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Procedia Engineering 31 (2012) 696 – 702

Procedia Engineering

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International Conference on Advances in Computational Modeling and Simulation

The flow field simulation on Dianchi Lake

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Abstract

According to the hydro-dynamics models' principle and the comprehensive roughness of the wetland determined by flume experiment, as well as some available information about Dianchi Lake, such as ecological environment construction plan, previous studies, wetland plants and the change of Lake water conditions, a vertical-averaged 2-D hydrodynamic model is established. The model is applied to simulate the flow field under 3 situations: present lake water, lake waters after breakwater removal and wetland build. Wetland plants and the change of the water boundary conditions influencing on the flow field are analyzed. The simulation results show that, removal of the breakwater to expand water have a faint effect on Dianchi Lake, however, it changes the boundary conditions and the part direction of wind-driven current, thus the part flow field is addition. The average flow velocity increases from 0.73cm/s to 1.18cm/s in the area between Fubao and Xishan in the north of Dianchi, increasing by 61.6%. The average flow velocity increases from 0.34cm/s to 0.57cm/s, increasing by 67.6%, in Kun-yang in the portion area of the north of Dianchi. In rest areas, the average flow velocity changes a little from 1.22cm/s to 1.32cm/s, increasing by 8.2%. The effect of ecological wetland on flow field of Dianchi lake mainly happens in the wetland areas, however, the effect on rest areas is limit. The average flow velocity of wetland is from 0.43cm/s to 0.14cm/s, deceasing by 67.4%. The velocity of the rest areas is basically constant, from 1.27cm/s to 1.21cm/s, deceasing by 4.7%. The research results play a significant role on restoring and constructing ecological environment of Dianchi Lake.

Keywords: Dianchi Lake; ecological wetland; hydro-dynamics model; flow field

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doi:10.1016/j.proeng.2012.01.1088

1. Introduction

Dianchi Lake is an important water source of the drinking, industry and agriculture productions, aquaculture and so forth in Kunming City, and is the largest freshwater lake on the Yunnan-Guizhou Plateau, the lake area of 310 square kilometers, the average water depth of about 4.4m. There is a length of about 160km breakwater along the shore of Dian Lake for historical reasons, the wetland behind which has become basic farmland, which results in the decrease of the water area of Dian Lake . Being of the natural link between Dian Lake and land broken by the breakwater, the integrity of lake ecosystem has been destroyed, the water quality is deteriorating, "water bloom" continuously breaks out. To protect the eco-environment, “The Ecological Protection Planning in Dian Lake Basin” was completed by Tsinghua University and other units in October 2003. In accordance with this planning and “The Tenth Five-Year Dian Lake Basin’s Water Pollution Control Plan”, the eco-environmental construction in Dian Lake’s surrounding area was done by Kunming City. The first phase of ecological environment construction is completed by the end of 2010. The Construction of ecological wetland focuses on the Dian Lake’s surrounding area of five districts, i.e. the north shore of Dianchi Lake (including the central city zone), Chenggong County, Jinning County, Kunyang County and the west shore of Dianchi Lake (including the estuary zone), and covers an area of about 45.9km2. The flow field and the ecological environment are influenced by the construction of ecological wetland.

For the Dianchi Lake, Zhou Xueyi[1] adopts two-dimensional wind-driven flow model to simulate the flow field of the shallow Dianchi Lake. On this basis, Jurui Yang[2] establishes model of flow field and the TN, TP, SS concentration field of Dianchi Lake in storm. In recent years, it is developing to use mathematical model to research hydrodynamic characteristics of the wetlands. In early times, Shimizu and Tsujimoto[3] established the k-ε turbulence model considering the effect of vegetation; Darby[4] established a vertical single-dimensional model to calculate the effect of flexible and rigid plants on water in the condition of uniform flow; Erduran And Kutija[5] adopted COMSIM model to simulate the impact of flexible and rigid plants on the water velocity of vertical distribution under the condition of submerged and non submerged plants. To investigate the impact of constructing ecological wetland on ecological environment of Dianchi Lake, based on the compositive roughness of wetland determined by the flume experiment, a two-dimensional dynamics model is established to simulate the flow field of Dianchi Lake. The simulation results play a significant role in ecological restoration of Dianchi Lake.

2. Model equations

Dianchi Lake is shallow, with an average depth of 4.4m. The surface of Dianchi is vast, Comprehensive 2-D ecological simulation model has been able to meet the project design and management needs. Thus, vertical-averaged 2-D hydrodynamic model of ecosystem is established as follow:

$$\frac{\partial \xi}{\partial t}+\frac{\partial (Hu)}{\partial x}+\frac{\partial (Hv)}{\partial y}+s=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial \xi}{\partial x}+fv-\frac{g}{c'^2}\frac{\sqrt{u^2+v^2}}{H}u-\frac{g}{c''^2}\frac{\sqrt{u^2+v^2}}{H}u+\frac{\tau_{sx}}{\rho H}+\varepsilon(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial \xi}{\partial y}-fu-\frac{g}{c'^2}\frac{\sqrt{u^2+v^2}}{H}v-\frac{g}{c''^2}\frac{\sqrt{u^2+v^2}}{H}v+\frac{\tau_{sy}}{\rho H}+\varepsilon(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}) \tag{3}$$

where ξ is the altitude of calculated point from the horizontal; H is the water depth; u, v are mean velocity components in x, y direction respectively; s is the source/sink term of water quantity(the evaporation of rainfall and the total of imported and discharged water); g is the acceleration of gravity; f is the Coriolis force coefficient; $c' = (1/n)H^{1/6}$ is Chezy coefficient,(n is the roughness coefficient of the bottom of the lake); i $c'' = (1/n^*)H^{1/6}$ s Chezy coefficient of the artificial wetland, (n^* is the composite roughness of the wetland); τ_{sx}, τ_{sy} are wind stress components in x, y direction respectively, ε is the eddy viscosity coefficient in the horizontal direction

Initial conditions:

$$\xi(x,y,0) = \xi^0(x,y) \qquad u(x,y,0) = u^0(x,y) \qquad v(x,y,0) = v^0(x,y)$$

where values with superscript character '0' are known values, which can be equal to 0 if counted from rest.

Boundary conditions: land boundary condition applies the slip velocity boundary condition $v \bullet n = 0$ (slipping along shore)

Water intake $v \bullet n \times h = Q_{in}^0$ Drainage outlet $v \bullet n \times h = Q_{out}^0$

where v is the mean velocity at the water intake or at the drainage outlet, h is the water depth at the water intake or at the drainage outlet. n is the unit normal vector at boundary, Values with superscript character '0' are known values, Q_{in}^0, Q_{out}^0 are unit-width discharges at the water intake and at the drainage outlet respectively

3. Model Parameters

3.1 Wind field treatment

The wind field data of surface is one of key conditions on the simulation of wind flow, mountains and other complex terrain around the lake often cause uneven distribution of wind speed. Therefore, monthly average wind speed is utilized in the simulation. And considering the role of the Western Hills of blocking the wind, the results of Tsinghua University's research, reduction 25% of wind speed to simulation[6] the region, is adopted.

3.2 Bottom roughness

Bottom roughness is an important factor in stability of the flow field, the roughness of the general calculation is often treated as a constant, so that it has deviation between calculation results with the results by actual monitoring in the local area. In order to improve stability and accuracy, the automatic adjustment of the bottom roughness is carried out[2].

$$n_k = n_{k-1}\left(1 - \frac{h_c - h_s}{h_s}\right) \tag{4}$$

Where n_k is the roughness when calculate to k-step; n_{k-1} is the roughness when calculate to (k-1)-step; When k = 1, n_0 is the bottom roughness of monitoring; h_c is calculated water level; h_s is measured water level.

3.3 Roughness coefficient of wetland

Water plants may increase the roughness of riverbed, block the flow of water, and change the turbulent structure of flow. At present, when calculating the flow field of wetland water, Composite Roughness is often used to treat the effect of plants on flow water. To determine the composite roughness of wetland plants, experiment of comprehensive roughness is carried out in the flume tank, seven meters long, 0.3 meter wide and 0.5 meter high, in hydraulic laboratory in Kunming University Science and Technology. Green plastic grasses with the height of 3cm, 5cm, and 9cm are selected as simulation plants, and twelve groups of experiments of composite roughness coefficient are carried out for the flow equaling to 5.3L/s, 8.4L/s, 10.3L/s respectively. According to the results, the function relation between composite roughness coefficients of wetland plants and heights of plants is

$$n^* = 0.0316\ln(h) + 0.0315 \tag{5}$$

where n* is composite roughness coefficient of artificial wetland, h is height of plant(cm).

4. Example and results analysis

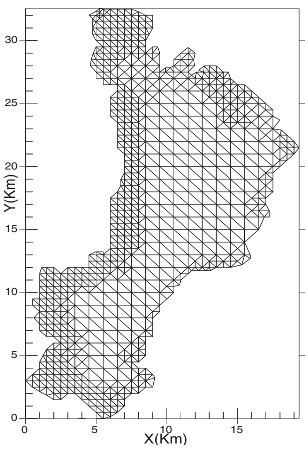
Up to 2010, Dianchi Lake wetland about 45.9km^2 has been basically completed. The artificial wetlands is completely constructed. After removal of the breakwater, thus the water of Dianchi Lake and the water of wetlands fully connect to form a new Dianchi Lake. Therefore, the range of this simulated model included the Dianchi Lake and the surrounding wetland. According to management plan of Dianchi Lake, the simulation of flow field is identified three kinds of schemes: Scheme 1 - existed Dianchi Lake water, Scheme 2 –the new Dianchi water after removal of the breakwater, Scheme 3 - the ecological lake after completely constructed the artificial wetlands.

In this paper, underwater topographic maps of 1:100,000 and the planned drawing of artificial wetland from " The Ecological Protection Planning in Dian Lake Basin " is selected to mesh the grid of flow field simulation. Meshing Grid are divided into two cases, one is to divide existed Dianchi Lake area into 780 nodes, 1360 triangle element mesh; another is to divide new water after removing the breakwater into 988 nodes, 1763 Triangle element mesh. Maximum mesh size is 1 / 2 × 1000m × 1000m, the minimum mesh size is 1 / 2 × 250m × 250m, the time step : t = 20 s. Scheme 1 is simulated by the first division of the grid, Scheme 2 and Scheme 3 are simulated by the second one. Grid models are shown in Figure 1 and Figure 2.

Hybridization step is adopted to the model equations, dividing into two halves before and after by time. Modified method of characteristics is adopted in the first half step, and lumped mass finite element method is solved the latter half. Detailed solution reference to literature [7].

Simulation results of the flow field of Dianchi Lake under 3 schemes are shown in Figure 3, Figure 4, Figure 5 and Table 1.

Figure 3 shows the results of the author's previous simulation[2], it just meet the results of Xueyi Zhou[1] adopting 2-D simulation of wind flow model to simulate the flow field of Dianchi lakes, indicating that the mathematical model for simulating flow field can be used for the flow field simulation of Dianchi Lake.



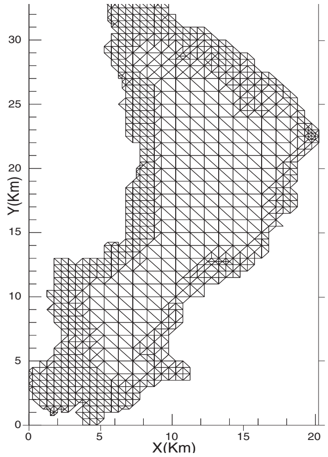
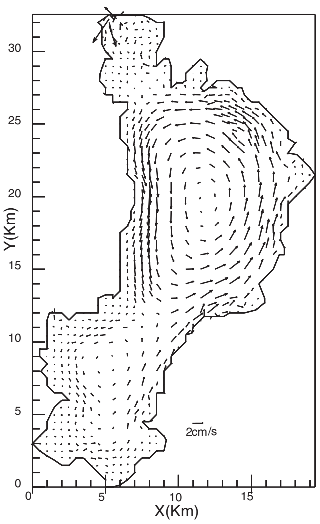
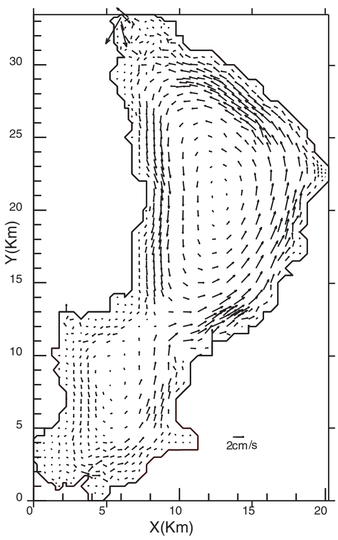


Fig.1 The gird model of existed Dianchi Lake Fig.2 The gird model of expanded Dianchi Lake





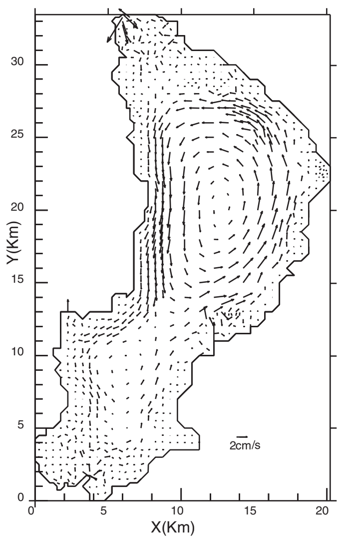


Fig.3 The flow field of scheme 1 Fig.4 The flow field of scheme 2 Fig.5 The flow field of scheme 3

Figure 3,Figure 4 and Table 1 show that Scheme 2 - the new Dianchi Lake water after removal of the breakwater compared with Scheme 1 - existed water, the flow field overall changes a little. The average velocity of water in existed Dianchi water changes from 1.16cm/s into 1.27cm/s, increasing by 9.6%. However, after removal of the breakwater, the water boundary conditions of Panlong and Daqing River estuaries region are changed and it makes the flow field bigger in the region between Xishan and Fubao in the north of Dianchi Lake. The regional average flow velocity changes from 0.73cm/s to 1.18cm/s, increasing by 61.6%. The wetland construction in Kun-yang area in the south of Dianchi, expands flow boundary conditions in the south of Dianchi Lake, and raises the flow field in the region. The regional average flow velocity changes from 0.34cm/s to 0.57cm/s, increasing by 67.6%. The average flow velocity changes from 1.22cm/s to 1.32cm/s, increasing by 8.2% in rest region of Dianchi, raises a little.

Figures 4 and 5 show that, Scheme 2 comparing with Scheme 3, flow field makes a change to a great extent in wetland region, however, it changes a little in the rest areas, because of the resistance effect of wetland plants on flow. The average velocity of flow changes from 0.43cm/s to 0.14cm/s in the wetland area, decreasing by 67.4%. In existed Dianchi area, the average velocity of flow changes a little from 1.27cm/s to 1.21cm/s, just decreasing by 4.7%. Thus, the resistance effect of wetland plants on the wetland area is great, while the effect on non-wetland areas is little.

Table.1 the simulation results of flow field of Dianchi Lake

Region		Scheme 1	Scheme 2		Scheme 3	
		Velocity of flow （cm/s）	Velocity of flow （cm/s）	Rate of increase compared with scheme 1 (%)	Velocity of flow （cm/s）	Rate of increase compared with scheme 2 (%)
Existed Diachi areas	Kun-yang area in the South of Dianchi	0.34	0.57	67.6	0.50	12.3
	Fubao-Xianshan area	0.73	1.18	61.6	1.09	7.6
	The rest areas	1.22	1.32	8.2	1.27	3.8
New Dianchi areas	Existed Diachi areas	1.16	1.27	9.6	1.21	4.7
	Wetland areas		0.43		0.14	67.4

The flow field of Dianchi lakes is the wind-driven circulation flow field, and is much influenced by boundary conditions and wind. The common boundary condition of the lake water and land is changed by wetland construction, and the bottom boundary condition of the wetland water is changed too. In this paper, the flow field of the Dianchi Lake is simulated by comprehensive roughness. But because the factors of impacting on simulation of the wetlands are very complex, it requires further study to simulate accurately.

5. Conclusion

According to the establishment of dynamic model of the lake, the flow field under 3 situations are simulated: existed Dianchi Lake waters, expanding lake waters after removal breakwater and the waters after completely constructed wetlands. Obtained the following conclusions:

The effect of removal of the breakwater to expand the waters on Dianchi Lake is little. But the boundary conditions of Dianchi Lake and the direction of part current are changed by removal of the breakwater, so that the flow of local area of Dianchi Lake turns larger. The average velocity of flow changes from 0.73cm/s to 1.18cm/s, increasing by 61.6% in the area between Fubao and Xishan. The velocity changes from 0.34cm/s to 0.57cm/s, increasing by 67.6% in the Kun-yang area in south.

The effect of constructing ecological wetland on the flow field of Dianchi Lake mainly happens at the wetland, it influences a little in rest areas. The average velocity of flow changes from 0.43cm/s to 0.14cm/s, decreasing by 67.4% in wetland, the velocity changes a little from 1.27cm/s to 1.21cm/s, decreasing by4.7%.

Acknowledgement

The work is Supported by The National Natural Science Foundation of China (No. 50769001). And Jurui Yang is the Corresponding author of the paper.

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