International Journal of GEOMATE, Oct., 2016, Vol. 11, Issue 26, pp. 2547-2552
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

CHANGES IN DEPTH AND THE SEDIMENT RATE BEFORE AND AFTER THE LAKESHORE DEVELOPMENT IN LAKE FUKAMI-IKE, JAPAN

Maki Oyagi[1], Megumi Nobori[2], Hiromi Ssuda[2], Akiko Yokoyama[3], Akihiko Yagi [2]

[1]Yokkaichi University, JAPAN, [2]Aichi Institute of Technology (AIT), JAPAN, [3]Water Agency Inc, JAPAN

ABSTRACT: Changes in depth and decrease of the sediment rate before and after a building breakhead maintenance construction were studied in small monomictic and eutrophic Lake Fukami-ike in central Japan. The maintenance of farm village drainage and the waterfront function was carried out for the activation of the town in 1992, and the water quality improvement was expected. However, variations of transparency were observed and no blue-green algal bloom outbreak had occurred before recently observed. Maximum depth changed from 9.3 m (1951), 8.5 m (1979), 8.1 cm (1992) to 7.8 m (2012), respectively. Changes in the autochthonous and allochthonous matters in the lake were thus considered. Sediment rates of 19.5 ± 10.19 $gm^{-2}d^{-1}$ (1978 to 1979) and 4.40 ± 2.27 $gm^{-2}d^{-1}$ (2007 to 2008) were observed, and decreased 22.6%. These deposition rate data corresponded to 3.1 cm $year^{-1}$ (1979) and 1.2 $cmyear^{-1}$ (2009), respectively. The decreased percentage of organic matter and the reduced deposition rate were because rice fields and forest around the lake give way to take concrete roads. It was considered to be because the inflow of sediment stopped when it rained, and allochthonous inorganic matter was significantly reduced.

Keywords: Eutrophic lake, Sediment rate, Ttransparency and Lakeshore development

1. INTRODUCTION

Fukami-ike is a natural eutrophic lake located in Oshimojo, Anan-cho, Shomoina-gun, Nagano prefecture, specifically, N35°19' and E137°49', and a sea level of 484 m. The minor axis of the lake is 150 m, and the major axis of the lake is 300 m. The area of the lake is 2.1 ha (Figure 1). The catchment area is 0.247 km^2 [1], and there were 12 residences within the catchment in 2008. As for land use prior to lakeshore development involving fertilization and nutrient salt influx, the land was used as an orchard. However, presently the land is only used as rice paddies (4% of the catchment area: 0.010 km^2) and for farm use (65%: 0.16 km^2). There are 10 inlets (7 locations have continuous influx) and one outlet.

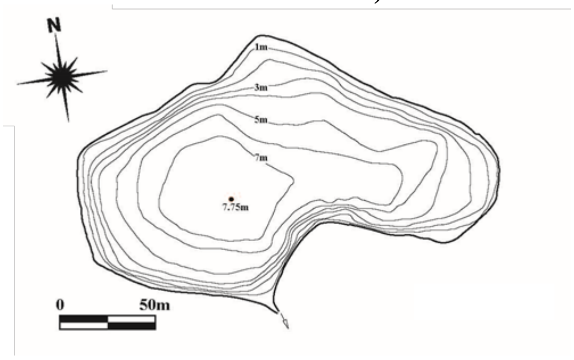

Fig.1 Lake basin of lake Fukami-ike

With Fukami-ike as the central point, Mount Hanso, the highest point in the surrounding area and located on the north side, and Senkizawa river on the south side were connected with a north-south line [2].

Fukami-ike is surrounded by mountains, and is located in a basin. It is affected little from the wind, and its depth is significant compared to the surface area. Therefore, temperature stratification of water occurs in the lake from April to November. Especially in midsummer, there is absence of oxygen under 4 m [3].

In this paper, we present several scientific characteristics of Fukami-ike. First, it is a natural eutrophic lake, rich in nutrient salt. Therefore, the lake water is cloudy, and dark or faded green in color. The values of pH and dissolved oxygen are high during the summer season. Furthermore, this lake has a high primary production which is produced by a large number of phytoplankton. Especially, during the autumn circulation period, chlorophyll a concentrations of 80 to 100 mg m^{-3} was measured throughout all the layers. Even during the winter season, phytoplankton bloom occurs, and chlorophyll a concentrations become higher than the summer [3].

At Fukami-ike, as a water environment improvement project (Led by Nagano prefecture), lakeshore construction began in November 1992. The two main goals of this water environment improvement project were (1) maintenance of farm village drainage and (2) landscaping as a hydrophilic function. As a result, due to maintenance of farm village drainage, gray water influx to the lake from the surrounding area stopped, and due to landscaping, boardwalks were built around the lake, and influx of surface water from water catchment area was almost eliminated. Afterwards, experts' opinions were taken into account, and the construction was carried out with the water depth lowered to 5 m instead of the usual 7.75 m, and instead of draining the whole lake water. Also, before and after the lakeshore development, there were no changes to the position and the height of the outlet. In this report, this water environment improvement project is defined as the lakeshore development of Fukami-ike and issues are discussed.

To determine whether internal production volume changed due to the lakeshore development of Fukami-ike, transparency and deposition rate were discussed based on the values reported in the literature in the past 50 years and the new observation results.

2. METHODS

Use at most three levels of headings that correspond to chapters, sections and subsections. The first level headings for chapter titles should be in 10pt, bold, justified, and upper case font. Leave one-blank line before and after the first level headings, respectively. Transparency was observed by secchi disk from 1978 to 2009. Precipitated matter were collected in sediment bottles each depth (3m, 5m and 7m) and recovery one month. Bottom sediment were collected by Ekman-Birge grab from 2007 to 2009. Water content ratio and density of bottom sediment were measured to find sediment rate. The formula [4] of the sediment rate was indicated.

$$h = (b / a c) \times (100 / (100 - w))\times 365$$

h:sediment rate (cm year^{-1}), w:average water contents of surface sediment (0-10cm depth), a:mouth area of sediment trap bottle (cm^2), b:dry weight of precipitated matter (g), c:density of sediment, t:total days

3. RESULTS AND DISCUSSIONS

3.1 Transparency

Transparency of Fukami-ike has been reported since July, 1950 [5]. Though there are many gaps, there are accumulated data of over half a century until December, 2009 [5],[6]. In this report, characteristics of transparency over each generation will be discussed based on these data (Figure 2).

Transparency of Fukami-ike was 0.7 m - 2.8 m (average value ± standard deviation, 1.38 ± 0.67 m) during 1950's. Later on, (1970's), prior to the lakeshore development (April 1992), values ranged from 0.50 m to 2.30 m (1.04 ± 0.30 m). Compared to during 1950s, both average value and seasonal changes are lower. After the lakeshore development (data from July 1999 to December 2009), average values increased significantly (0.35 m - 4.70 m : 1.93 ± 0.88 m).

Fig.2 Changes of transparency

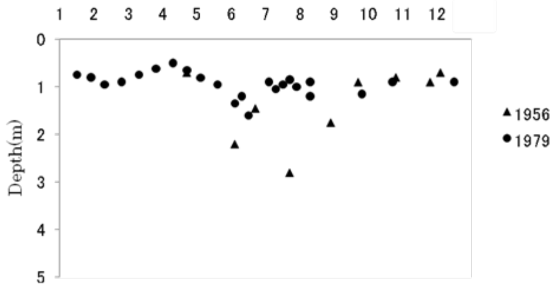

Fig.3 Seasonal changes of transparency (before lakeshore development)

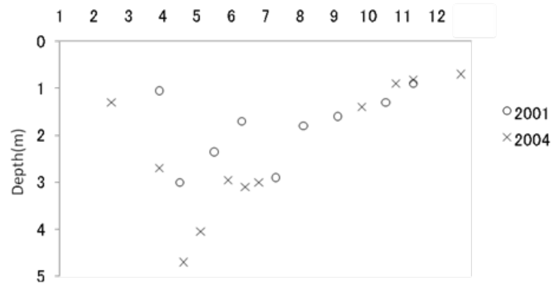

Fig.4 Seasonal changes of transparency (after lakeshore development)

Generally, primary production is high in lakes during the summer season when the water temperature is high, and low during the winter season when the water temperature is low. However, Fukami-ike has unusual characteristics as reported by [3]. There is little regression of nutrient salt from deep to surface water layers occur during the summer stratification period. During the autumn circulation period, nutrient salt is carried to the surface layer, and primary production is high even during the winter. Seasonal changes in transparency prior to the lakeshore development are shown in Figure 3, and after the development are shown in Figure 4. Average values and seasonal changes show some variations. But in both before and after the development, transparency is high during the stratification period when regression of nutrient salt from deep-water layer is low, and transparency is low during the circulation period when primary production is high. These results confirmed the unusual characteristics of Fukami-ike.

The highest value of transparency during 1950 to 2009 was 4.70 m in April 2004, and the lowest value was 0.35 m in June 2000. At that point, the presence of blue-green algae was visually confirmed. Until then, the presence of blue-green algae has not been confirmed. But since the latter half of 1990s, it was confirmed several times, and even local residents reported the presence of blue-green algae. All the observations were made after the lakeshore development, thus the presence of these algae is assumed to be related to the lakeshore development, and will be discussed in detail later. The lowest value of chlorophyll a concentration, 357 μg L^{-1}, was observed in the surface layer, and was determined to represent the decreased depth due to phytoplankton bloom. Though it is a eutrophic lake, Fukami-ike did not have notable occurrence of blue-green algae in the past, and was considered an unusual lake. But after the lakeshore development in 2000, blue-green algae were noted often.

The distribution of nitrate nitrogen concentration is shown in Figures 5 and 6 as water quality data of nutrient salt before and after the lakeshore development. During 1978 to 1979 before the lakeshore development, high NO_3-N values of 10 to 50 μgat L^{-1} (0.14～0.70mg L^{-1}) were observed during October to May. From August to early October, values remained low at around 1 μgat L^{-1} (0.014 mg L^{-1}). From 1999 to 2000, a period after the lakeshore development, values ranged from 0.4 to 7 μgat L^{-1} (5.6～98μg L^{-1}). Before and after the lakeshore development, seasonal changes have a similar trend, but the concentration of nitrate nitrogen dropped significantly to about 10%. At Fukami-ike, it was shown by [7] that nitric acid flows in from the water catchment area after precipitation. This may indicate an influx of surface water from orchards and rice paddies around the lake prior to the lakeshore development, but after the lakeshore development, concrete block boardwalks were built around the lake shore and thus direct influx of surface water ceased. Furthermore, after the lakeshore development, influx of sewage ceased as well. In Washington Lake, USA, since sewage influx to the lake ceased, a significant increase in transparency was observed. This is due to the change in composition of zooplankton community from the decreased nutrient salt [8]. Based on these understandings, we believe that the decreased concentration of nitric acid after the lakeshore development contributed to the increased transparency of Fukami-ike.

Next, seasonal changes in chlorophyll a per unit area before and after the lakeshore development are shown (Figures 7 and 8). During 1978 to 1979, a period before the lakeshore development, the values ranged from 45 to 260 mg m^{-2}, and during 1999 to 2000, a period after the lakeshore development, values ranged from 25 to 965 mg m^{-2}. Blue-green algae were noted in July 1999 (844 mg m^{-2}) and June 2000 (233 mg m^{-2}). The highest value was noted in January 2000, but no blue-green algae were noted at that time. Seasonal changes of chlorophyll a before and after the lakeshore development had low values during the stratification period, and a trend of high values during the circulation period. These results agreed well with the seasonal changes of transparency. However, chlorophyll a concentrations roughly increased after the lakeshore development, and do not agree with the increasing trend of transparency. It's been suggested that the changes in transparency may be caused by changes in size compositions (zooplanktons changing from small to large ones) [9]. These results indicate that at Fukami-ike, the cause is the size composition of zooplanktons instead of phytoplankton concentrations.

The cause of the increased average transparency value at Fukami-ike is as follows: First, before the lakeshore development, sewage influx and surface water influx from rice paddies and orchards of water catchment area during precipitation were occurring. But all of that ceased after the development, leading to a decrease in concentration of nitric acid, a nutrient salt. Secondly, a chrolyphyll concentration increase after the lakeshore development was confirmed, and the possibility of the size composition of zooplankton was pointed out. However, the lowest value was observed after the lakeshore development, and increased chlorophyll a concentration and presence of blue-green algae were observed; thus, significant decrease in nutrient influx led to a decreasing trend in internal production volume. Yet it is believed that the material circulation in the lake has changed.

3.2 Depth variation

Bathymetric maps were drawn three times for Fukami-ike in 1951, 1978 and 2004. The maximum depth was of the pond reported to be 9.3 m in 1951 by Ueno (1952), and was reported to be 8.5 m in 1979 (1993) and 7.85 m in 2004 (Figure 9) by Yagi, et al. Although bathymeric maps were not prepared, the maximum depth was determined to be 7.85 m in 2009. Decrease in depth from 2004 to 2009 cannot be confirmed, but the survey determined there had been a significant decrease of 1.45 m in depth over a period of 58 years.

The rate at which sedimentation built up in the pond prior to lakeshore development was shown to be 3.1 cm y^{-1} by [10] based on 1978-1979 data.

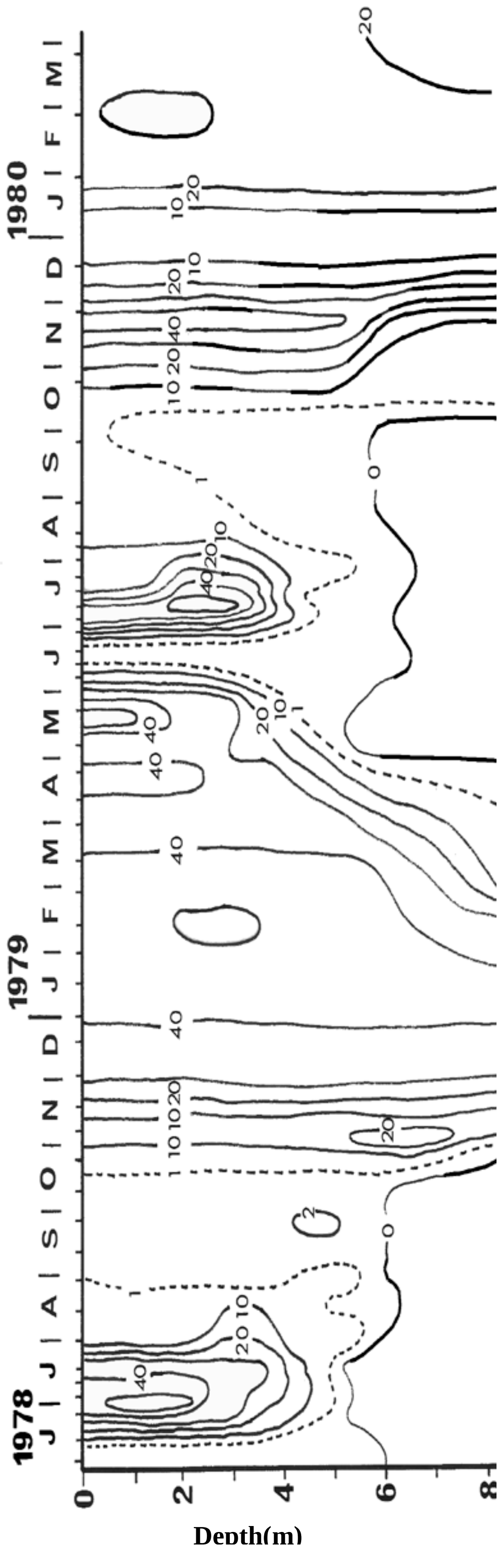

Fig.5 Seasonal changes of nitrate (before lakeshore development) unit: μ gat L^{-1}

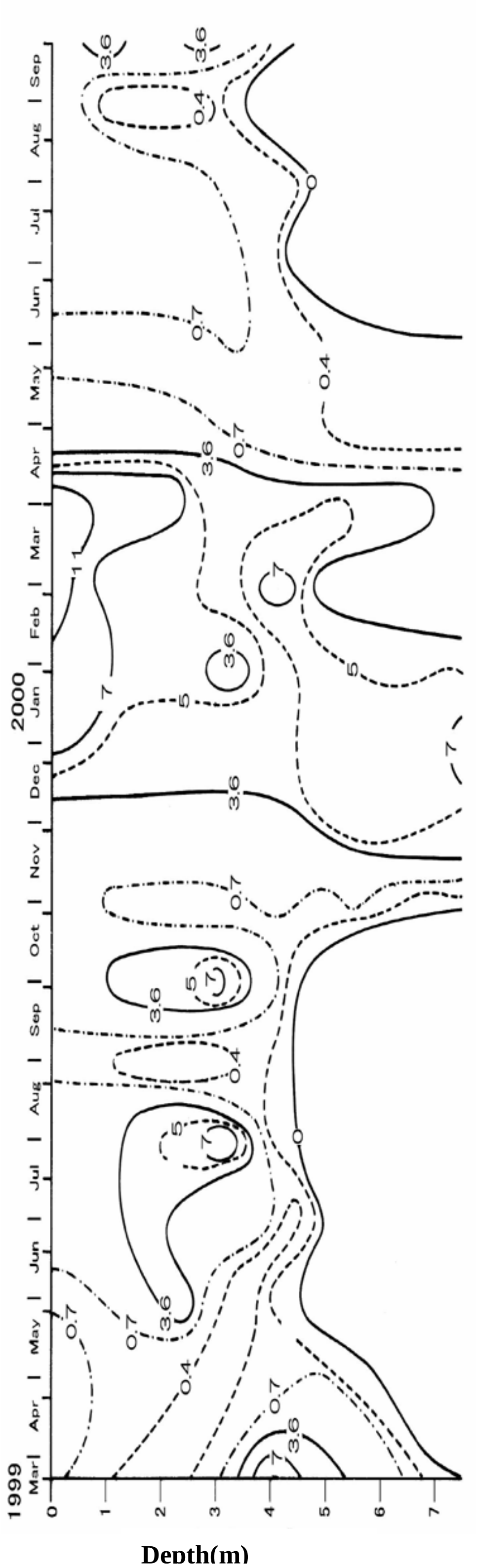

Fig.6 Seasonal changes of nitrate (after lakeshore development) unit: μ gat L^{-1}

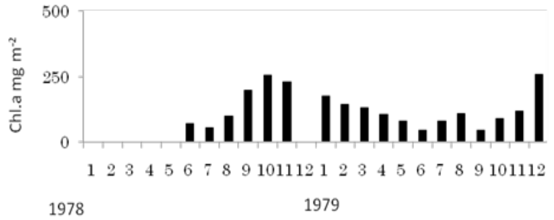

Fig.7 Seasonal changes of chloropfll-a (before lakeshore development)

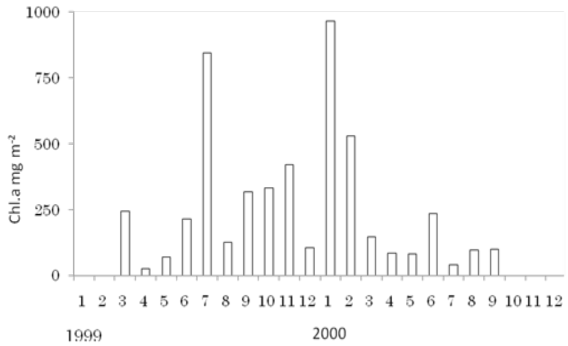

Fig.8 Seasonal changes of chloropfll-a (after lakeshore development)

Also, sedimentation rate after improvement of lakeshore drainage facilities was calculated based on 2007-2008 data. Figure 10 shows sedimentation rate for each month from January 2007 to December 2008. It was 0.69 cm/yr^{-1} during the stratification period (late March to early October) and 1.24 cm yr-1 for circulation period (mid October to mid March), presenting a higher value during the circulation period. This corresponded well with the decreasing trend of transparency during the circulation period. Newly obtained average sedimentation rate was 1.17 cm/yr^{-1}about 37% of the sedimentation rate from 1978 to 1979 prior to the lakeshore development. This clearly shows that sedimentation rate significantly decreased after improvement of lakeshore wastewater treatment facilities.

The annual average of ignition loss for new sediments (IL) was 37.9 ± 9.94%. To understand the movement of load to Fukami-ike, total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) load for the total inflow and outflow were obtained (Table 1). For each item, the outflow load was lower than the inflow load. TOC (113.8 g C day^{-1}), TN (100.3 g N day^{-1}), and TP (10.4 g P day^{-1}) accumulated in the lake due to internal production. These results conclude that the new sediments derived from internal production of the lake.

Firstly, depth decrease measured during 1951 to 1979 was 80 cm over 28 years. When this value is compared to the sedimentation rate obtained by [10] by trap experiments, the results were consistent with the actual measurement of 80 cm (3.1 cm x 28 years = 86.8 cm over 1951 to 1979). Depth decrease measured over 30 years (1979 to 2009) was 65 cm. From 1979, until the lakeshore development

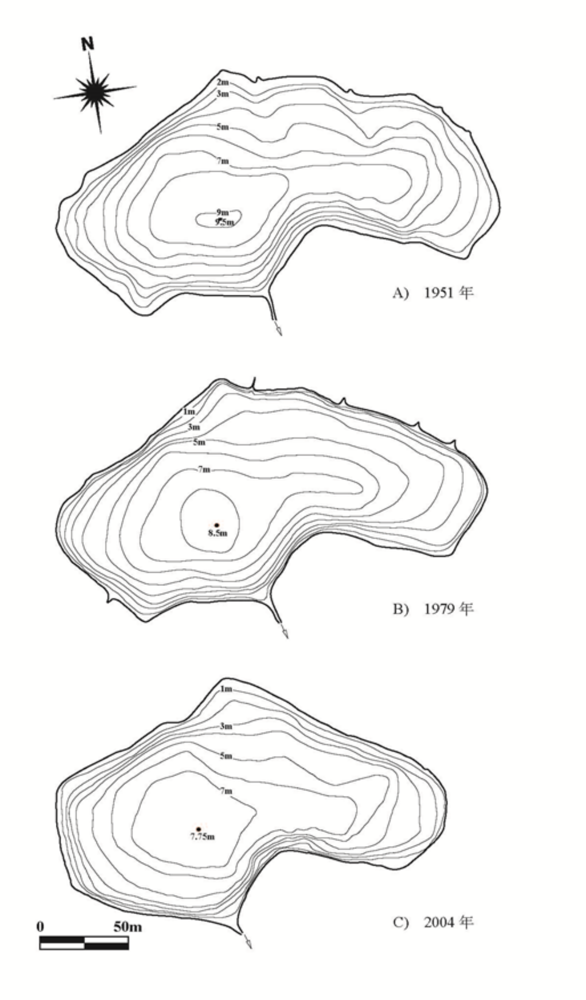

Fig.9 Changes of maximum depth at lake Fukami-ike

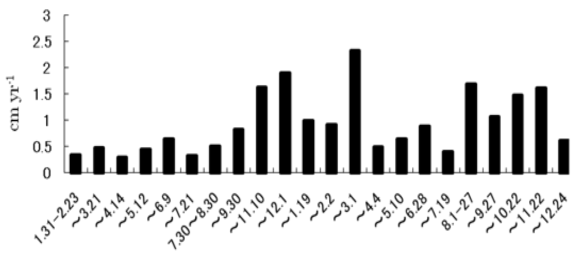

Fig.10 Seasonal changes of sediment rate (from 2007 to 2008)

in 1992, sedimentation rate of 3.1 cm yr^{-1} [10] was used. Up to 2009, after improvement of lakeshore wastewater drainage facilities, depth decrease was calculated using the newly obtained sedimentation rate of 1.17 cm/yr-1. Results were 40.3 cm (3.1 cm x 13 years) for 1979 to 1992, and 19.9 cm (1.17 cm x

17 years) for 1992 to 2009. A total depth decrease of 60.2 cm was estimated by calculation. The calculated value is approximately the actual 65 cm depth decrease. And these results show that before and after improvement of lakeshore facilities, sedimentation rate decreased considerably in the pond, decreasing the internal production significantly. Although eutrophication did progress, the rate of depth decrease became more gradual.

4. CONCLUSIONS

This report focuses on transparency and sedimentation rate of Fukami-ike, an eutrophic lake. Using long-term data over half a century, changes in internal production before and after the lakeshore development were investigated. Although long-term variation has been monitored in extensive lake and marsh areas, there has currently not been much research data from long-term monitoring of small lakes. This lake, however, has been affected by lakeshore development; through transparency and sedimentation rate changes, we were able to show that the resulting cessation of sewage introduction by improvement of farm village drainage facilities had a large effect on internal production of the lake. Although eutrophication has advanced despite increased annual average transparency and decreased sedimentation rate, it has become more gradual following lakeshore drainage facilities improvement. Since blue-green algae was still observed following lakeshore facilities improvement, it would not be accurate to assume that man-induced eutrophication problems have been solved. By continuing the observation, we hope to more clearly understand the effect of the improving lakeshore wastewater facilities on lakes and marshes.

5. REFERENCES

[1] Nagano pref. ``Improvement project of water environment report", 1991 (in japanese).

[2] Limnology Comittee of Shimoina Kyoiku-kai ``Shimoina-shi". Editorial Committee of Shimoina-shi 2009 (in Japanese).

[3] Yagi, A., I. Shimodaira, H. Terai and Y. Saijo, `` Seasonal change of chlorophyll-a and Bacteriochlorophyll in Lake Fukami-ike". Jpn. J. Limnol, 1983 44:283-292.

[4] Koyama T., Handa N. and Sugimura Y. ``Analysis of lake and sea water", Kodansya scientific 1983 (in Japanese).

[5] Ueno, M. ``Lake Fukami-ike in Shimoinagun, Nagano Prefecture", An educational association of Shimoninagun, IIda. 1952 (in Japanese).

[6] Sakurai Y. and Watanabe Y. ``Limnoligy of Shinsyu area", No.1, Society for scientific study of environmental chemistry 1974 (in Japanese).

[7] Terai, H. ``Influence of precipitation on development of the denitrification process in Lake Fukami-ike", Jpn. J. Limnol., 1988, 49:87-92.

[8] Edward A. Laws ``Basic sience of water environment", Gihodo shuppan Co., Ltd, 1996 (in Japanese).

[9] Haga H. and Otsuka T. ``Changes in transparency (Secchi disk reading) of the pelagic zone of the main basin of Lake Biwa over a span of 73 years", The Japanese Society of Limnology, 2003, 64:133-139. (Translated from Japanese with English abstract)

[10] Yagi A., Miyachi S. and Shimodaira I ``Change in depth by sedimentation of autochtonous organic sunstances in eutrophic lake", Journal of Nagoya Women's University, 1993, No.39:77-82 (in Japanese).

International Journal of GEOMATE, Oct., 2016, Vol. 11, Issue 26, pp. 2547-2552..
MS No. 5189 received on June 16, 2015 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in Oct. 2017 if the discussion is received by April 2017.
Corresponding Author: Maki Oyagi