The Characteristics of Water Exchange in Taihu Lake of China

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Abstract Water exchange is an important hydrodynamic character for the study of the environmental capacity of large water bodies. An enhanced understanding and better characterization of the exchange ability has fundamental significance in studying the transport of contamination and the eutrophication of large shallow lakes. In this research, a relation matrix is set up to describe the characteristics of water exchange in Taihu Lake. The Taihu Lake is divided into five areas and the effect of seasonal wind is taken into consideration. The half-exchange time of the lake water and the relation matrix are calculated to describe the characteristics of water exchange.

Key words: water exchange, relation matrix, half-exchange time, water quality model, Taihu Lake

INTRODUCTION

Water exchange is an important hydrodynamic character for the study of the environmental capacity of large water bodies. Recently, due to both natural and human causes, eutrophication and water blooms in Taihu Lake have become a serious environmental problem and a hot topic. The study on water exchange will be helpful to the estimation of the assimilative capacity of Taihu Lake.

Hydrodynamic models have been used widely to predict water circulation and water quality in rivers, estuaries, lakes, etc. In a previous work, a two dimensional hydrodynamic model [1] and a water quality model [2] were implemented to study the distribution characteristics of total phosphorus (TP) in Taihu Lake. The results show that the distribution of TP varies from place to place, which is coincided with the observed result.

In this research, based on the water quality model, a relation matrix [3] is set up to describe the interaction among different areas of Taihu Lake. The Taihu Lake is divided into five areas and the effect of seasonal wind is taken into consideration. The results show the half-exchange time of the lake water and the interaction among different areas of Taihu Lake affected by seasonal wind.

RELATION MATRIX OF WATER EXCHANGE

A lake with a large area or complex terrain can be divided into several subareas for the investigation of the water ex-change property among areas.

Figure 1 shows a rectangular lake which is divided into four areas. Let $t_0 = 0$ as the initial time. At a certain time $t_1 (t_1 > t_0)$ which can be called characteristic time, the water volume in area A_1 consists of four component volumes $V_{11}, V_{12}, V_{13}, V_{14}$ which are the residual water volume of A_1 and contribution of water volume from areas A_2, A_3, A_4. Then the lake water weightings $r_{11}, r_{12}, r_{13}, r_{14}$ of area A_1 contributed by the four areas A_1, A_2, A_3 and A_4 can be defined as follows

$$r_{11} = \frac{V_{11}}{V_1}, \quad r_{12} = \frac{V_{12}}{V_1}, \quad r_{13} = \frac{V_{13}}{V_1}, \quad r_{14} = \frac{V_{14}}{V_1}$$

where V_1 is the total water volume of area A_1 The constitution of the water volume in A_1 can be expressed by a row vector $(r_{11}, r_{12}, r_{13}, r_{14})$. Similarly, other three row vectors can be defined for areas A_2, A_3, and A_4 respectively at $t = t_2$,

t_3, t_4. Combining the four vectors gives the following relation matrix

$$\boldsymbol{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix}$$
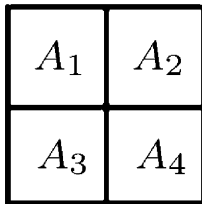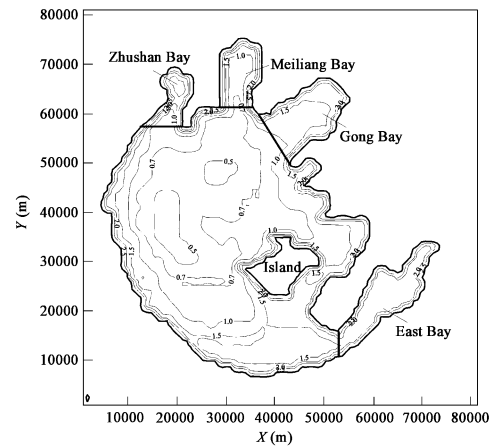

Figure 1: Layout of the areas

Figure 2: Taihu Lake and the division

A column vector can be obtained by combing the characteristic times

$$\boldsymbol{\tau} = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{bmatrix}$$

The lake water half-exchange time T_i of area A_i is defined as the time when the initial water volume in area A_i is decreased to the half, which can be expressed as

$$r_{ii}(T_i) = \frac{1}{2}$$

It is obvious that the following equation will be satisfied for the whole area is a closed region.

$$r_{i1} + r_{i2} + r_{i3} + r_{i4} = 1$$

SIMULATION OF WATER EXCHANGE FOR TAIHU LAKE

The Taihu Lake (Figure 2) is a cosed inland lake, with little inflow and outflow from it. It consists of five areas, the Zhushan Bay, the Meiliang Bay, the Gong Bay, the East Bay, and the Taihu Center.

The relation matrix and the lake water half-exchange time can be obtained by calculating the concentration of the dissolved conservative material by using the water quality model. The details are given in [4,5].

The total simulation time is set at 500 days. The water quality model is switched on after 3 days when the lake current has been stable. The model is appied to two cases, the summer-wind case and the winter-wind case. In the summer-wind case, the summer wind is taken into account, the average wind speed being 8 m/s and the average wind direction being southeast. In the winter-wind case, the winter wind is taken into account, the average wind speed is 8 m/s and the average wind direction being northwest.

RESULTS AND DISCUSSION

The lake water half-exchange time (day)

Summer - wind case

$$\boldsymbol{\tau_1} = \begin{bmatrix} 3.85 \\ 5.73 \\ 7.96 \\ 210.50 \end{bmatrix} \begin{matrix} \text{Zhushan Bay} \\ \text{Meiliang Bay} \\ \text{Gong Bay} \\ \text{East Bay} \end{matrix}$$

Winter - wind case

$$\boldsymbol{\tau_2} = \begin{bmatrix} 5.05 \\ 8.59 \\ 21.20 \\ 393.69 \end{bmatrix} \begin{matrix} \text{Zhushan Bay} \\ \text{Meiliang Bay} \\ \text{Gong Bay} \\ \text{East Bay} \end{matrix}$$

The relation matrices at characteristic time τ_1 and time τ_2 are as follows, respectively.

$$
\boldsymbol{R}_1 = \begin{bmatrix} 0.50 & 0.03 & 0.01 & 0.01 \\ 0.00 & 0.50 & 0.17 & 0.03 \\ 0.00 & 0.00 & 0.50 & 0.03 \\ 0.00 & 0.00 & 0.00 & 0.50 \\ 0.50 & 0.47 & 0.32 & 0.43 \end{bmatrix} \begin{matrix} \text{Zhushan Bay} \\ \text{Meiliang Bay} \\ \text{Gong Bay} \\ \text{East Bay} \\ \text{Taihu Center} \end{matrix} \qquad \boldsymbol{R}_2 = \begin{bmatrix} 0.50 & 0.00 & 0.00 & 0.01 \\ 0.09 & 0.50 & 0.01 & 0.03 \\ 0.07 & 0.23 & 0.50 & 0.04 \\ 0.00 & 0.00 & 0.03 & 0.50 \\ 0.34 & 0.27 & 0.46 & 0.42 \end{bmatrix} \begin{matrix} \text{Zhushan Bay} \\ \text{Meiliang Bay} \\ \text{Gong Bay} \\ \text{East Bay} \\ \text{Taihu Center} \end{matrix}
$$

A column in each relation matrix is formed by the water weightings contributed by the area labeled with the column until the characteristic time. Take the first column of R_1 for example. The first 0.50 means that until the characteristic time for the Zhushan Bay, half of the water in the Zhushan Bay is from itself. The fifth figure 0.50 means that half of the water in the Zhushan Bay comes from the Taihu Center at the half-exchange time of the Zhushan Bay.

Figure 3 shows the variation of lake water weightings for the Taihu Center contributed by each area in the two cases. The variation of lake water weightings for the other areas is also calculated but omitted here due to space limitations

By comparing τ_1 and τ_2 we find that the four half-exchange times of the summer-wind case are all shorter than those of the winter-wind case, which means the water exchange is obviously affected by the wind field. Both τ_1 and τ_2 show that the half-exchange time of the East Bay is much longer than that of the other three bays, which is due to its long and narrow outline. As is shown in Figure 3, the weighting of the Taihu Center is always bigger than 0.5. That means the initial water volume in the Taihu Center is almost impossible to decrease to the half. This is because the area of the Taihu Center is so large that most of the water in it can only flow inside.
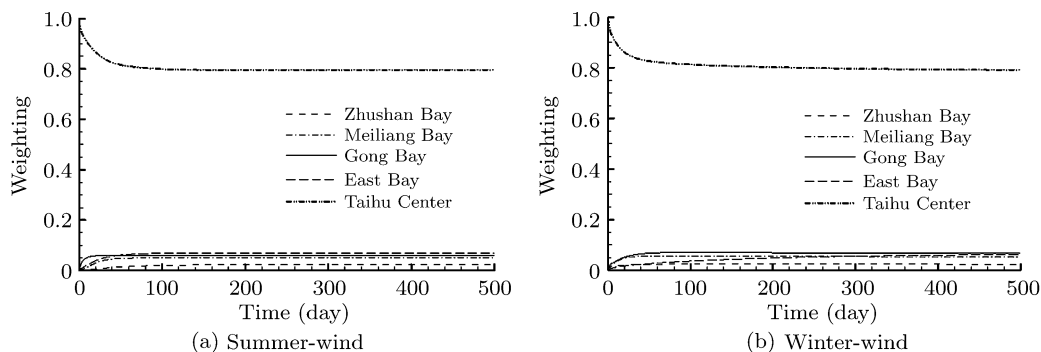

(a) Summer-wind

(b) Winter-wind

Figure 3: Variation of lake water weightings for the Taihu Center contributed by ench area

CONCLUSIONS

In this research, through introducing the relation matrix and the half-exchange time, water exchange property of Taihu Lake is investigated. The results show that summer wind is more propitious to the water exchange of Taihu Lake; except the Taihu Center, the East Bay has the longest half-exchange time. So wind and geometrical features are the impacting factors on the water exchange of Taihu Lake.

Acknowledgements

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