Study on the Ecological Operation of Artificial River-Communicating Lakes during Non-Flood Period

Zhaohui Chai*, Shiming Yao and Tonghuan Liu
Changjiang River Scientific Research Institute, Wuhan, Hubei, 430010, China
*Corresponding author’s e-mail: a3515522@126.com

Abstract: River-communicating lakes in the middle and lower reaches of the Yangtze River connect with river through culverts and sluices except Poyang Lake and Dongting Lake. Its water quality is poorer due to the lack of natural exchange of water, especially in dry season. Taking Huayang Lake group as an example, the feasibility of ecological operation and the specific plan during non-flood period were studied by data analysis, field investigation and numerical simulation. Data analysis result presents the concentration of TN and TP decreases with the increase of water level, but the tendency slows down when the water level exceeds a certain value. In addition, based on the current sluice gate dispatching mode, relationship between river and lakes, flood control security, improvement of water environment and the simulated results, the ecological operation plan was obtained, that is, using Yangwan and Huayang sluices to control the water level in the lake from October to December at 13 m, January to February at 12.5 m and March to April at 11.8 m.

1. Introduction
Lakes are densely distributed in the middle and lower reach of the Yangtze River, which naturally connected with the Yangtze River, and formed a compound system consisting of rivers and lakes in history. With the development of economic and society, there are only two natural links left, Poyang Lake and Dongting Lake[1]. And most of the other lakes connect the rivers and lakes in the form of culverts and sluices. The water self-purification ability of these lakes is weakened because of the block, especially in low water period. On the other hand, it is feasible to use culvert gates for scheduling to improve lake water quality due to the existence of culvert gates. Much interesting and elaborate research had been done by scholars, for example, Kang et al [2] and Zhao et al [3] analyzed the effects of improving the aquatic ecosystem of lake group by diverting the Yangtze River (Yangtze River) to Dong Lake (East Lake, Shahu Lake, Yanxi Lake and Beihu Lake) by numerical simulation; Zhang et al[4] studied the feasibility of ecological dispatching plan for water replenishment from Danjiangkou Reservoir to Baiyangdian Lake and the result presents the average annual water supply of Baiyangdian Lake can be increased by more than 48% under the new plan. However, little research has been done on the ecological dispatching plans of artificial river-communicating lakes in the non-flood season. And many artificial river-communicating lakes are part of flood storage areas (e.g. Wuhu Lake, Huayang Lake), which is mainly for flood control in flood season and short of ecological dispatching conditions. Thus, taking the Huayang Lake group in the Huayang River flood storage and detention area as an example, its ecological dispatching plan in the non-flood season was studied by data analysis, field investigation and numerical simulation, with a view to provide some reference for similar lakes.
2. Overview of the research area

Huayang Lake group, including Longgan Lake, Huanghu Lake, Daguan Lake and Pohu Lake, are located in the southwest of Anhui Province, the south of Susong County and the north bank of the lower reaches of the Yangtze River. The lakes are simple with zonal distribution. The water level rises and the lakes are united during the flood season. Huayang River and Yangwan River are the links between the lakes and Yangtze River and two control gates were built. Xinxian River, Erlang River and Liangting River pour into the Huayang River basin from west to east, draining into Longgan and Pohu Lake.

Floods in Huayang River basin are caused by precipitation. Its water level is related not only to rainfall, but also to the operation of Huayang and Yangwan gate. According to the observed data in Xiacangbu and Tianxiangzu station, the annual maximum water level generally occurs in July to September. The highest water level in Xiacangbu station is 17.35 meters in September 1999 and the lowest water level in is 11.56 meters in April 1 1963, as shown in Figure 1. The annual precipitation, temperature and maximum wind speed are 1285.8mm, 16 to 16.8°C and 10.2m/s.

![Figure 1. Annual maximum water level in Xiacangbu and Tianxiangzu station.](image)

Due to the development of modern economy, the increase of population and the construction of hydraulic engineering facilities, the underlying surface structure of natural lake water systems and watersheds has been changed, and a large amount of wastewater rich in nitrogen and phosphorus nutrients has been brought into lakes, which intensifies the process of lake eutrophication, resulting in rapid deterioration of water quality, loss of lake water function. Table 1 presents the average annual value of COD, TN, TP in Huayang Lake group from 2016 to 2018. As seen from the table, the water quality is poor in the west and better in the east. And the water quality of Longgan Lake is the worst. Its TP concentration has exceeded the limit value of water quality standard III (0.05 mg/L) from 2016 to 2018, and has been deteriorating year by year. The exceeding multiples are 0.1, 0.12 and 1.2, respectively. The TP concentration in Longgan Lake is low in flood season and high in non-flood season. Its value exceeding the standard value basically occurs from January to March, and the minimum concentration basically occurs in flood season from April to October, as shown in Figure 2. The main reason is that pollutant has been diluted and degraded to a certain extent with the gradual increase of water level and reservoir capacity in flood season, which makes the concentration lower. Thus, it is feasible and necessary to use Yangwan sluice and Huayang sluice to regulate the water level of Huayang Lake group in non-flood season to improve the water environment.

| Parameter | 2016 | 2017 | 2018 |
|-----------|------|------|------|
|           | Annual average | Exceeding multiple | Annual average | Exceeding multiple | Annual average | Exceeding multiple |
| Longgan   | COD | 18.735 | - | 16.625 | - | 16.27 | - |
| Lake      | TN  | 0.795  | - | 0.91 | - | 1.05 | - |
|           | TP  | 0.055  | 0.1 | 0.056 | 0.12 | 0.11 | 1.2 |
| Huanghu   | COD | 16.19  | - | 16.5 | - | 12.55 | - |
Lake | TN | COD | TP | TN | COD | TP |
---|---|---|---|---|---|---|
Daguan Lake | 0.58 | 16.01 | 0.044 | 0.63 | 11.17 | 0.018 |
Pohu Lake | 0.68 | 17.61 | 0.08 | 0.93 | 13.14 | 0.072 |

Note: The limit value of water quality standard III: COD: 20mg/L; TN: 1.0mg/L, TP: 0.05mg/L (lake and reservoir).

Figure 2. Annual variation of TP in Longgan Lake (Anhui-Hubei junction section).

3. Ecological dispatching plans in non-flood season
The main purpose of the ecological dispatching plan is to improve the water environment of the lakes on the premise of flood control safety. It mainly considers four aspects: current gate dispatching mode, river-lake relationship, flood control safety and water environment improvement.

3.1 Current gate dispatching mode
Yangwan and Huayang sluice are operated in the following ways at present: the normal storage water level is controlled at 11.8 m from March to September (Xiacangbu station, Wusong elevation system), at 12.0 m from October to February of next year, and the storage water level can be raised appropriately according to the drought conditions.

3.2 River-lake relationship
The change of water storage capacity of Huayang Lake group is influenced by the switch of Yangwan gate and Huayang gate since 1956. The river-lake relationship was analysed through the data collected before and under the Huayang sluice gate, because the Yangwan and Huayang sluice are close to each other and have the same water level relationship between the inner lake and the outer river. Figure 3 shows the comparison of water level between before and under the Huayang sluice gate. In the main flood season (May-October), the water level of the Yangtze River is higher than that of the Huayang Lake group, and the flood cannot be discharged, while the water level of the lake group is higher than that of the Yangtze River in the non-flood season. After the completion of the Three Gorges Dam in 2003, the time distribution of the natural runoff of the Yangtze River has changed, and the hydrological elements of the lower reaches have also changed. The main manifestation is that the average water level of the Yangtze River has decreased from April to December, and the water level of the Yangtze River has risen from January to April in the non-flood season. The rise of the water level of the Yangtze River will affect the discharge of the two sluices. Meanwhile, the average annual water level in the last ten days of September is about 13.45m, which is higher than the current non-flood season control water level (11.8m-12.0m), meaning that water dispatching in non-flood season scheduling is achievable.
3.3 Flood control safety

The total number of polders above 1000 mu around Huayang lake group is about 59, with a protected area of 639.86 km² (the cultivated land is 506 km²). The elevation of dike is basically above 16.0 m. From the point of view of flood control, the water level of Huayang Lake group should not exceed 16.0 m in the non-flood season. However, the dikes of Huayang Lake group are mostly constructed in segments and thin. When the water level exceeds 15.0m, there will be some risks. Therefore, the highest water level cannot exceed 15.0m in the dispatching plan. At the same time, Huayang Lake group is located in Huayang River flood diversion and storage area, which is an important part of the overall flood control in the middle and lower reaches of the Yangtze River. It is an important engineering measure to deal with excess flood in the estuary area and ensure the flood control safety in the key areas of the middle and lower reaches of the Yangtze River. Thus, the water level of Huayang Lake group should be lowered to the limited water level (11.8m) before flood season to prevent flood in the Yangtze River.

3.4 Water environment improvement

Elevation of water level can reduce pollutant concentration to a certain extent. The different lake flow movement patterns formed by water level change profoundly affect the transfer of mass, momentum and energy of water, leading to change the diffusion, siltation and purification of sediment and pollutant inflowing into lakes, and consequently alter the health status of lake water environment. However, according to the measured data, the downward trend of TN and TP concentration becomes slower with the increase of water level, when the water level of the lake group is higher than 13.5m, as shown in Figure 4.
Based on the above four principles and opinions of local units (the water level should be controlled at 13-13.5m, 13m recommended by Susong and Taihu county water conservancy bureau, at 12.5m by Huayang River farm), the water level of Huayang Lake group was firstly considered to rise to 12.2m, 12.5m and 13m.

3.5 Discharge time before flood season
As mentioned above, in order to ensure the flood control safety of the Yangtze River, the water level of the lake group should be reduced to 11.8m before flood season. It is very important to determine the discharge time before flood season. If the lifting water level and the measured average water level after 2003 are adopted to calculate the discharge, the two gates can be discharged by the designed discharge, which would influence its safety and the downstream riverbed. Thus, the measured average discharge (254 and 77 m$^3$/s for Yanwan and Huayang sluice) was used to compute the discharge time, and the result is presented in Table 2. The higher the elevation of the lake water level in non-flood season, the longer it takes to meet the pre-flood requirement, such as, the time needed for 13m to 11.8m is about 1.7 times as long as 12.2m to 11.8m. In other words, the higher the elevation of the lake water level in non-flood season, the sooner the discharge begins.

Table 2. Calculated results of the discharge time before flood season.

| Change of water level | Beginning time | Incoming flow ($10^4$ m$^3$) | Change of lake volume ($10^4$ m$^3$) | Total discharge ($10^4$ m$^3$) | Duration of discharge (day) |
|-----------------------|---------------|-------------------------------|-------------------------------------|-------------------------------|-----------------------------|
| 12.2m to 11.8m        | January 1     | 0.42                          | 3.68                                | 4.1                           | 15                          |
|                       | February 1    | 6.20                          | 3.68                                | 9.88                          | 35                          |
|                       | March 1       | 2.26                          | 3.68                                | 5.94                          | 21                          |
|                       | April 1       | 6.35                          | 3.68                                | 10.03                         | 36                          |
|                       | January 1     | 0.42                          | 6.43                                | 6.85                          | 24                          |
| 12.5m to 11.8m        | February 1    | 6.20                          | 6.43                                | 12.63                         | 45                          |
|                       | March 1       | 2.26                          | 6.43                                | 8.69                          | 31                          |
|                       | April 1       | 6.35                          | 6.43                                | 12.78                         | 45                          |
|                       | January 1     | 0.42                          | 11.02                               | 11.44                         | 41                          |
| 13m to 11.8m          | February 1    | 6.20                          | 11.02                               | 17.22                         | 61                          |
|                       | March 1       | 2.26                          | 11.02                               | 13.28                         | 47                          |
|                       | April 1       | 6.35                          | 11.02                               | 17.37                         | 61                          |
| 13m to 12.2m          | January 1     | 0.42                          | 7.35                                | 7.77                          | 28                          |
|                       | February 1    | 6.20                          | 7.35                                | 13.55                         | 48                          |
| 13m to 12.5m          | March 1       | 0.42                          | 4.6                                 | 5.02                          | 18                          |
|                       | April 1       | 6.20                          | 4.6                                 | 10.8                          | 38                          |

Note: The incoming flow refers to a typical flood year with a guaranteed rate of $P=25\%$ based on the measured data of many years in non-flood season (October 1972 to April 1973).

3.6 Preliminary plan
Based on the above analysis results, five plans were designed, as described next.

Plan 1: controlling the water level in the lake at 12.2m from October to February, and at 11.8m from March to April;

Plan 2: controlling the water level in the lake at 12.5m from October to February, and at 11.8m from March to April;

Plan 3: controlling the water level in the lake at 13m from October to January, and at 11.8m from February to April;

Plan 4: controlling the water level in the lake at 13m from October to December, at 12.5m from January to February, and at 11.8m from March to April;

Plan 5: controlling the water level in the lake at 13m from October to December, at 12.2m from January to February, and at 11.8m from March to April.
4. Numerical simulations
The hydrodynamic module (HD) and convection-diffusion module (AD) in MIKE21 were employed to study the water quality changes of Huayang Lake group under different dispatching plans. The simulation range includes Longgan Lake, Daguan Lake, Huanghu Lake, Pohu Lake, Yangwan River and Huayang River, which are about 900 km$^2$. In the initial conditions, the water level and initial velocity at each grid are set at 12.8 m and 0 m/s. The initial concentration of water quality parameter is taken as the measured average value from 2015 to 2018. The boundary conditions include the TN and TP concentration at the point source of the lake, the incoming flow discharge into the lake, the wind factor (wind speed: 4.0 m/s, wind direction: NE) and so on.

4.1 Model verification
The model was validated using the data from 23 sampling sites in Longgan Lake, Daguan Lake, Huanghu Lake and Pohu Lake from October 2015 to April 2016. Figure 5 shows the comparison between calculated and measured data, where the Coriolis force constant is $7.27 \times 10^{-5}$ s$^{-1}$, the transverse diffusion coefficient is 1.0 m$^2$/s, the wind resistance coefficient is 0.0012, the roughness is 0.02, the degradation coefficient of TN is $0.013d^{-1}$, and the degradation coefficient of TP is $0.008d^{-1}$. It can be seen from the figure that the calculation error of the model is between 0.27% and 8.41%, which meets the relevant requirements and can be used to simulate the water quality changes of lakes under different plans.

![Comparison between calculated and measured data](image)

Figure 5. Comparison between calculated and measured data

4.2 Result analysis
Figure 6 compared the results of the simulations in different plans. As can be seen from the figure, the water quality of Huayang Lake group has been improved after the rising of water level in non-flood season. There are two main reasons: one is that the rising of water level in the lake area increases the lake capacity (for example, the lake capacity increases by 920 million m$^3$ from 12.0 m to 13 m), and pollutants are diluted, causing the pollutant concentration to reduce. The other is that the convective transport of pollutants will be increased during the emptying of excess water before flood season, to a certain extent. For the maximum decreases of TP and TN, the TN in plan 3, the TP in plan 4 and plan 5 decrease the most. Plan 4 or 5 was chosen for the further optimization because TP pollution is the most serious problem in the Huayang Lake group. For these two plans, the TP concentration from January to April of plan 4 is smaller than that of plan 5. The main reason is that, the water level of plan 4 is higher than that of plan 5 at January and February, and the flow velocity is also higher at the water level falling period in March and April. Therefore, plan 4 is superior to plan 5, which is the final recommendation plan.
Figure 6. Comparison of the simulation results in different plans, (a) The maximum reduction of TN and TP; (b) TP concentration in plan 4 and 5.

5. Conclusions
Taking the Huayang Lake group as an example, this paper studied the ecological dispatching plans in non-flood season of artificial river-communicating lake, and the main conclusions obtained are as follows: 1. the water quality of Huayang Lake group is poor in the west and better in the east. Among them, the water quality of Longgan Lake is the worst, mainly for TP exceeding the standard. 2. With the increase of water level, the concentration of TN and TP in Huayang Lake group decreased, but when the water level was higher than 13.5 m, the concentration of TN and TP decreased slowly. 3. Based on the four principles, current gate dispatching mode, river-lake relationship, flood control safety and water environment improvement, and the numerical simulation results, the ecological dispatching plan in non-flood season is finally determined: using Yangwan and Huayang sluice to control the water level in the lake at 13 m from October to December, at 12.5 m from January to February, and at 11.8 m from March to April.

This study is mainly aimed at Huayang Lake group and the application of the results has certain limits; however, the research process and results have certain reference significance for similar lakes.

Acknowledgments
This study work was supported by the National Key R & D Programof China (No: 2018YFC0407601) and National Natural Science Foundation of China (No: 51609012, 51579015, 51679010).

References
[1] Wan, R.R., Yang G.S., Wang, X.L., Qin, N.X., Dai, X. (2014) Progress of research on the relationship between the Yangtze River and its connected lakes in the middle reaches. J. Lake. Sci., 26: 1-8.
[2] Kang, L., Guo X.M., Wang, X.L. (2012) Study on water diversion schemes of large urban lake group. J. Hydro. Engin., 31: 65-69.
[3] Zhao, Y.X., Zhang, W.S., Wu, J., Wang, Y. (2012) Numerical simulation of water dicersion to improve the water quality of the Donghu Lake in Wuhan city, Res. Environ. Yangtze. Basin., 21: 168-173.
[4] Zhang, L.L., Yin J.X., Zhang S.G., Jiang, Y.Z. (2012) Ecological operation schemes on water diversion from Danjiangkou reservoir to Baiyang Lake. Wetland. Sci., 10: 32-39.