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CHANGES OF CHLOROPHYLL-A, BACTERIOCHLOROPHYLL-C AND DOC BEFORE AND AFTER REVETMENT WORK IN LAKE FUKAMI-IKE, JAPAN

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

[1]Aichi Institute of Technology (AIT), Faculty of Civil Engineering, Department of Urban Environment, 1247 Yachigusa, Yakusa-cho, Toyota 470-0392, Japan.
[2]Yokkaichi University, Japan
[3]Water Agency Inc., Japan

ABSTRACT: Lake Fukami-ike is a small eutrophic lake of 2.1 ha with a maximum depth of 7.70 m in central Japan and water stratified from March to October. Anoxic conditions prevailed below 4-5 m depth from April to October and a photosynthetic green sulfur bacteria (BChl.c) accumulated in the hypolimnion. In Lake Fukami-ike, the revetment work was environment maintenance for activation of the town in 1992, and the water quality of this lake was considered to be clean. However, fluctuation in the transparency became larger than before. Data before and after revetment work (1992) was studied. The DOC amount of stagnation period was increased after revetment work more than before it, and the difference between maximum and minimum values also increased. Chl.a was increased in both water concentration and the water column. BChl.c had been confirmed to increase concentration and biomass. The inflow of domestic wastewater did not stop; nutrients increased and Chl.a, BChl.c and the DOC also increased. Such a phenomenon is considered to be one of the factors in the variation in the transparency increase.

Keywords: Chlorophyll-a, Bacteriochlorophyll-c, DOC, Eutrophic lake

1. INTRODUCTION

Lake Fukami-ike is a small eutrophic lake of 2.1 ha with a maximum depth of 7.70 m in central Japan (Fig. 1). The lake is well protected from the wind and lake water stratified from March to October. Anoxic conditions prevailed below 4-5 m depth from April to October and a photosynthetic green sulfur bacteria (BChl.c) accumulated in the hypolimnion [1], [2]. Transparency, dissolved oxygen, hydrogen sulphyde and vertical distributions of nutrients have been observed in detail since 1978 in Lake Fukami-ike [1]-[9]. In Lake Fukami-ike, the revetment work was environment maintenance for activation of the town in 1992, and the water quality of this lake was expected to be clean. However, fluctuation in the transparency became larger than before.

2. PURPOSE

The chlorophyll-a amounts in winter were higher than in summer. The reason for such a difference was considered because of the long stagnation period [1]-[4]. Transparency was clearly changed before and after revetment work (1992), 70-280 cm in 1950s, 50-150 cm in 1970-'80s, and 35-470 cm in 1990s-2000s (Fig. 2). Thus recent transparency changes have remarkably high values. Stable state of the lake water was obtained so that the inflow of nutrient amount was stopped and had been disturbed in water column after the revetment work. Differences before and after the data were studied to clarify the influence of revetment work.

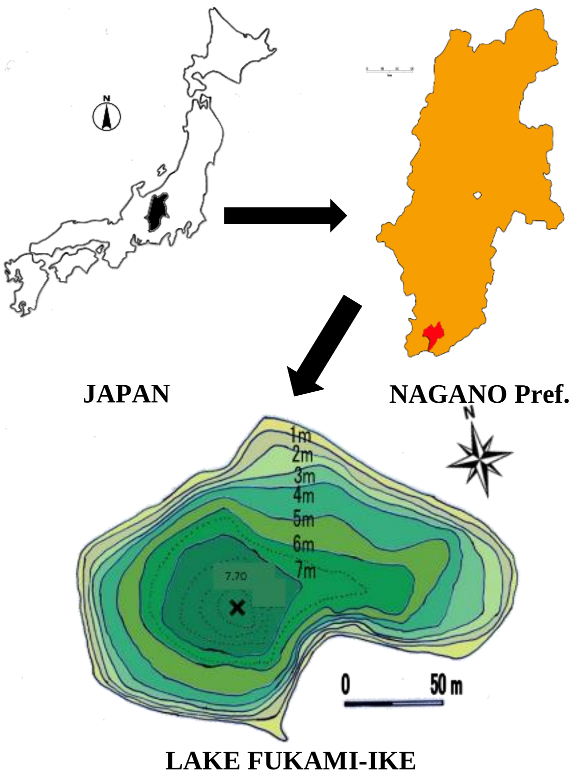

Fig. 1 Investigation spot

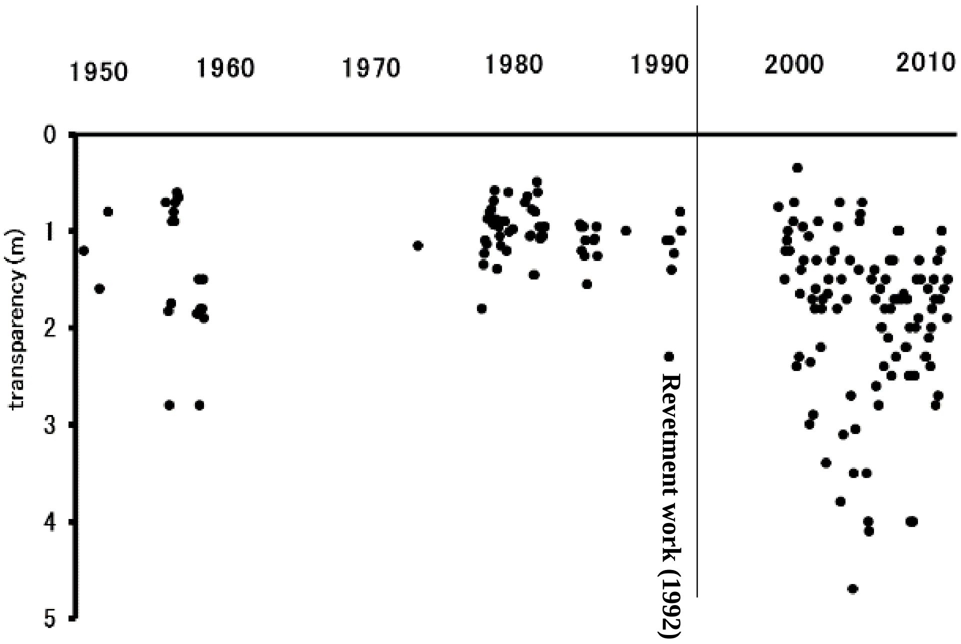

Fig. 2 Transition of transparency

3. METHODS

3.1 Investigation Spot

Lake Fukami-ike is located in Nagano Prefecture, Japan (North latitude 35° 32′ 55″ 77, East longitude 137°81′93″56) and has an area of 2.1 ha (maximum depth of 7.7) [7]-[8]. There are 6 inflowing streams and one outflow. The lake receives the runoff water from orchards and domestic sewage.

3.2 Water Sampling Method

Water samples were taken with a polyvinyl-chloride tube and a hand pump. In principle, the water was taken at 25-cm intervals in redox interface and 50~100 cm intervals in the other layer. Water samples were filtered with glass filter (GF/F, 47 mm). Water sample which was not filtered was total and the filtrated sample was dissolved, respectively. Chlorophyll-a and bacteriochlorophyll-c were determined by the spectrophotometric method [1].

3.3 Measuring Method

3.3.1 Water temperature (WT), Dissolved oxygen (DO)

WT and DO were measured by a DO meter (input electrode type, fluorescence method, HACL Inc., turned electrode type).

3.3.2 Chlorophyll-a (Chl.a) and bacteriochlorophyll-c (BChl.c)

Chl.a and BChl.c were measured by colorimetric method; Chl.a by using 663, 645, 630 nm wavelength, and BChl.c by using 662 nm [10]. BChl.c was photosynthetic sulfur bacteria and it grew extensively at the boundary layer of the oxic and anoxic layers.

3.3.3 Total organic carbon (TOC) & dissolved organic carbon (DOC)

Water samples were placed in 10 mL plastic bottle and mixed after adding in 0.1 mL of 1N H_2SO_4. Five minutes after, the inorganic carbon was completely expelled from water samples. The DOC was filtered. The TOC and DOC were quantified by total organic carbon meter (TOC-V (SHIMAZU)) [6], [7].

Picture 1 Lake Fukami-ike (20 Jul 2013)

4. RESULT & DISCUSSION

4.1 Water Temperature (WT), Dissolved Oxygen (DO)

Water temperature in 1979 of 4.5℃ in winter circulation period, gradually became 8℃ up in water stratification. 28℃ in the epiliminion of the summer stratification period and 10 ℃ under the water temperature stratification reached the stable state in the hypolimnion. In 2014, 4℃ in winter circulation period besides water temperature in the hypolimnion increased to 12℃. Low DO 1 mgL^{-1} concentration was obtained below 6 m depth in April and below 3.5 m because of stable water temperature stratification in August of 1979, respectively. An anoxic layer started previously below 5.75 m depth at the end of March and the uppermost anoxic layer appeared at 4 m depth in July, 2014. Decreases in the oxic and anoxic layers were measured.

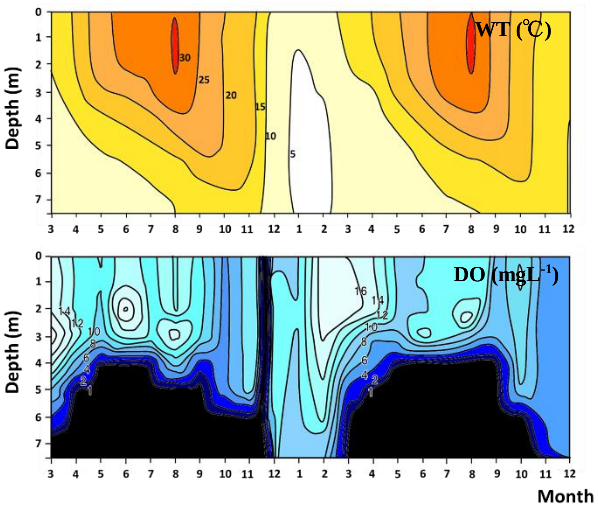

Fig. 3 Isotherm (℃) and DO isosmotic line (mgL^{-1})

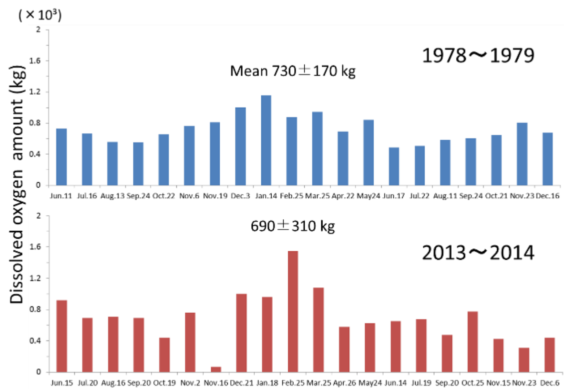

Fig. 4 Monthly changes of dissolved oxygen amount (kg)

Amount of DO in Lake Fukami-ike was measured by the depth and each volume to obtain the difference before and after revetment work. Maximum value of 1978-79 and 2013-14 were 1150 kg in January and 1550 kg in February, respectively. Minimum value of 1978-79 and 2013-14 were also 490 kg in June and 70 kg in November, respectively. 1978-79 and 2013-14 for maximum value minus minimum value were 660 kg and 1480 kg, respectively. Mean value was not different, but standard deviation was larger.

4.2 Chlorophyll-a (Chl.a) and Bacteriochlorophyll-c (BChl.c)

Figure 5 shows the aging of Chl.a amount and transparency in the oxide layer. Compared before and after revetment work, the mean of Chl.a amount before revetment work was 109 mgm^{-2}, and 174 mgm^{-2} after that work. It was 1.6 times. And the mean before that in the circulation period was 243 mgm^{-2}, 427 mgm^{-2} after the work. It was 1.8-fold. The Chl.a amount in the circulation period was larger than that of the stratification period, and this trend did not change before and after work.

Figure 6 shows the monthly variation of Chl.a in the water column in the oxidized layer. The amount in winter was more than in summer. It was the trend from ancient times of Lake Fukami-ike. The change to the circulation period from the stagnation period was calm before that work. In contrast, the fluctuation increased after that work.

Figure 7 shows monthly variation of Chl.a and BChl.c. The Chl.a and BChl.c value showed no difference in 1979 (before revetment work), but BChl.c increased in 2008 & 2013 (after revetment work). Maximum Chl.a amounts were 0.5 gm^{-2} and 0.7 gm^{-2} in 1979 and 2008, respectively. It had increased 1.4 times, but decreased 0.4 gm^{-2} in 2013. Maximum BChl.c amounts were 0.18 gm^{-2} in 1979, 2.6 gm^{-2} in 2008, and 2.9 gm^{-2} in 2013. The average Bacteriochlorophyll-c amounts in the water column in 1979 (before revetment work), 2008 & 2013 (after revetment work) were 74.4 mgm^{-2} in 1979, 1576 mgm^{-2} in 2008 and 1081 mgm^{-2} in 2013, respectively. That data in 2008 and 2013 increased 21 times and 15 times that in 1979, respectively.

As a feature of the internal production, phytoplankton and photosynthetic green sulfur bacteria amounts in the water column were 209 mgm^{-2} and 1081 mgm^{-2}. Therefore, the photosynthetic green sulfur bacteria amount was 5 times more than that of phytoplankton in Lake Fukami-ike in 2013.

Chl.a concentration decreased a little after work in the stagnation period, but increased after work in the circulation period. Bchl.c maximum value before work in August was 100 μgL^{-1}, after work it was 702 μgL^{-1}, growing 7 times. Similarly, in September, it increased 100 μgL^{-1} to 664 μgL^{-1} (Fig. 8).

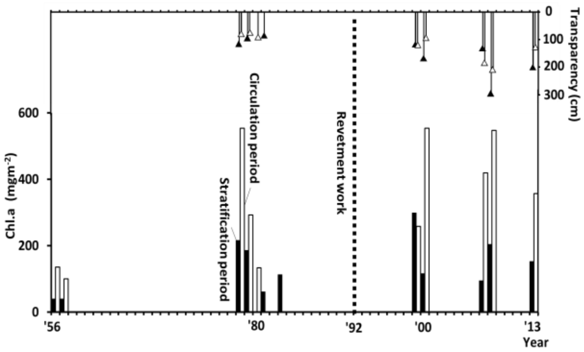

Fig. 5 Aging of the Chl.a amount and transparency in the oxide layer (1959-2013)

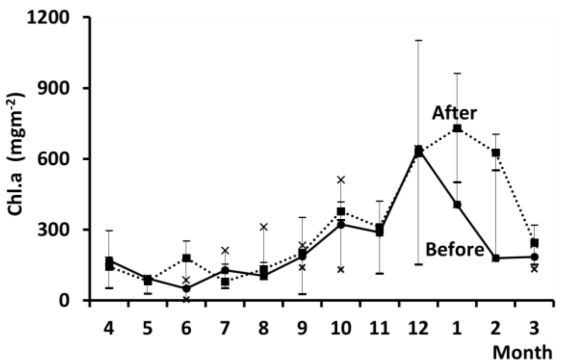

Fig. 6 Monthly variation of Chl.a in water column in oxidized layer

Table 1 Chl.a (mgm^{-2}) maximum, minimum and average value before and after revetment work.

	Before			After		
month	max	min	ave	max	min	ave
4	171	171	171	294	50	144
5	92.9	92.9	92.9	100	26.8	81.9
6	85.6	3.4	50.1	250	56.7	180
7	212	124	128	153	50	79.9
8	312	104	104	159	88.2	133
9	233	139	186	350	24.4	201
10	512	131	321	416	340	378
11	288	288	288	420	112	311
12	643	643	643	1101	150	626
1	406	406	406	960	500	730
2	180	180	180	703	550	627
3	237	133	185	319	150	246

4.3 Dissolved Organic Carbon (DOC)

Figure 9 shows aging of the DOC in the water column in the stagnation period. Figure 10 shows

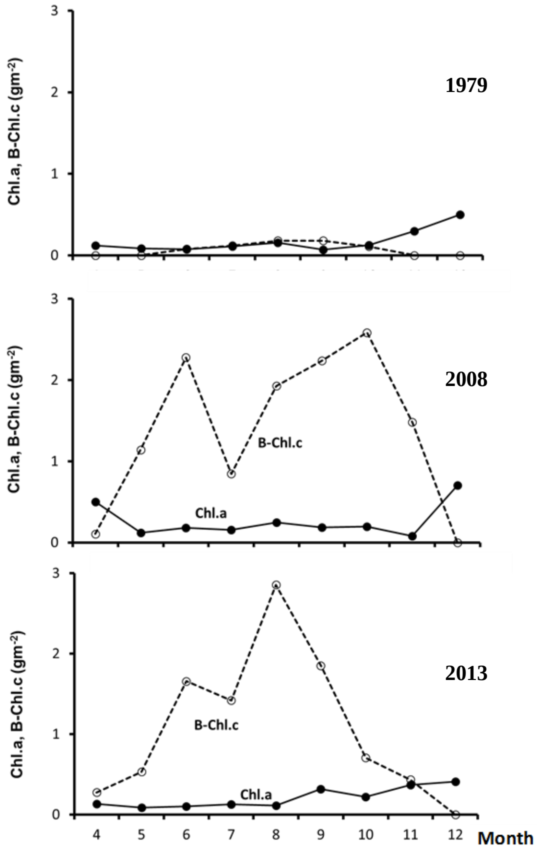

Fig. 7 Monthly variation of Chl.a and BChl.c in water column.

monthly changes of the DOC in the water column. Fluctuations of DOC amounts were observed before work, but not after it. The mean DOC amount before work was 4.24 gm^{-2}, against 9.05 gm^{-2} after work. It became 2-fold. The difference between maximum and minimum value was up to 1.9 gm^{-2} before work, and 5.5 gm^{-2} after work. Therefore, Lake Fukami-ike was stable throughout the year before work. There was the rice field around the lake before revetment work and the runoff inflowed directly. Lake Fukami-ike is stable because the purifying effect of rice field was acting on influent water such as household waste water (low C/N ratio) and precipitation. But after the work it was not stable. It seems possible that some domestic wastewater (low C/N ratio) was still flowing into this lake.

Figure 11 shows vertical distribution of the DOC. Change of the DOC was not observed before revetment work, but a high concentration was noted in the hypolimnion from June to September. A uniform concentration was observed from epilimnion to hypolimnion before work, but different values were seen at each depth after work.

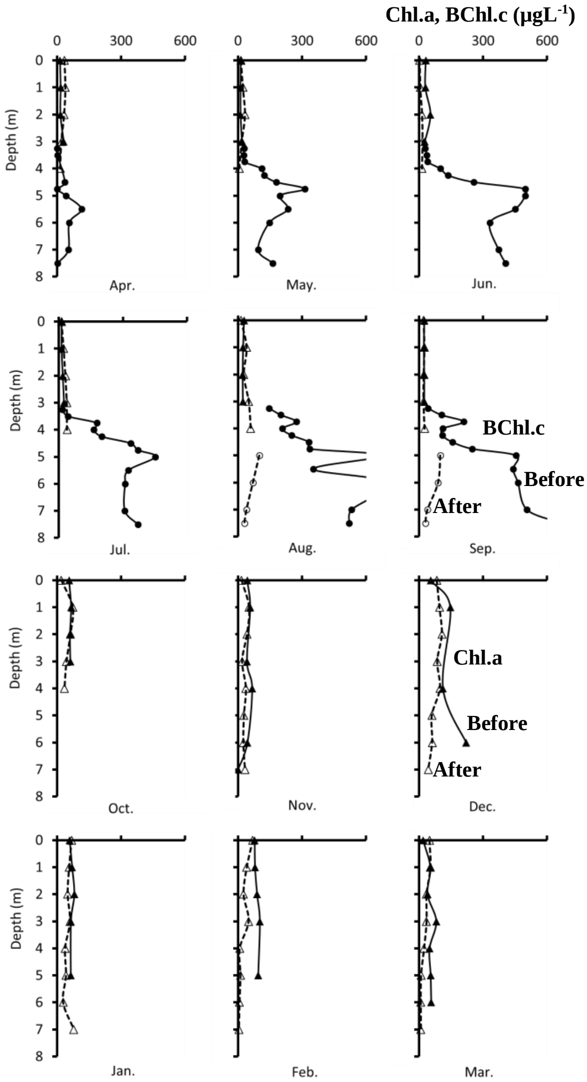

Fig. 8 Monthly vertical distribution of Chl.a and BChl.c (μgL^{-1}) (before and after revetment work)

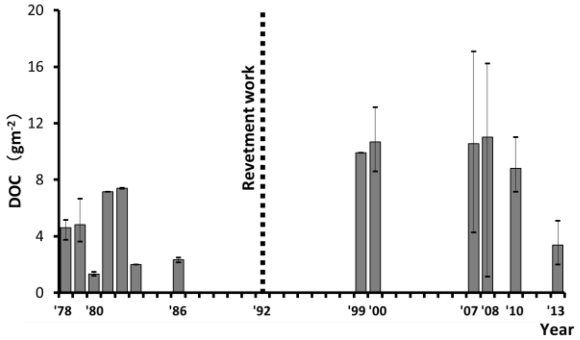

Fig. 9 Aging of the DOC in the water column in stagnation period

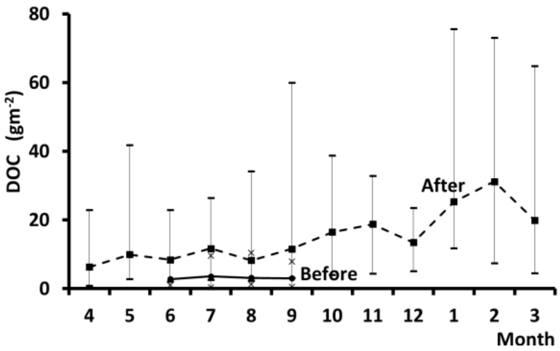

Fig. 10 Monthly changes of DOC in the water column (Before and after revetment work).

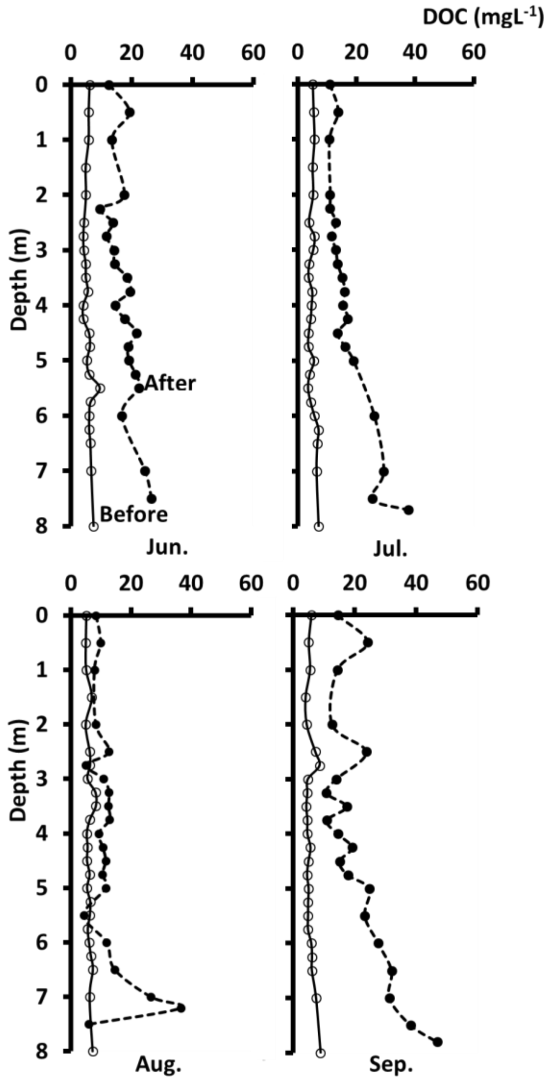

Fig. 11 Vertical distribution of DOC (before and after revetment work)

Table 2 DOC amounts (gm^{-2}) in the water column in the stratification period (maximum, minimum and average)

year	ave	max	min
1978	4.6	5.2	3.8
1979	4.8	6.7	3.6
1980	1.3	1.5	1.2
1981	7.2	7.2	7.2
1982	7.4	7.4	7.4
1983	2	2	2
1986	2.3	2.5	2.2
1999	9.9	9.9	9.9
2000	10.7	13.1	8.6
2007	10.6	17.1	4.3
2008	11	16.2	1.2
2010	8.8	11	7.1
2013	3.4	5.1	2

5. CONCLUSION

The mean of Chl.a amount before revetment work was 109 mgm^{-2}, and 174 mgm^{-2} after that work. It was 1.6 times. And the mean before that in the circulation period was 243 mgm^{-2}, 427 mgm^{-2} after the work. It was 1.8-fold. The Chl.a amount in the circulation period was larger than that of the stratification period, and this trend did not change before and after work. BChl.c had been confirmed to increase concentration and biomass. The mean DOC amount before work was 4.24 gm^{-2}, against 9.05 gm^{-2} after work. It became 2-fold. The difference between maximum and minimum values also increased. The revetment work was environment maintenance for activation of the town in 1992, and the water quality of this lake was expected to be clean. However, the inflow of domestic wastewater did not stop; nutrients increased and Chl.a, BChl.c and the DOC also increased. Such a phenomenon is considered to be one of the factors in the variation in the transparency increase.

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Corresponding Author: Megumi Nobori