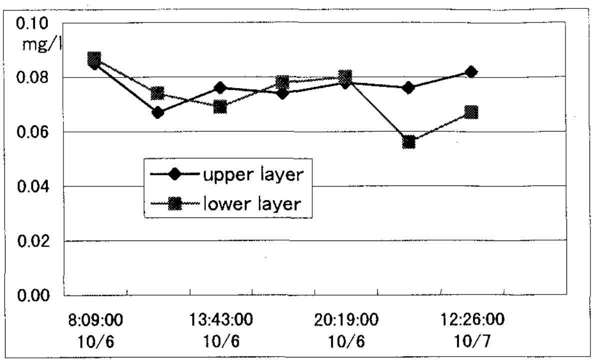

Fig. 18 Measured TP (mg/l) in Yanaka block

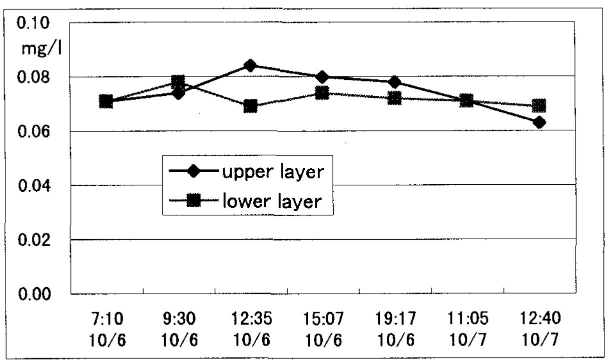

Fig. 19 Measured TP (mg/l) in North block

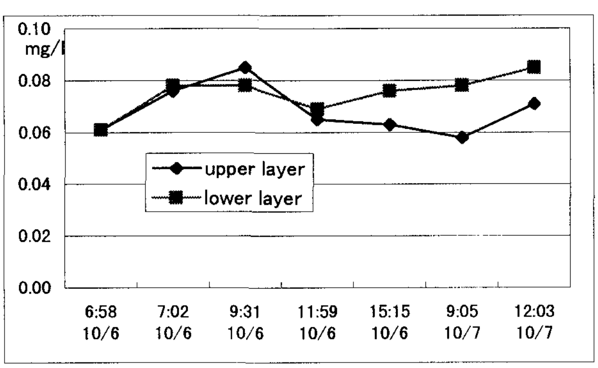

Fig. 20 Measured TP (mg/l) in South block

4. CONCLUSIONS

There were a spring bloom and an autumn bloom in recent years in Lake Yanaka. The spring bloom is caused by inflow load of nutrients and the rise of water temperature due to season change. The autumn bloom is hypothesized to be due to bottom release of nutrients induced by outflow and also due to transport of nutrients from near-levee region to pelagic region of the lake because of the water level drop. This suggests that the reduction of inflow load of nutrients may not be immediately effective in suppressing the autumn bloom. The time lag could be years. It is uncertain how the internal loading will react to a decrease of the external loading. Thus, in addition to long term measures, short-run treatment should be considered. Since the bottom release of nutrients depends largely on the dissolved oxygen level near the bottom, improving DO condition may effectively reduce the internal loading. An important factor in the analysis of DO balance in water is the sediment oxygen demand (SOD). A plunging flow may bring oxygen into bottom layer on the one hand, but on the other hand, it may also enhance SOD, so that the overall balance might become negative. At this moment, SOD level in Lake Yanaka and its seasonal variation remains unclear. We are now working to get some insight into SOD in Lake Yanaka.

Field observations conducted in the past two years have shed some new and valuable light on the hydrodynamic behavior of the lake and the difference of water quality condition between blocks. According to the field data, a multi-layer approach should be taken to model the lake currents, and a multi-block model is necessary for better understanding the eutrophication process in Lake Yanaka. The obtained three dimensional flow structures are currently being used in building up a multi-layer flow model for Lake Yanaka.

Besides, continuous water sampling shows an appreciable difference in diurnal variation of nutrients concentrations between blocks although the mean values are quite close to each other. Therefore, we would like to make a hypothesis that the spatial heterogeneity in phytoplanton productivity is time-scale dependent.

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