京都大学防災研究所年報　第 53 号 B　平成 22 年 6 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 53 B, 2010

Influence of the Ane River Basin on Dissolved Oxygen Concentration of Lake Biwa: Sensitivity Study of the Biwa-3D model.

Pedro Luiz Borges CHAFFE*, Yosuke YAMASHIKI, Kaoru TAKARA, Masato KATO* and Maho IWAKI**

* Graduate School of Engineering, Kyoto University
** Graduate School of Human and Environmental Studies, Kyoto University

Synopsis

Due to its importance for the water resources of Japan, Lake Biwa characteristics have been studied by many scientists. So far it is not clear how river discharge from Lake Biwa Basin influences the water quality in the Lake. The objective of the present work was to analyze the influence of the Ane River Basin on the dissolved oxygen (DO) concentration of the Lake Biwa through a sensitivity analysis of the circulation model Biwa-3D. We compared the DO results calculated using Biwa-3D under two different scenarios. First, we ran Biwa-3D model using observed discharge from Ane River as input. Second, we changed the discharge characteristics of the Ane River and tried to compare the influence of this difference in the simulated DO concentration. Despite the fact that the model is sensitive to DO input, there were no clear difference between the two scenarios studied.

Keywords: Lake Biwa, Dissolved Oxygen, Biwa-3D, Ane River Basin

1. Introduction

Due to its importance for the water resources of Japan, Lake Biwa characteristics have been studied by many scientists. Most studies focus in measuring several water quality parameters (Tanaka et al., 2010) of the lake and also in modeling the lake circulation (Akitomo et al., 2009, Yamashiki et al., 2003a) and water quality (Hosoda *et al*, 2009, Yamashiki et al., 2003b). Lake Biwa has experienced many environmental problems such as loss of species habitat and changes in Dissolved Oxygen (DO) concentration (Kumagai et al., 2003).

The physical circulation processes such as stratification and gyre during the summer season and vertical mixing during the winter season in the lake with freshwater were studied by applying and modifying the Biwa-3D model, especially for their turbulent model structure using Mixed Scaling Formulation Model (MSFM) as Very Large Eddy Simulation (VLES) (Yamashiki et al., 2003a). Akitomo et al. (2009a, 2009b) did a complete simulation for predicting temperature and current distribution in the lake and the gyre formation due to a thermocline.

Physical parameters such as temperature are key variables influencing both directly and indirectly ecological aspects of the lake, such as cyanobacterial growth. Other important parameter is the DO concentration. It is known to be largely varied in Lake Biwa and periods of anoxia can persist (Kumagai et al., 2003). Usually cooled water brings oxygen to hypolimnion through *vertical* convection and turbulent diffusion (Hosoda et al., 2009). Lake Biwa is sensitive to climate and changes in air temperature and rainfall may directly affect the temperature and DO of the Lake. The change in climate may affect transport of oxygen inflow and winter mixing. Another consideration is that dense cold water from snowmelt may intrude directly in the lake have a particular strong influence on hypolimnetic oxygen (Kumagai and Fushimi, 1995, Kitazawa and Kumagai, 2005).

Since the water inside the lake comes from the Lake Biwa watershed, we should try to understand lake-watershed dynamics as a whole. One of the most important basins that contribute to Lake Biwa water quantity and quality is the Ane River Basin, but its influence is not fully understood. Hence, he objective of the present work was to analyze the influence of the Ane River Basin on the dissolved oxygen concentration of the Lake Biwa through a sensitivity analysis of the circulation model Biwa-3D. Successful management depends not only on the understanding of the limnological controls on water quality (Kumagai et al 2003) but also on the hydrological ones.

2. Study Areas

2.1 Lake Biwa

Lake Biwa is the largest freshwater body in Japan. The surface area is 674 km^2 with maximum depth of 104 m in the Northern deep basin. The total catchment area is 3174 km^2 with the outlet located in the Southern shallow basin (Figure 1).

2.2 Ane River Basin

The Ane River Basin is located in the Northeast region of Shiga Prefecture (Figure 1). With and area of 686 km^2 it is the largest contributing basin to Lake Biwa. In the winter, there is snowfall in this region and snowmelt during spring is a big part of total river discharge.

3. Methods

The basic idea of this paper was to compare the DO results of a circulation model (Biwa-3D) considering two different scenarios. First, we ran Biwa-3D model using observed discharge from Ane River as input. Second, we changed the discharge characteristics of the Ane River and tried to compare the influence of this difference in the simulated DO concentration.

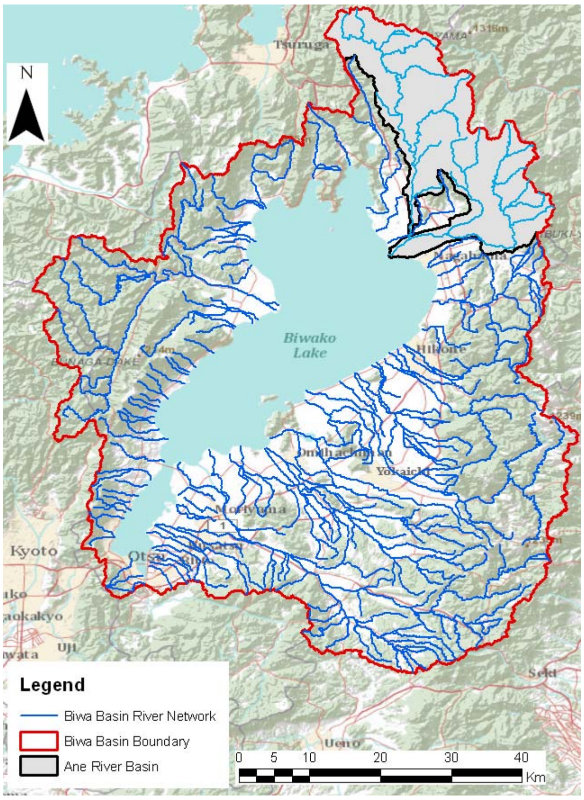


Fig. 1 Lake Biwa and Ane River Basin.

3.1 Biwa-3D Circulation Model

The circulation model used in this study is the Biwa-3D, which is a non-hydrostatic three dimensional model that uses a Mixed Scaling Formulation Model to solve the hydrodynamic component. The grid-filtered, incompressible Navier-Stokes and mass transport equations in a rotating environment can be expressed as follows

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial \bar{\rho} \bar{u}_j}{\partial x_j} = 0 \qquad (1)$$

$$\frac{\partial(\overline{\rho u_i})}{\partial t} + \frac{\partial(\overline{\rho u_i}\,\overline{u_j} - \lambda_{ij})}{\partial x_j} = \mu \frac{\partial}{\partial x_j}\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \frac{\partial P}{\partial x_i} + \bar{\rho} F_j \frac{\partial x_3}{\partial x_i} + f \bar{\rho}\left(\bar{u}_2 \frac{\partial x_1}{\partial x_i} + \bar{u}_1 \frac{\partial x_2}{\partial x_i}\right) \qquad (2)$$

$$\frac{\partial(\overline{\beta})}{\partial t}+\frac{\partial(\overline{\beta}_i\overline{u_j}-\chi_j)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\mathrm{K}\frac{\partial\overline{\beta}}{\partial x_j}\right)+Ps \quad (3)$$

where x_i is eastward(i=1), northward(i=2) and upward(i=3) directions, f is the coriolis parameter, u_i (i=1,2,3)is water velocity for each direction, β is the scalar, μ is the dynamic viscosity and $\kappa = k/\rho_0$ where k is the molecular diffusivity of the water and ρ_0 is a reference density of the water, P is water pressure, ρ is water density, F is gravity force, and S is the source term of the scalar (Yamashiki et al. 2003a, 2003b, 2010).

The resolution for computation used was a 500 m regular horizontal grid by 2 m vertical grid spacing corresponding to 83 × 128 × 51 cells in total.

3.2 DO Calculation in Biwa-3D

Two species of nutrients (inorganic nitrogen and inorganic phosphorus), three groups of phytoplankton (diatom, blue-green algae and the other phytoplankton), zooplankton, detritus and dissolved organics, are assumed to be the main components in ecosystems of lakes and reservoirs, henceforth, they are included in the Biwa-3D model variables.

Dissolved oxygen (DO) is also included in the model as an important component that strongly affects the transformation mechanisms. The equations describing DO transformation are:

$$Ps_{DO} = \left(P_{DO} - C_{DO}\right) \quad (4)$$

$$P_{DO} = Phyto_{DO} + P_{DO\_Surface} \quad (5)$$

$$C_{DO} = Z_{DO} + COD_{DO} + C_{DO\_Bottom} \quad (6)$$

in which P_{DO}, C_{DO} is the Production and Consumption term of dissolved oxygen, $Phyto_{DO}$ is DO production term through photosynthesis, $P_{DO\_Surface}$ is the DO production through surface aeration.

3.3 Hydro-meteorological Data

The forcing meteorological dataset used in this study were obtained from the Automated Meteorological Data Acquisition System (AMeDAS). Wind and Temperature from six AMeDAS stations were interpolated and used for the surface boundary condition of the model.

The observed discharge of 22 main rivers around Lake Biwa were used as input to the Biwa-3D model. The model was applied twice with a change made in the Ane river discharge (Figure 2). The Discharge scenario tries to simulate the effect of a dam, where discharge is reduced during snowmelt season and slowly liberated afterwards.

The temperature and DO of the Ane River was the same for both cases, the time series used as input to the Biwa-3D is in Figure 3.

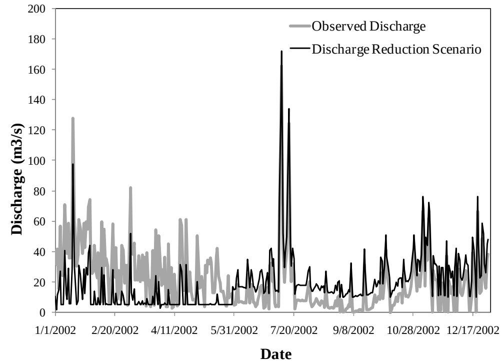


Fig. 2 Lake Biwa and Ane River Basin.

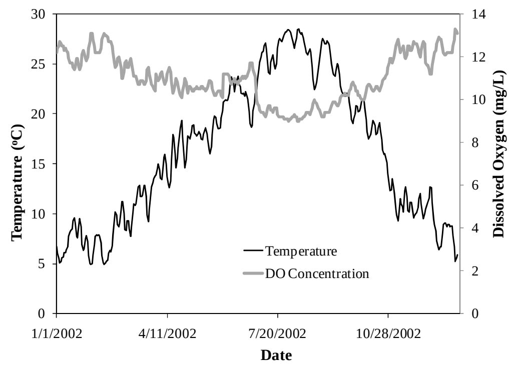


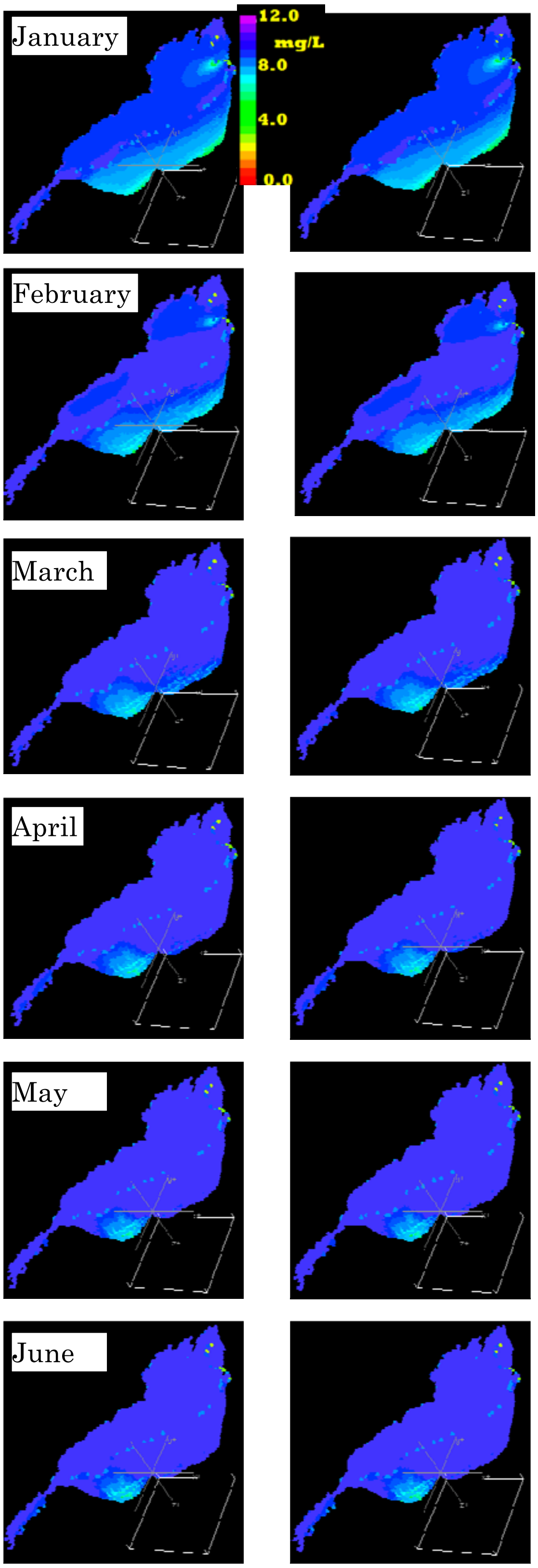
Fig. 3 Lake Biwa and Ane River Basin.

3.4 DO Data

The Biwa-3D model was compared against field DO observation data obtained by the Lake Biwa Environmental Research Institute. This data was measured monthly in ten observation points along a north-south cross-section of the lake in the year 2002. The data was interpolated in 3D using a inverse-distance method so it could be visually compared with the calculated one.

4. Results and Discussions

The DO simulation results for the period of study (2002) are in Figure 4.



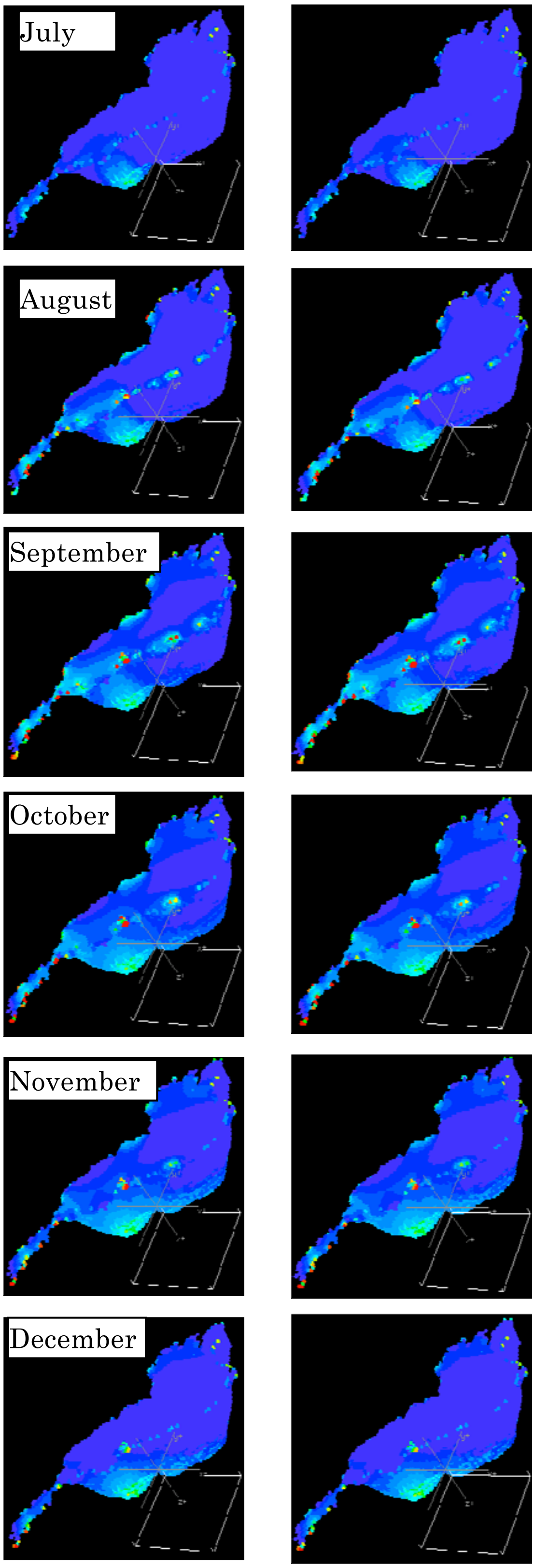


Fig. 4 Simulation of DO in Lake Biwa. (Left) Ane river observed discharge. (Right) Ane river discharge reduction scenario.

In the left side of Figure 4 are the results using observed discharge of the Ane River Basin. In the right there is the simulation for the reduction discharge scenario. In the first two months we used lower level of DO from Ane River so we can confirm the sensitivity of the model to the discharge input. However, we cannot find significant difference between the two scenarios simulated.

Figure 5 shows vertical distribution of dissolved oxygen calculated by the same model and same condition at the vertical section between Ado River mouse to Maibara city region. At this calculation only slight difference in February has been detected by the model. This may because of either smaller discharge from Ane River compare to the scale of the Lake Biwa or sensitivity of the model.

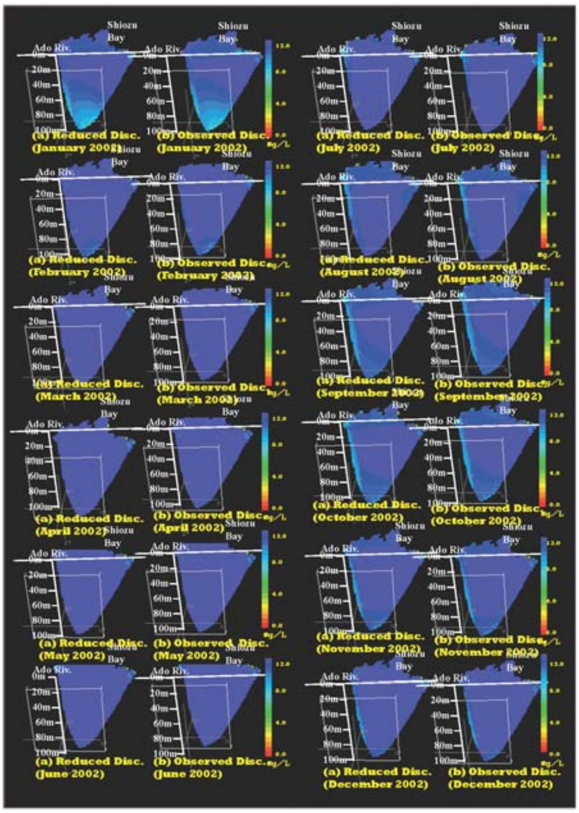


Fig. 5 Simulation of DO in Lake Biwa (Ado-Maibara vertical section). (Left) Ane river observed discharge. (Right) Ane river discharge reduction scenario.

BIWA-3D can simulate the temperature in Lake Biwa but the DO parameters still need to be calibrated. The simulations shown in Figure 4 are point results and may not represent monthly average. Therefore a routine that averages monthly calculation should be implemented.

The input DO and Temperature used for the Ane River discharge were the same, only the discharge was modified. This is problematic since there should be some variation of DO with different discharge scenarios. The discharge scenario created may not be realistic and more careful preparation should be done.

So far, only qualitative comparison through visual inspection was done, but we need quantitative evaluation of the errors.

5. Conclusions

The present study used the circulation model Biwa-3D to analyze the influence of Ane River Basin in the Lake Biwa DO concentration. Despite the fact that the model is sensitive to DO input, there were no clear difference between the two scenarios studied. This might be due to small difference between the observed discharge and DO concentration used as input to Biwa-3D and the discharge reduction scenario utilized. Another cause might be that the discharge from Ane River plays a small role in the Lake Biwa DO, however, more scenarios should be studied to take further conclusions.

The authors would like to stress the limitations of the results presented and that they will be dealt with in future work.

References

Akitomo, K., Tanaka, K., Kumagai, M. and Jiao, C. (2009a): Annual cycle of circulations in Lake Biwa, part 1: model validation, Limnology, Vol. 10, No. 2, pp. 105–118.

Akitomo, K., Tanaka, K. and Kumagai, M. (2009b): Annual cycle of circulations in Lake Biwa, part 2: mechanisms, Limnology, Vol. 10, No. 2, pp. 119–129.

Hosoda, T., Isono, T. and Malembeka, F. P. (2009): Some considerations on numerical experiments of thermal convection in the northern part of Lake Biwa by means of Stochastic Model, Turbulence, Heat and Mass Transfer 6, pp. 893-896.

Kitazawa, D. and Kumagai, M.(2005): Numerical Simulation on Seasonal Variation in Dissolved Oxygen tension in Lake Biwa.

Kumagai, M. and Fushimi, H. (1995): Inflows due to snowmelt, pp. 129-139. In: Okuda, S., Imberger, J., Kumagai, M. Physical processes in a large lake: Lake Biwa, Japan. Coastal and Estuarine Studies, AGU Washington, D.C.

Kumagai, M., Vincent, W. F., Ishikawa, K. and Aota, Y. (2003): Chapter 1, Lessons from Lake Biwa and other Asian lakes: Global and Local perspectives. Freshwater management, Global versus Local perspectives, Springer-Verlag Tokyo, pp. 1-22.

Tanaka, L.L., Sudo, M. and Ban, S. (2009): The spatial and temporal distribution of rice herbicides in Lake Biwa, Japan. Hydrological Research Letters, Vol. 3, pp. 45–48.

Yamashiki, Y., Kato, M., Takara, K., Nakakita, E., Kumagai, M. and Jiao, C. (2010): Sensitivity Analysis on Lake Biwa under the A1B SRES climate change scenario using Biwa-3D Integrated Assessment Model: part I – projection of lake temperature, Hydrological Research Letters, Vol. 4, pp. 45-49.

Yamashiki Y., Kumagai, M., Jiao, C., Nezu, I. and Matsui, S. (2003a): Numerical simulation of thermally induced gyres in Lake Biwa, Hydrological Processes, Vol. 17, pp. 2947-2956.

Yamashiki, Y., Matsumoto, M., Tezuka, T. and Matsui, S. (2003b): Three dimensional eutrophication model for Lake Biwa and its application for framework design of transferable discharge permits, Hydrological Processes, Vol. 17, pp. 2957-2973.

姉川河川水の琵琶湖水質に及ぼす影響評価:Biwa-3D統合水質モデルを用いた感度分析

Pedro Luiz Borges CHAFFE*・山敷庸亮・寶　馨・加藤雅人*・岩木　真穂**

*京都大学院工学研究科
**京都大学院人間環境学研究科

要　旨

琵琶湖の水質に関して様々な研究が行われてきたが，河川水の湖水への影響を直接評価したものは限られており，その影響は十分に解明されているとはいえない。本研究の目的は琵琶湖の水質，特に溶存酸素に対する姉川の影響を三次元統合水質評価モデルBiwa-3Dを用いて評価することであり，姉川の溶存酸素濃度への影響に対するひとつの解析結果を示すことである。姉川流量として2002年の観測値と，上流に水利構造物が建設されたと仮定した流量を境界条件として用いてBiwa-3Dによる年間の溶存酸素濃度の感度解析を行った。モデルは河川水質変化に対して十分な感度を有していると考えられたが，本計算結果においては両ケースで明らかな濃度変化を見ることはできなかった。

キーワード：琵琶湖，Dissolved Oxygen，Biwa-3D，姉川流域