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# CHARACTERISTICS OF WATER QUALITY IN LAKE SHIKINAWA OF FUKUOKA, JAPAN

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ABSTRACT: Water quality is one of the main characteristics of water storage reservoirs or lakes. A water quality profile, in both of spatial and temporal variations, plays a very important role in assessment and management of lake water quality. In order to understand the lake water quality parameters, some observation plans were carried out for Lake Shikinawa, in different climate conditions including summer, typhoon occurring time, end of autumn, and before spring. Results of the first observation, which were done in summer, are presented and discussed in this paper. Some important properties of water quality situation of Lake Shikinawa were obtained and analyzed. Measured data also gave a clear understanding of the relationship among water quality parameters, effects of climate condition and aquatic plant coverage on lake water quality distribution. Besides, periods predominated by activities of convection term and wind induction on water quality were cleared from analyzed data.

Keywords: Water quality in lake, water temperature, dissolved oxygen, eutrophication

## INTRODUCTION

Lake Shikinawa is located in Kasuya Machi, a small city in the east area of Fukuoka prefecture (see Fig. 1). Water from this lake is used for agricultural irrigation. Some main characteristics of Lake Shikinawa are shown in Table 1. Based on lake classification standards, this is a small and shallow lake.

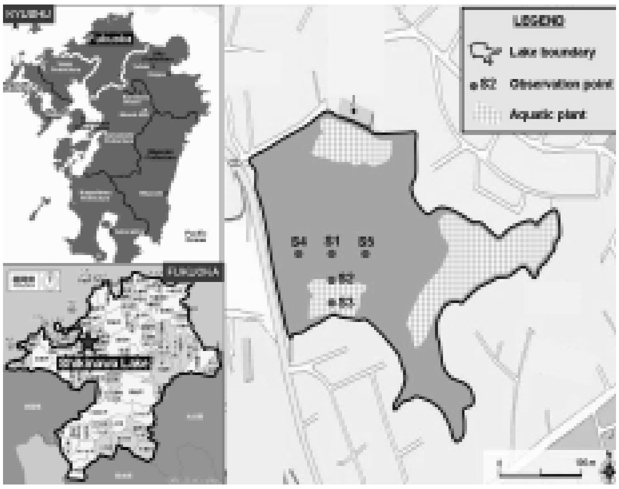

Fig. 1 Location of Lake Shikinawa and observation points

Table 1 Main characteristics of Lake Shikinawa

| Characteristic | Unit | Value |
|---|---|---|
| Basin area | ha | 25.8 |
| Water surface area | ha | 4.93 |
| Total volume | $m^3$ | 123,000 |
| Effective volume | $m^3$ | 123,000 |
| Average depth | m | 2.5 |
| Maximum length | m | 350 |
| Maximum width | m | 175 |

## DATA COLLECTIONS

Field observation was performed in two days, 7th and 8th August, 2007 at Lake Shikinawa. In order to find out effects of aquatic plant cover on variation of water quality parameters, five measuring stations were set at the south-west side of the lake (see Fig. 1). Station S1 was set near to the center of the lake, station S3 was located at the middle of water surface area where covered by aquatic plant, station S2 was defined at the boundary of two above areas. In addition, two other stations, namely S4 and S5, were also used to investigate water quality inside the lake water body at shallow and deep areas, in comparison with other locations within the lake.

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*Note:* Discussion on this paper is open until June 2009

Water temperature, dissolved oxygen (DO), pH, conductivity, turbidity, and total dissolved solids were measured directly inside the water column at every 0.5 m interval up to the depth of 2.5 m. All of these data were observed in 24 hours with time interval of one-hour in daytime and two-hour during nighttime. The equipment used was a portable multi-probe, called Horiba W-23XD (Horiba, Ltd., Kyoto - Japan).

For vertical water temperature profiling, five sensors systems were set at the observation points. Temperature was measured at 0.2m intervals from the water surface downward. Data were recorded automatically at every one minute in 24 hours using thermo-dac recorders.

Water samples were collected from the field at the depths of 0.1 m, 1.5 m and 2.5 m. These samples were then analyzed for total nitrogen (T-N), ammonia, nitrite, nitrate, total phosphorus (T-P), and ortho-phosphorus using ion chromatography method. The equipment used in the analysis was SwAAt, a full-automatic wet chemical Auto-Analyzer developed by BL TEC K.K., Japan.

Hydraulic and meteorological data were also measured at the same time and locations of water quality measurements.

There are a lot of water quality data, however, in this paper, we focused mainly on the analysis and discussion for data obtained from three stations: S1, S2 and S3.

Data series of vertical water temperature at station S1 were unexpectedly stopped at 5:25 of the 8th August due to recorder error. Generally, this series had similar trends when compared with data obtained from other stations. Therefore, data series measured at station S1 were considered representative for the non-covered aquatic plant area.

## RESULTS AND DISCUSSIONS

### Meteorological Data

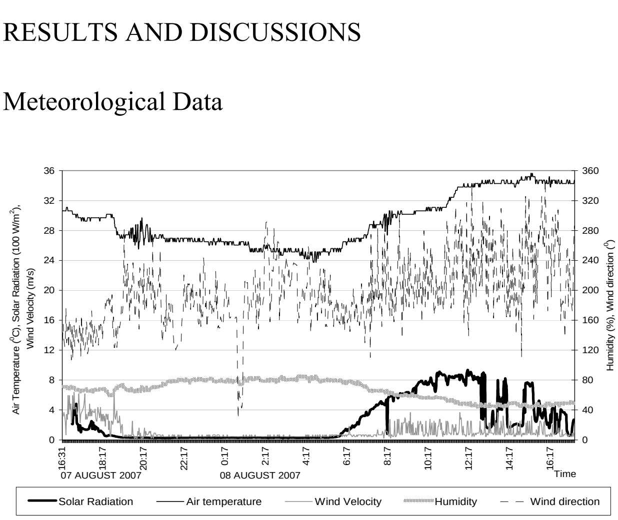

Fig. 2 Meteorological data

Air temperature reached the peak (35.7$^0$C) at around 15:15, and the lowest value (23.8$^0$C) was observed at early morning (see Fig. 2). The difference between the highest and the lowest temperatures was 11.9$^0$C and about 11 hours in time. It reflected the effect of solar radiation, which was high in daytime but very low during nighttime period. The highest solar radiation value, 0.93 kW/m$^2$, occurred around 12:00, approximately 3.5 hours earlier than the time when air temperature reached the maximum value. As usual, the level of solar radiation was high during daytime, but sometime it dropped to a very low level. We also found that air temperature started to increase at about 1 hour earlier than solar radiation started to rise.

At the time of observation, wind speed was strong during daytime, especially wind velocities increased up to about 6 m/s at around 5:00 of the first day, with the prominent direction being South-East. At the daytime of the second day, the average wind velocity was 3 m/s, with directions varying from south of South-West to west of South-West. During nighttime, wind speed was low in the true South direction.

Contrary to the changing tendency of wind speed, solar radiation and air temperature, relative air humidity was high during nighttime (around 80%), about two times higher than daytime humidity.

### Water Temperature

#### *Daily cycle of water temperature*

-Water temperature at station covered by aquatic

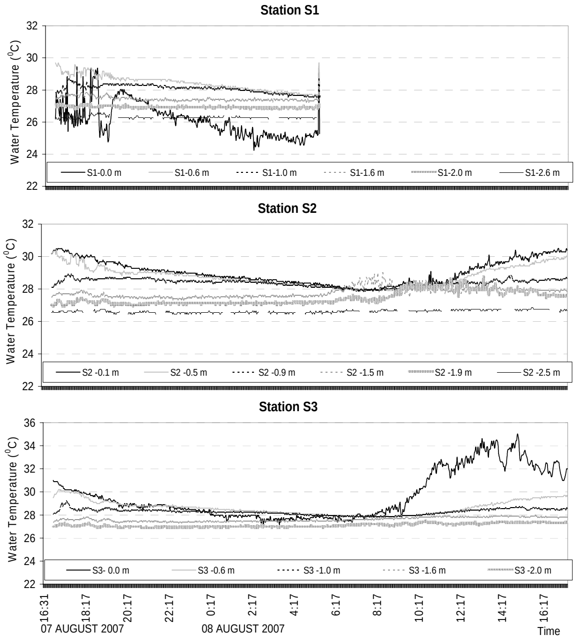

Fig. 3 Daily cyclic water temperature by layers at three stations

Table 2 Daily cyclic properties of water temperature and some meteorological parameters

| Item | Starting to increase | | Starting to decrease | |
|---|---|---|---|---|
| | Min Value | Time | Max Value | Time |
| Air temperature ($^{0}$C) | 23.76 | 04:30 | 35.65 | 15:30 |
| Solar Radiation (100 Wh/m$^{2}$) | 0.0 | 5:30 | 0.90 | 13:00 |
| Wind Velocity (m/s) | 0.46 | 02:00 | > 6.0 | 17:00 |
| Water temperature at S1 ($^{0}$C) | 26.0 - 27.5 | 7:00 | large variations | 17:15 |
| Water temperature at S2 ($^{0}$C) | 26.5 - 28.0 | 8:00 | large variations | 17:15 |
| Water temperature at S3 ($^{0}$C) | 27.5 - 28.0 | 8:30 | large variations | 17:30 |

plant (S3) tended to decrease later than other stations and about 4.5 hours later than the time at which solar radiation started to decrease. This time difference was not found when comparing data measured between S1 and S2 (see Fig. 3 and Table 2).

-The highest values of solar radiation were found at about 3.5 hours earlier than the peak values of water temperature. It meant that heat from solar and air needed time to heat up water in the lake. In this case, time for water to reach the highest temperature was long, due to the effect of strong winds.

-We found that the time at which water temperature started to increase at station S1 was about 1.5 hours later and at S2 it was 1.0 hour earlier than the time at which solar radiation started to raised. At S3, water temperature started to increase later than that at S2 about 0.5 hour. These findings reflected the effect of aquatic plant in delaying heat that came into water from solar radiation.

-Daily cycle of water temperature at different layers had the same tendency at a time. This was a distinct property of a shallow lake, where heat took a very short time to come from surface to bottom of the lake.

-Larger fluctuation in water temperature occurred when wind velocity was high. At the surface layer of stations S1 and S3, changes in temperature were very large, especially at S3 sometime water temperature was nearly equal to air temperature.

-The deeper the water column, the smaller variation of water temperature. There were no significant temporal changes observed at the bottom layers of stations S2 and S3. In the lower layers, water temperature was found higher at S3, while it was lower at S1.

*Vertical profile of water temperature*

At the water surface, the effect of wind action was very high. As shown in Fig. 4, the trend of vertical water temperature in the upper layers at station S1 and station S3 were inversed in comparison with each other, while it was not so much different at station S2.

- Mixed layer depths (thermoclines) started at depths from 1.4 m to 1.6 m at station S1, from 1.3m to 1.4 m at station S2, and from 1.2 m to 1.4 m at station S3. It meant that aquatic plant cover played an important role in controlling the mixing phenomenon. At the station where there was no plant cover, heat from solar radiation could mix more deeply into the water column.

-Temperature tended to decrease in increasing water depths. Large variation of temperature was found at shallower water layers, while at deeper layers, such a variation was very small at all time. This phenomenon was affected by solar radiation.

-In comparing temperature measured at three stations, we found that there was very small difference at the surface layers. In contrast, at the bottom of the lake, highest values appeared at station S3, while it was smaller at S2 and lowest at S1.

-At station S1, water temperature at the lake surface was smaller than that in the lower layers. This difference did not observe at S2, while it was inversed at S3. This phenomenon was affected by wind actions and aquatic

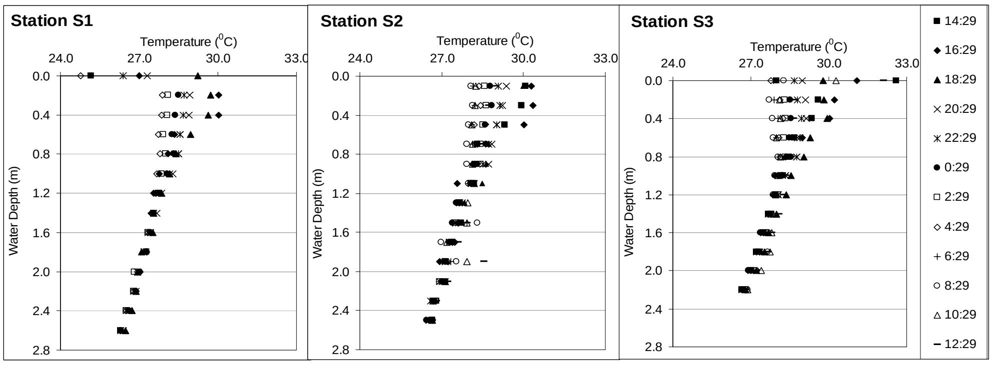

Fig. 4 Time variation of vertical temperature measured at three stations

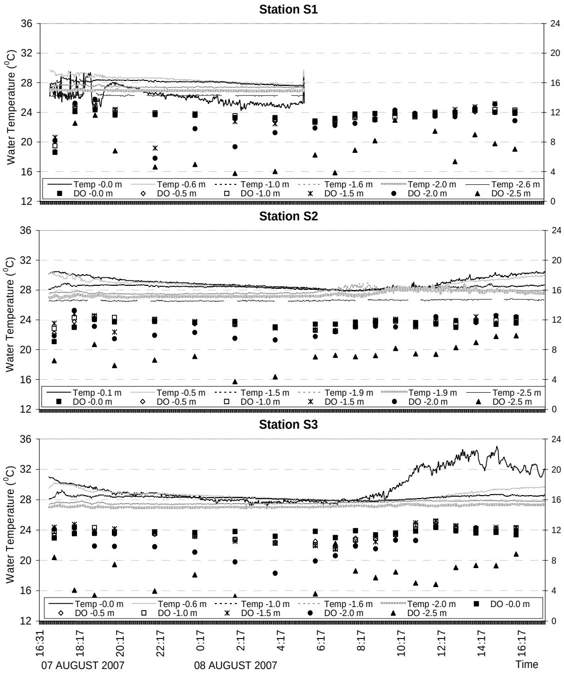

Fig. 5 Daily cyclic DO, temperature by depths at three stations

plant cover (Ozaki et al., 2004).

## Dissolved Oxygen

### *Daily cycle of DO*

-This lake had high concentration of DO (see Fig. 5), especially at water depths smaller than 1.6 m. All measured DO concentrations were satisfied Japanese standard (see Table 3) of water quality used for agriculture and natural environmental conservation.

-DO concentration of shallow water layers (at depths smaller than 1.5m) at three stations had the same changing tendency of water temperature. This phenomenon caused by photosynthesis of aquatic plant.

-The average water transparency in the lake was measured around 1.6 m. Therefore, in layers deeper than this depth, photosynthesis of aquatic plant was weak and, conversely, respiration activity was high. These caused lower values of DO at deeper layers.

-Shallow layers hold high DO concentration during periods having strong wind action that could accelerate DO levels in water On the contrary, DO concentrations at deeper layers were low and unstable.

-During daytime, DO at station S1 was generally higher than that at stations S2 and S3, and it was inversed during nighttime. This phenomenon was similar to the general trend of water temperature variation that caused by high solar radiation and strong wind action during daytime and the daily convection cycle of the water inside the lake.

-When wind speeds were high, the difference of DO levels at each water layer was small. When wind action was weak, conversely, such difference was high. This phenomenon demonstrated that the lake was well-mixed under strong winds.

### *Vertical variation of DO*

-Because the lake was shallow and easily mixed by wind, DO concentration (see Fig. 6) was fairly consistent throughout the water column at the time when wind action was strong. When it was calm, some pronounced declines with depth were observed.

- DO profile had an inverse tendency when compared with the profile of water temperature. These data showed that the activity of aquatic plant, algae, and other processes consuming DO in water column was increasing with water depths down to 2.0 m, even the average transparency level measured was about 1.6 m.

-On the other hand, upper water layers normally contain higher DO than lower layers do, however the trends in all three stations were inversed. This occurrence showed that at a high water temperature, the dissolving ability of oxygen was limited. Another reason was due to the convection of water layers being affected by wind action.

-DO concentrations in the layers near to the lake bottom dropped to very low values because oxygen

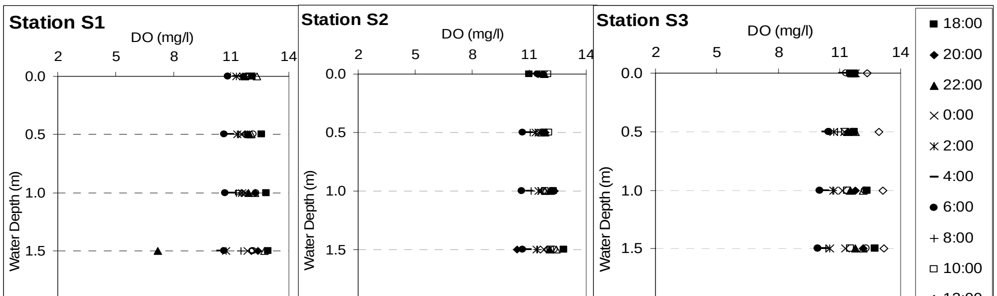

Fig. 6 Time variation vertical DO concentration measured at three stations

Table 3 Japan standard for water quality parameters

| | Water use | Standard pH | Standard DO |
|---|---|---|---|
| AA | Water supply class 1, fishery class 1, conservation of natural environment, and uses listed in A-C | 6.5 - 8.5 | 7.5 mg/l or more |
| A | Water supply classes 2 and 3, fishery class 2, bathing, and uses listed in B-E | 6.5 - 8.5 | 7.5 mg/l or more |
| B | Fishery class 3, , industrial water class 1, agricultural water, and uses listed in C | 6.5 - 8.5 | 5 mg/l or more |
| C | Industrial water class 2 and conservation of the environment | 6.5 - 8.5 | 2 mg/l or more |

*(Source: Ministry of the Environment - Japan*)

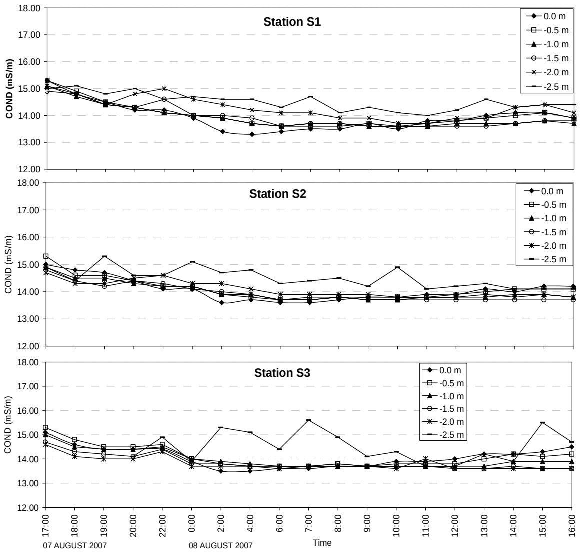

Fig. 7 Daily cyclic conductivity measured at three stations

consumption was greatest near the bottom of the lake, where sunken organic matter accumulated and decomposed.

Conductivity

*Daily cycle of conductivity*

-Daily cycle profile of conductivity reflected the temperature sensitive property of conductivity of water in a lake. These trends were found in all water layers at three stations (see Fig. 7).

-At station S1, where water surface was not covered by aquatic plant and vertical changes of water temperature were large, the difference of conductivity in each water layer was big during daytime while became small during nighttime. Conversely, as presented by data obtained at stations S2 and S3, where vertical profiles of water temperature were more stable, such differences in conductivity during daytime were bigger than that during nighttime.

-Generally, bottom layers had high but unsteady conductivity. The highest conductivity difference found at three stations was not big (from 15.3 to 15.5 mS/m), but this value of data measured at S1 was found in the first layer, at S2 it was the second layer, while at S3 it was the bottom layer.

-The lowest conductivity, 13.25 mS/m, was measured in the surface layer at station S1 at time 4:00 AM of the second day, when water temperature was dropped to the lowest values. This value was 13.6 mS/m at S2 and 13.5 mS/m at S3, occurring about 2 hours earlier than S1.

*Vertical variation of conductivity*

-As shown in Figs. 7 and 8, the conductivity of the bottom layers tended to increase with water depths. This was inversely proportional to vertical water temperature profiles and did not follow general temperature sensitive property of conductivity.

-Another important property of conductivity variation affected by aquatic plant cover was found here. At station S1, the largest time difference in conductivity was observed at the surface layer, while it was found at the bottom layer of S3. At station S2, time variation was found to be similar at all water layers from the surface to

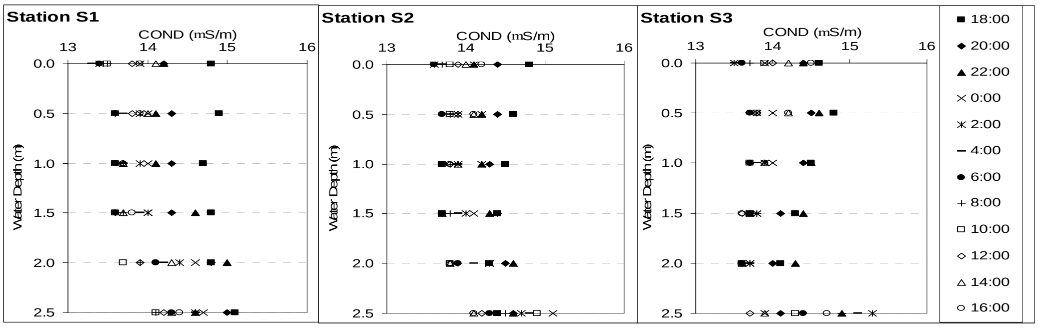

Fig. 8 Time variation of vertical conductivity measured at three stations

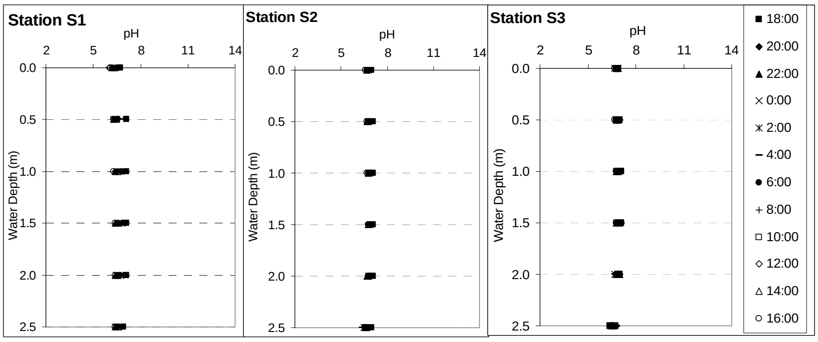

Fig. 9 Time variation of vertical pH measured at three stations

the bottom of the lake.

-From above investigations, it could be conclude that, beside the effect of ion concentration in waste water drained into the lake, aquatic plant cover had significant impact to the variation of conductivity of the lake water.

## Variations of pH

There was no big change in both of temporal and spatial variation of pH (see Fig. 9).

In estimation of vertical pH, at station S1 (no coverage) pH slightly increased from the water surface to the bottom of the lake. This tendency was not found at station S2 and inversed at station S3 (aquatic plant cover). The distribution of pH in the vertical direction has the same trends with that of conductivity.

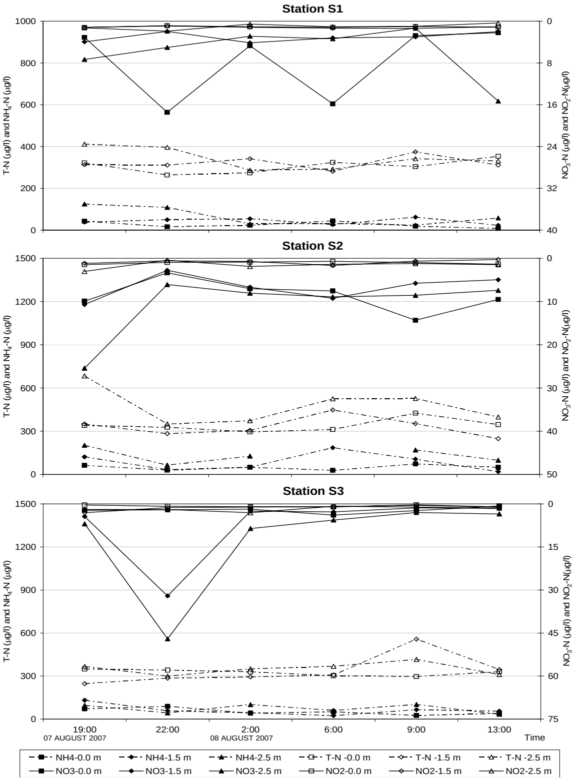

Fig. 10 Daily cycle of nitrogen components measured at three stations

At the surface layers, values of pH increased from S1 to S3, this is inversed in comparison to tendency of water temperature.

## Nutrient

### *Daily cycles of nitrogen components*

In the water column, nitrogen exists in three main types which are ammoniac ($NH_3$), nitrite ($NO_2^-$), and nitrate ($NO_3^-$). They are usually found in the water and, therefore, are very important for water environment.

Ammoniac $NH_3$ has two main components including $NH_3$ and $NH_4^+$ and depends on pH of water. If pH low, ammoniac tends to hold higher concentration of ion $NH_4^+$ and, on a contrary, this ion is high at high pH environment. In relationship to water temperature, the concentration of $NH_4^+$ is low at high temperature. If the concentration of ammonia is high, at high temperature, water tends to contain higher concentration of $NO_2^-$.

As results shown in Fig. 10, there were no significant tendencies in daily cycle of almost nitrogen components. Values of $NH_4^+$ were a little high but they still satisfied the water quality standard for domestic uses of the European Union (EU), less than 0.5 mg/l, and World Health Organization (WHO), less than 1.5 mg/l. The tendency of $NH_4^+$ also depends on pH and water temperature in the lake. Other nitrogen components, e.g., nitrite ion $NO_2^-$, and nitrate ion $NO_3^-$ were low and all of analyzed data were lower than water quality criteria for agricultural uses of EU (50 mg $NO_3^-$/l, 0.1 mg $NO_2^-$/l), WHO (50 mg $NO_3^-$/l, 3 mg $NO_2^-$/l), and America (45 mg $NO_3^-$/l, 3.3 mg $NO_2^-$/l). T-N concentrations were satisfied Japan water quality criteria for agriculture and fishery (see Table 4).

When evaluating the impact of aquatic plant cover on variations of nitrogen components, some notable results were defined. The concentration of ion $NO_3^-$ measured at station S1 was much higher than the concentration of ion $NO_2^-$. This distinction was smaller at station S2 and very small at station S3.

Table 4 Japan Standard for T-N and T-P

| Class | Water use | Standard value | |
|---|---|---|---|
| | | T-N | T-P |
| I | Conservation of natural environment and uses listed in II-V | ≤ 0.1 mg/l | ≤ 0.005 mg/l |
| II | Water supply classes 1, 2, and 3 (except special types), fishery class 1, bathing, and uses listed in III-V | ≤ 0.2 mg/l | ≤ 0.01 mg/l |
| III | Water supply class 3 (special types) and uses listed in IV-V | ≤ 0.4 mg/l | ≤ 0.03 mg/l |
| IV | Fishery class 2 and uses listed in V | ≤ 0.6 mg/l | ≤ 0.05 mg/l |
| V | Fishery class 3, industrial water, agricultural water, and conservation of the environment | ≤ 1 mg/l | ≤ 0.1 mg/l |

Values of T-N and $NH_4^+$ had the biggest daily variation at the bottom of station S1, and it occurred at some deep layers at S2, but no big changes were found at S3. These trends were conversed when comparing with the obtained values of ion $NO_3^-$. Changes of $NO_2^-$ concentration in a daily cycle were very small.

*Daily cycles of phosphorus components*

- Similar to nitrogen components, the daily cyclic variations in the concentration of T-P and ion $PO_4^-$ had no clear trends (see Fig. 11).

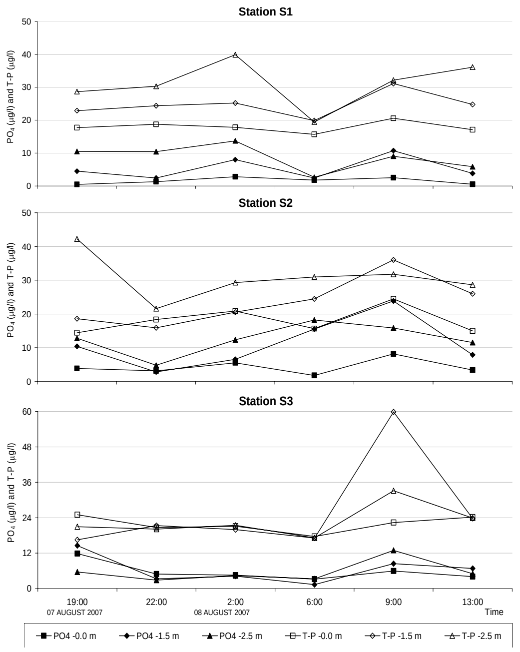

Fig. 11 Daily cycle of phosphorus components measured at three stations

Table 5 N : P ratios measured in the Shikinawa Lake – data observed in summer time

| Time | Depth (m) | TN/TP Ratio | | |
|---|---|---|---|---|
| | | S1 | S2 | S3 |
| 19:00 | 1.5 | 13.71 | 18.79 | 14.98 |
| 2:00 | 1.5 | 13.58 | 14.89 | 14.73 |
| 6:00 | 1.5 | 14.19 | 18.31 | 18.01 |
| 9:00 | 1.5 | 12.04 | 9.79 | 9.31 |

-All values of T-P measured at three stations S1, S2 and S3 were lower than the permissible value (0.1 mg/l) as regulated by Japanese water quality standard for uses of agricultural and water environmental conservation (see Table 4).

-The variation of T-P was large in both temporal variation and layer difference at station S1, while it was smaller variation at S2 and more steady at S3 (except separated values analyzed from sample collected at time 9:00 AM of the second day).

-Almost values of $PO_4^-$ were smaller than 10 µg/l. The smallest amount and most stable variation of $PO_4^-$ were observed at station S3, while they were higher and unstable at two stations S1 and S2. The lower water depth, the higher levels of $PO_4^-$, as a result of oxygen depletion at bottom layers.

*Limiting nutrient*

In eutrophication management it is often important to identify which one among several nutrients used for plant nutrition which ultimately controls the growth of plant in the water body. A first cut at identifying this “limiting nutrient” is to compare the level of the nutrients in the water with the cell stoichiometry. This is most commonly done for nitrogen and phosphorus. A rough rule of thumb for assessing which nutrient in the water is limiting relates to the nitrogen-to-phosphorus ratio. This ratio in biomass is approximately 7.2 (Charpa, 1998), therefore, N : P ratios less than 7.2 suggest that nitrogen is limited and, conversely, higher levels imply that phosphorus will limit plant growth.

Another data set of TN and TP, which was observed at the end of autumn, was also considered to estimate eutrophication state of the lake as shown in Table 6.

Table 6 N:P ratios measured in the Shikinawa Lake – data observed at the end of autumn

| Time | Depth (m) | TN/TP Ratio | | |
|---|---|---|---|---|
| | | S1 | S2 | S3 |
| 13:00 | 1.5 | 18.20 | 30.70 | 39.91 |
| 19:00 | 1.5 | 22.28 | 23.74 | 17.12 |
| 2:00 | 1.5 | 14.66 | 20.92 | 22.46 |
| 9:00 | 1.5 | 21.44 | 20.18 | 28.64 |
| 13:00 | 1.5 | 12.57 | 9.54 | 14.56 |

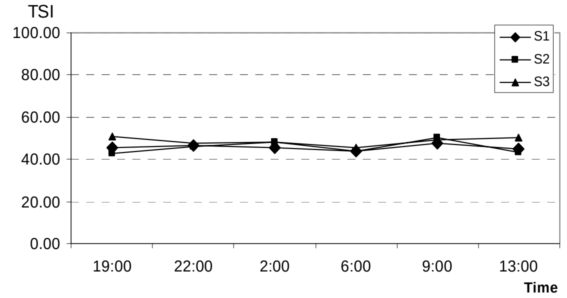

Fig. 12 TSI index calculated at three stations using surface concentration of T-P (summer time)

Determining Trophic Status of the Lake

The trophic state index (TSI), or the Carlson index, has been devised for "rating" lakes (Hoeven, 2005). A lake which has TSI less than 40 can be classified as an oligotrophic lake, if TSI is greater than 60, it is called a eutrophic lake, and mesotrophic status is defined with TSI ranged from 40 to 60.

As the analyzed data shown in Tables 5 and 6, at all observation points in Lake Shikinawa, ratios N : P were higher than 7.2, meaning that phosphorus is the limiting factor in this lake.

TSI can be calculated by using the Secchi disk depth (a method to measure transparency level of water in lakes), the total phosphorus (T-P) concentration at the surface of the lake, or the chlorophyll a concentration at the surface. Either one day’s values or, preferably, average values over the summer can be used.

In this paper, measured average transparency level of the lake (about 1.6m) and values of T-P analyzed from collected water samples were used to calculate TSI following these equations:

Using Secchi disk depth:

$$TSI = 60 - 14.41 (\text{In } SD) = 60\text{-}14.41(\ln 16.0) = 53.2$$

Using T-P: $TSI = 14.42 (\text{In } T\text{-}P) + 4.15$

where SD is the Secchi depth in meters, T-P is the total phosphorus concentration measured in the surface water in µg/l, and ln stands for the natural log of a number.

Based on results of TSI calculated from transparency level of the water and amount of T-P analyzed (see Figs. 12 and 13), Lake Shikinawa could be classified as a mesotrophic lake.

CONCLUSIONS

Based on data observed in Lake Shikinawa, we found the interesting characteristics of the lake water quality, effects of meteorological condition and aquatic plant cover as well as the trophic status of the lake, which are the followings:

1. All water parameters measured in Lake Shikinawa were satisfied the water quality standards of Japan for agricultural supply and water environmental conservation. However, some strange point found at increasable ion concentration and high value of ammonia might be caused by contaminations came from drainage water that drained into the lake.
2. Most of water quality parameters had a clear variation tendency in a daily cycle. But in vertical distribution, it was difficult to define general trends of nutrient components.
3. Meteorological factors, especially wind action and heat flux from solar radiation had significant effects on the level and distribution of water quality in the lake.
4. Aquatic plant cover played an important role in controlling the lake’s water quality, in both horizontal and vertical directions.
5. When evaluating eutrophication using N:P ratio, phosphorus limiting situation was found in this lake, it meant that after a limited time, phosphorus ran out, thus algae could no longer grow and excess nitrogen remained in the water.

Finally, from observed and analyzed results, it can be concluded that Lake Shikinawa was a small, shallow, mesotrophic, and phosphorus limited lake at the time of observation.

In a further study, some other observations for Lake Shikinawa water quality have been planned. Additional data will help us to know more about this lake’s water quality situation and the variation of water quality parameters in a longer cycle instead of only a daily cycle. Besides, a three-dimensional model for simulatiing hydraulic and water quality parameters has been developed, which allows us to predict or simulate the variation or movement of water quality concentrations inside the lake.

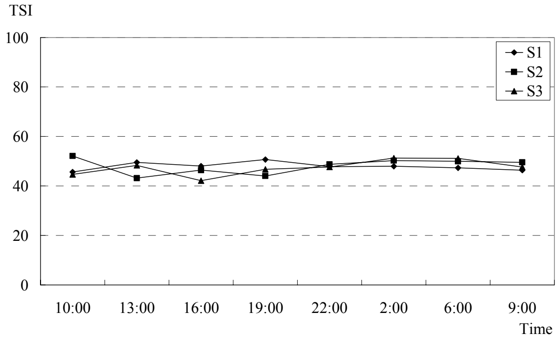

Fig. 13 TSI index calculated at three stations using surface concentration of T-P (end of autumn)

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