ABSTRACT

Lake Biwa is the largest freshwater body in Japan and its water quality (e.g., COD(Mn)) is worsening since 1985 despite various pollution prevention measures. In order to implement more effective measures, “Lake Biwa Basin Integrated Management Model (LBIM)”, which can simulate hydrological and material cycle situation in Lake Biwa Basin, was constructed. LBIM consists of three component models; the land model, the lake flow model, and the lake ecological model. As a result of the calculation of water quality and quantity in Lake Biwa Basin by applying LBIM, those were simulated well including the difference between areas. In addition, the effect of some measures to the lake water quality was evaluated.

Key Words: Lake Biwa Basin, Hydrological and Material Cycle Simulation, Water Quality, Lake Management, Evaluation of Measures

INTRODUCTION

Lake Biwa is the largest freshwater body in Japan with area of 670km² and maximum depth of more than 100m (Figure 1). Approximately 460 rivers originating from the surrounding mountains flow into the Lake. The water volume from the rivers is about 5km³/year, so the retention time is average 5.5 years. There are about 1.3 million people in the catchment area and most of them live around the southern part of the lake.
Figure 1. Outline of Lake Biwa
Lake Biwa is the largest freshwater body in Japan.

Figure 2. Trends of Water Quality Indexes (COD(Mn), BOD)
COD(Mn) is worsening since 1985, but BOD is improved. The reason is not clearly revealed.

Figure 3. Outline of LBIM
LBIM, which calculates water quality and quantity in Lake Biwa Basin, consists of three component models; the land model, the lake flow model, and the lake ecological model.

The trends of water quality indexes show a higher level of eutrophic in the early 1970s and since then the deterioration of the lake water quality has been improved, but COD(Mn), which is the index of organic matter, has shown an upward trend (i.e., worsening) since 1985 despite various pollution prevention measures. On the other hand, BOD, which is also the index of organic matter, is improved contrary to the COD’s trend (Figure 2). However, the mechanism of the contamination in Lake Biwa is not clearly revealed until now.

In order to understand the phenomena occurring in Lake Biwa and implement more effective measures for improving water quality, it is necessary to comprehend the quantitative relationship between the load from the land and the lake water quality. To do this, it is the most effective way to construct the simulation model which can forecast water quality changes due to the implementation of measures in Lake Biwa and the Basin. Therefore, “Lake Biwa Basin Integrated Management Model (LBIM)”, which can simulate hydrological and material cycle situation in Lake Biwa Basin, was constructed. In this paper, we explain the outline of LBIM and report the simulation results.

METHODS

LBIM consists of three component models; the land model, the lake flow model, and the lake ecological model (Figure 3). Each model simulates hydrological and/or material cycle in Lake Biwa Basin, after reading input data about climate, land use, social situation, and so on, and output data from other models. In other words, LBIM calculates water quality and quantity in Lake Biwa Basin by coupling three component models.

The land model, which consists of 5 factor models, simulates water quality and quantity on the land area (e.g. river discharge, river water quality, and groundwater quality) (Figure 4). The land is divided into 500m meshes, that is “distributed model”. In this model, rain water is divided into evapotranspiration, infiltration, and surface runoff by the evapotranspiration model. Infiltrating water and surface runoff go into the groundwater model and the
surface runoff model respectively, and flow into the river channel model, finally the lake flow/ecological models. Through this water flow, load from point (e.g. domestic waste water) and non-point (e.g. waste water from urban area) source is aggregated in each factor model (Sato et al., 2006).

Figure 4. Land Model and its Factor Model The land model, which consists of 5 factor models, simulates water quality and quantity on the land area.

The lake flow model simulates flow direction, flow velocity, and water temperature in the lake, using “difference method” (Figure 5). Lake Biwa is divided into 1km meshes horizontally and 8 layers vertically, that is, 3 dimensional model. The base equations used in this model are dynamic equation of each dimension, water temperature balance equation, and equation of continuity, assuming hydrostatic pressure and Boussinesq approximation.

Figure 5. Lake Flow Model The lake flow model, which is 3 dimensional model, simulates flow direction, flow velocity, and water temperature in the lake.

The lake ecological model simulates lake water quality (e.g. Organic Carbon, Nitrogen, and Phosphorus) by calculating biochemical process (Figure 6) with “nonlinear system dynamics”. The structure of Lake Biwa is the same as the lake flow model (i.e. 3 dimensional model). The lake ecological model consists of 6 compartments in water and 3 compartments in the sediments. In this model, food web is simulated among nutrients, plankton, fish, detritus, and so on (Komatsu et al., 2006).

Figure 6. Lake Ecological Model The lake ecological model simulates lake water quality by calculating biochemical process.
RESULTS

Firstly, we calculated water quality and quantity in Lake Biwa Basin by applying LBIM and validated it comparing with monitoring data. The target year for validation was set in 2004 (Apr.1 2004 – Mar.31 2005).

The results of hydrological and material cycle simulation on the land area are shown in Figure 7. In this year, 36% of the rain was infiltrated and 19% was run off on the surface. Finally, 42 hundred millions ton water inflowed to the lake through river channels and groundwater. In case of COD, 15,762 ton was generated from non-point source and 4,322 ton was discharged from point source. This load was purified in river channels and/or underground and, as a result, 10,695 ton COD inflows to the lake.

The results of the lake water quality simulation are shown in Figure 8. In this picture, the x-axis means the monitoring points for environmental standard (Figure 9), and y-axis means annual average of lake water quality (COD, TN, TP). Comparing predicted values with observed values, the differences between areas are simulated well especially in COD. There are some differences in southern part of the lake (9B, 8C, 6B, 4A) between predicted and observed, and it implies that the mesh size (1km) is large relative to the area of the southern lake.

Through examination results above, we evaluated effects of some measures for improving water quality. Mainly below 3 measures were set in this paper.

1. Constructing the sewage system (ratio of sewage installation is increased from 80.4% to 85.6%)
2. Improving the quality of the discharge from sewage system
3. Taking measures for decreasing non-point load (environmental friendly agriculture, purification of the rivers, etc.)

As a result of these measures, for example, the water quality at 12B is improved by about 0.05 points in TN (Figure 10). In this way, LBIM can evaluate the effectiveness of measures to water quality quantitatively.

![Figure 9. Monitoring Points for Environmental Standard. This picture shows the eleven monitoring points which are used as environmental standard.](image)

![Figure 10. Evaluation Results of Measures (12B). As a result of measures (e.g. constructing the sewage system), the water quality at 12B is improved by about 0.05 points in TN.](image)

DISCUSSION

The most important characteristic of LBIM is that LBIM integrates three models; the land model, the lake flow model, and the lake ecological model. This enables us to evaluate measures which are often implemented on the land area.

From now, we can calculate the effect of various measures to water quality and quantity in Lake Biwa Basin and compare them each other. Moreover, we examine what integrated lake basin management should be by considering not only hydrological and material cycle but also ecosystem, landscape, economy, culture, and so on. In other words, we should evaluate measures after analyzing the effects to various values of Lake Biwa.

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REFERENCE
