Research article

Impacts of an Agricultural Water Use Restructuring Project on the Water Quality of Oxbow Lake

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Abstract Oxbow lakes in the Ishikari River Basin, Japan, are used as irrigation water sources, flood control ponds, and waterside parks, etc. In this study, we monitored water quality over the course of the restructuring project at Lake Chashinainuma. In this catchment area, irrigation water was pumped from the lake until 2010, but is now drawn from a distant river. As a result, the total nitrogen load balance changed from an outflow type to a storage type due to decreased removal of water from the lake. The lake water retention time also increased significantly. However, total nitrogen concentration decreased after the pumping station was abolished. We suggest that this reduction in total nitrogen concentration after 2011 reflected decreased particulate nitrogen due to biological purification effects that are expected with increased chlorophyll concentration. Hence, the change in load balance to an accumulation type may have been influenced by changes in agricultural water management and transformation of paddy fields into upland.

Keywords water quality paddy field, load balance, agricultural land improvement project

INTRODUCTION

Oxbow lakes are remnants of meandering floodplain rivers that have been cut off and physically isolated from their respective main river channels (Cullum et al., 2006). There are many oxbow lakes in the Ishikari River basin, and both naturally and artificially formed lakes are used as irrigation water sources, flood control ponds, and waterside parks. Hence, they are recognized as regional resources with multiple functions (Yamamoto et al., 2001). Many oxbow lakes are closed type waterways in which eutrophication occurs easily. Because oxbow lakes originate from rivers, much drainage water flows into them, and their water quality is strongly influenced by human activities, including agriculture in the catchment area. Yamamoto et al. (2002, 2004) studied the effects of nutrient inflow from an agricultural area in Hokkaido on the water quality of an oxbow lake.

Currently, land improvement projects, including land partition, enlargement, and rearrangement, creation of multipurpose paddy fields, and restructuring of irrigation and drainage facilities are ongoing in the Lake Chashinainuma watershed in Bibai, Hokkaido. These projects incur changes of land use and water management, and hence, influence water quality and the hydrological environment. However, few studies have examined the relationship between human activities, including land improvement projects, and water quality of oxbow lakes.

OBJECTIVE

This study object is to determine the impacts of the water use restructuring project on the physical and chemical water properties of the oxbow lake "Chashinainuma" in terms of; (1) Changes of nitrogen concentration in the lake and drainage water, (2) Impact of pumping station on water balance and water quality in the lake and (3) Evaluation of water balance and total nitrogen load balance of the lake.

And this investigation contributes to the evaluation of changes in water quality following land improvement projects.

METHODOLOGY

This survey was performed at Lake Chashinainuma between 2007 and 2012. Lake Chashinainuma is located in the middle stream of the Ishikari river Basin. It has a water surface area of 13.1 ha and an average depth of 1.02 m. The size of the catchment area changed from 106 to 127 ha with the improvement project (Table 1, Fig.1), and the land is mainly used as farmland. In this watershed, irrigation water was pumped up from the lake until 2010, when the pumping station was abolished, and is now drawn from a distant river via open channels and pipelines. In addition, a new drain (D4) was constructed and the land use and crops were changed each year of the project. There are four direct drainage and inflow points from the farmland. In the restricting area, the drainage water from the fields cannot flow directly into the lake. The pressure-controlled tank for pipeline irrigation (T) and the surplus water from this tank drain into the lake via the D3 water management facility.

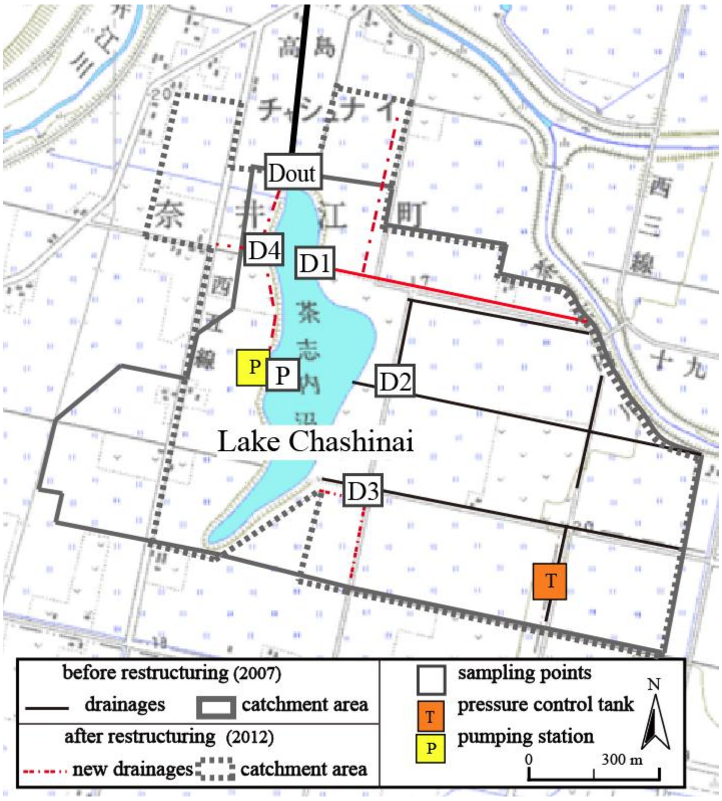


Fig. 1 Outline figure of catchment area and sampling points

To measure water quality, water was drawn from outflow drainage and inflow drainage sampling points in the lake. Water sampling was conducted about two times per month during irrigation periods, and once per month during non-irrigation periods from April 2007 to August 2012. Water sampling was performed two times a day during the paddling period (May) and once per day during normal irrigation periods (June–August) using an automatic water sampler (ISCO Inc.) from 2009 to 2012. Total nitrogen (TN), dissolved total nitrogen (DTN), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), and ammonium nitrogen (NH_4-N) contents were determined. These analyses conformed to Japanese Industrial Standards (JIS). Dissolved inorganic nitrogen (DIN) was calculated as the sum of NO_3-N, NO_2-N, and NH_4-N. Total organic nitrogen (TON) was estimated by subtraction of DIN from TN. Particulate organic nitrogen (PON) was estimated by subtraction of DTN from TN. Dissolved organic nitrogen (DON) was calculated as the difference between DTN and DIN.

Table 1 Changes of land use and projects in the investigated area

Year		2007	2008	2009	2010	2011	2012
Catchment area (ha)		112	112	112	112	106	127
Crop type (ha)	Paddy	64	N.D.*	42	45	24	60
	Upland crop	42	N.D.*	59	60	71	67
Water body	2009; Water supply changes in a part of D1 catchment area						
Plantation	2011; Pumping station stopped and land arrangement in D4 catchment area						
Upland paddy	2012; Land arrangements in parts of D1 and D3 catchment area						

* *Crop type investigation was not carried out in 2008 because it was considered same in 2007.*

Precipitation data were used in the Automated Meteorological Data Acquisition System (AMeDAS) at Bibai and Iwamizawa cities. Evapotranspiration was calculated according to Penman's method.

RESULTS AND DISCUSSION

Changes of water quality in the lake

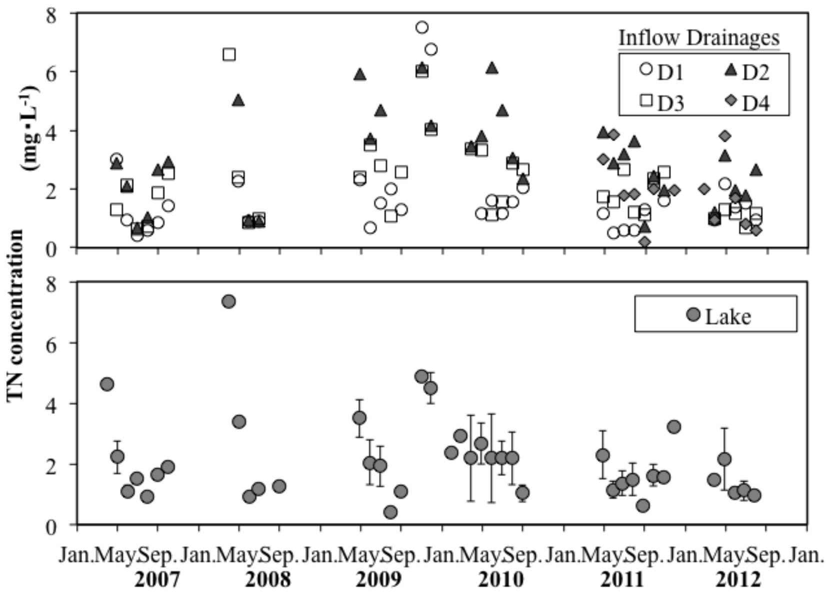


Fig. 2 Changes in TN concentration in the lake and its drains

Figure 2 shows monthly changes in TN concentration in the drains (D1–D4) and in the lake. When more than three samples were taken in a month, data are presented as the mean ± standard deviation. The concentration of TN in the lake changed periodically, with high values during April and May, low values during the normal irrigation period, and a concentration rise again in the winter. This trend was reflected in samples from the drains. Compared with D1 and D3, the concentration of TN in D2 was markedly increased. In the D2 catchment area, paddy fields are prevalent in the downstream and influence the water quality easily. Accordingly, the concentrations of TN in samples from D4 were high during the paddling period.

Figure 3 shows the changes in concentration of each nitrogen form in lake water. TN is comprised mainly of TON and NO_3-N. Concentrations of TN exceeded those allowed by the Japanese agricultural water use standard and environmental standard for environmental conservation (≤1.00 mgL^{-1}) for most of the study period. Comparison of TN concentrations before and after the pumping station was abolished show that TN concentrations decreased. Figure 3 shows that this is reflected by decreased TON concentrations. Changes in NO_3-N concentration could not be confirmed.

During the years 2011 and 2012, approximately 70% of TON (40% of TN) was composed of PON, indicating a significant influence of PON on TN concentrations in this lake.

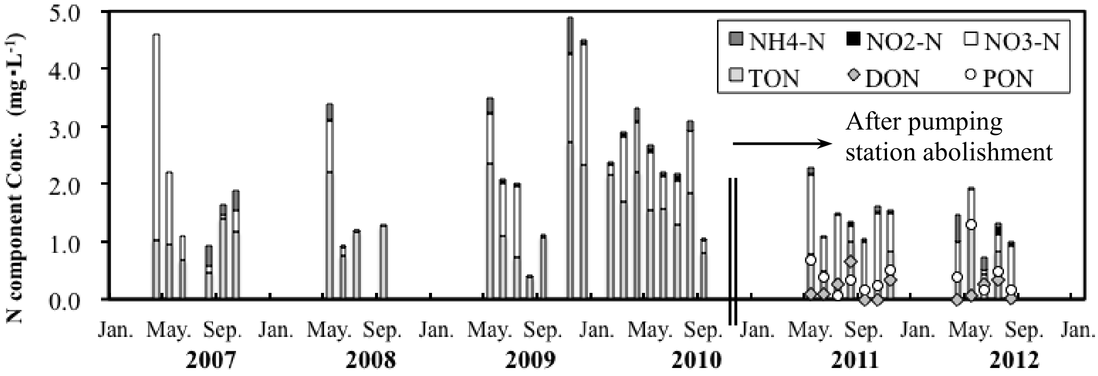


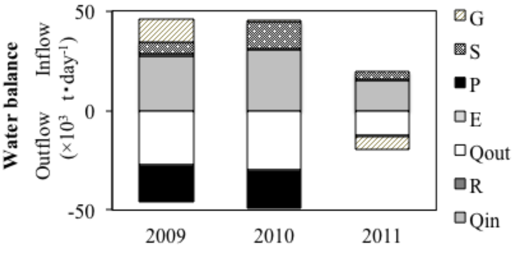
Fig. 3 Changes in nitrogen component of the lake water

Changes of water balance and total nitrogen balance during irrigation periods

Water balance during irrigation periods was calculated using the relation expression (Equation 1). The inflow discharge in 2011 decreased compared with levels seen in 2009 and 2010 (Fig. 4) due to advance of the pipeline and consequent decreases in paddy field area. Prior to 2010, approximately 40% of the lake water was left via the pumping station, thus abolishment of the pumping station caused significant changes in water balance during 2011. In addition, the transformation from paddy fields to cultivated area was accompanied by decreased inflow and outflow, and the retention time of the lake water increased from 3.37 day in 2009 to 5.98 day in 2011.

$$\Delta h = Q_{in} - Q_{out} + R - E \pm G + S - P \quad (1)$$

Δh, change in storage discharge; Q_{in}, discharge of inflow into the lake; Q_{out}, discharge from the lake outlet; R, precipitation; E, evapotranspiration; S, surplus water from pressure control tank; G, groundwater balance; P, discharge of intake water by pumpstation.



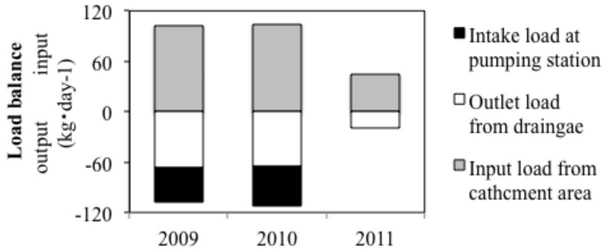


Fig. 4 Water balance of the lake **Fig. 5 Nitrogen Load balance in the lake**

Total nitrogen balance during the irrigation periods of 2009–2011 was calculated from water balance and concentration. The concentration of TN in the lake water was used to calculate that of the intake water for the pumping station, and changes in nitrification and outflow through the ground were considered constant. The difference between input and output loads was approximately 110 kg day^{-1} and did not differ with that in 2009 and 2010. TN load balance during irrigation periods changed from an outflow type to a storage type due to decreased removal by pumping (Fig. 5), suggesting that TN may accumulate in the future.

Changes in water quality factors under the agricultural water use restriction project

We predicted that decreased water removal after the pumping station was abolished would cause increased TN concentrations in the lake water. Though removal of water by pumping tends to take pollution from the lake, total nitrogen concentrations fell in 2010. Thus, changed inflow volume appears to be the main factor that influenced water quality in the lake. Although inflow water volume and load decreased after 2011, TN retention in the lake increased. Therefore, another process in the lake may also affect changes in water quality.

Consistent with the phenomena observed in Lake Chashinainuma, a study of Lake Kasumigaura confirmed that increasing retention time caused load removal from the lake (Nakamura and Amano, 2007). We suggest that extension of retention time may cause (1) sedimentation of particulate matter, (2) nitrogen fixation by phytoplankton or aquatic plants, and (3) organic matter decomposition due to microbes. Moreover, drawdown of the water level in the lake during the irrigation period was confirmed after 2011, and expansion of the habitation area for emerging plants was observed. On the other hand, increasing retention time may advance the organic decomposing effect, thereby increasing DIN by decomposing DON or organic matter in bottom sediments. However, exuberant reed growth was seen in 2011 and 2012 on the northern part of the lake and may have lowered concentrations of dissolved water items by absorbing DTN.

CONCLUSION

The results indicate that the water inflow volume from the catchment area decreased after the project, and the TN load balance of the lake changed to storage type despite decreased input load at Lake Chashinainuma. This decreasing of water inflow volume could be caused by changes of land use. The pumping station abolishment and the changing of water balance could affect the change of TN load balance. Interestingly, the concentration of TN in the lake water decreased after the project, largely due to fixation of TON. This decrease in TN concentration is attributed to physical biological phenomenon that stem from changes in the hydrological environment and crop types.

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REFERENCES

Cullum, R.F., Knight, S.S., Cooper, C.M. and Smith, S. 2006. Combined effects of best management practices on water quality in oxbowlakes from agricultural watersheds. Soil and Tillage Research, 90, 212-221.

Nakamura, K. and Amano, K. 2007. Performance of lacustrine “Artificial Lagoon” for the control of diffuse pollution. Civil engineering journal, 49, 40-45. (in Japanese)

Yamamoto, T., Nagasawa, T., Inoue, T. and Kusa, D. 2001. Evaluation of Oxbow Lakes in Ishikari River Basin for its function of water quality conservation. Journal of Rural Planning Association, 3, 49-54. (in Japanese)

Yamamoto, T., Nagasawa, T. and Inoue, T. 2002. Effect of lake utilization and watershed agricultural landuse on water quality in Oxbow Lakes of Ishikari River Basin. Journal of Rural Planning Association, 4, 157-162. (in Japanese)

Yamamoto, T., Kanbe, T., Nagasawa, T. and Inoue, T. 2004. Water environment of Oxbow Lake and landuse of its watershed in the Ishikari River Basin. Journal of Rural Planning Association, 23, 67-72. (in Japanese)