The regulation of three gorges dam on lake Poyang: an assessment of the lake water level change during the dry season

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Abstract. With a combination of field data analysis and numerical simulation on 2D river-lake hydrodynamics, this study focuses on the water level change in Lake Poyang regulated by the Three Gorges Dam (TGD) during the dry season. Based on the long-term measured water level series (1956-2012), after the completion of TGD, the dry season in Lake Poyang is promoted to start early, and its duration is extended. With the regulation of TGD during the impoundment period, more outflow from Lake Poyang pours into the Yangtze River, leading to the decrement of lake water level and an earlier occurrence (about 4-5 days forward) of the dry season. Besides, with the regulation of TGD during the flushing period, the water level in Lake Poyang is elevated, making a relief to the lake drought during the dry season.

1. Introduction
The Lake Poyang is the largest rive-connected fresh lake in China, which presents features as lake in the flood season while as river in the dry season. The difference on lake size in the two seasons is quite significant. Lake Poyang has five inflow rivers (Ganjiang River, Fuhe River, Xinjiang River, Raohe River and Xiushui River), and it connects to the Yangtze River at Hukou, the lake outlet to the Yangtze River. Due to the competition between the Yangtze River and its five inflow rivers, the water level in Lake Poyang varies notably. During April-June, the flood from five inflow rivers pours into Lake Poyang, leading to increment of lake water level. During July-September, the flood in the Yangtze River flows back into Lake Poyang through the outlet Hukou, resulting into higher lake water level. After October, with the retreat of flood, the lake water level decreases, and it is the dry season in Lake Poyang from November to March.

In recent years, the lake water level change has new trends, presenting a much earlier occurrence and a much longer duration of the dry season and the lowest water level frequently. These changes received much attention and many investigations. Many studies reported that the aggravated drought in Lake Poyang are related with factors, such as, the reduced precipitation in the Yangtze River basin, the reduced runoff from five inflow rivers, the sedimentation in the lake, the bed deepening in the Yangtze River, the increment of industrial and domestic water demand and the regulation of Three Gorges Dam (TGD)[1-7]. Although there have been some studies that discussed the water level change in Lake Poyang[8-11], they mainly focus on qualitative description on field data. Moreover, the influence of TGD's regulation during the impoundment and flushing periods on the lake water level is relatively less investigated.
With the combination of analysis of field data and numerical simulation, this study presents detailed analysis of water level change in Lake Poyang, regulated by TGD during the dry season. The paper is organized as follows. Following the brief introduction, Section 2 describes the study area and numerical simulation used for evaluating the lake water level change influenced by TGD’s regulation. Section 3 presents quantitative results of water level change in Lake Poyang and the influence of TGD on it. Section 4 summarizes major findings.

2. Data and methodology

2.1. Study area and data
The Yangtze River, called as the mother river by Chinese, plays a very important role in the history, culture and economy of China. This river, also popularly known as Chang Jiang for Chinese, is the longest river (around 6300 kilometers) in China. It originates from glaciers in Tibet Plateau, flows across southwest, central and east China, and finally ends into the East China Sea. The Yangtze River basin drains 1.8 million km² in 11 provinces, about one-fifth of the land area of the People's Republic of China.

China has built more than half of the world’s large dams since 1950, among which the Three Gorges Dam (TGD) Project is the most noticeable one. It is the world's largest hydropower project, in terms of installed capacity. This project began in 1994 and the Yangtze River is dammed in 1997; on 1st June 2003, the dam is finished and impounded its first water.

The Poyang Lake (115°49′E~116°46′E, 28°24′N~29°46′N), the largest freshwater lake in China, located in the north of Jiangxi Province and connected to the Yangtze River at Hukou (Figure 1). With a drainage area of 162,200km², it covers about 9% of the total area of Yangtze River basin. Its water level fluctuates significantly between dry and wet seasons. This lake is famous for its bird habitat, which supports half a million migratory birds in winter, and its wetland was included in The Ramsar Convention List of Wetlands of International Importance.

The field data[5, 12] during 1956-2012 was used to analyze the characteristics of lake water level regulated by TGD during the dry season. The terrain data are mainly based on field measurements in 2011, while part of them (the east Poyang Lake) were measured in 2010. With assumption that the geography in the Poyang Lake didn’t change significantly during 2010-2011, those terrain data were used as the terrain boundary condition in 2011 in the numerical simulation. The hydrology boundary condition in 2011 is from the Annual Hydrological Report of P. R. China.

Figure 1. The Poyang Lake drainage.  
Figure 2. Coordinate net for the computational domain.
2.2. Numerical simulation

2.2.1. Verification of the model  The software MIKE21 with the Flow Model (FM) module is employed to simulate the lake water level change process during the impoundment period and flushing period under the regulation of TGD. The prototype of study area is about 180×200 km$^2$, which is large enough to cover the lake size during the flood season. The size of discrete grid is in the range of 30-160 m (Figure 2), among which fine grids are used to resolve the main channels and regions with sharp terrain difference and coarse grids are used for the wide and smooth lake basin. The discharge at Jiujiang Station ($Q_1(t)$ in Figure 2) and discharges in five inflow rivers ($Q_2(t)$~$Q_8(t)$ in Figure 2) are used as inflow boundary condition in the computation, while the water level at Pengze Station ($Z(t)$ in Figure 2) is used as outflow boundary condition.

The river-lake interaction influenced by TGD during the impoundment period in 2011 and 2012 is simulated for verification. Simulated hydrological variables (such as water level, velocity and discharge) are compared with measured data, and some of the results are listed in Figure 3 and Figure 4. As listed in Figure 3, magnitudes and trends of velocities at four cross sections are very well simulated, so is the lake water level change in Figure 4.

2.2.2. With/without the impoundment of TGD  Runoff data with impoundment of TGD could be obtained from the gauging stations distributed in the Yangtze River and lake inflow rivers. According to Fang et al. (2012)[13], in 2011, the TGD dam impounded water on 15th September, and reached its full storage state on 31th October; with the regulation of TGD, the discharge at Jiujiang Station decreased by 4200 m$^3$/s. Assume that $Q_1(t)$ in the Yangtze River without the impoundment of TGD could be obtained by the sum of measured runoff series at Jiujiang Station and the increment of 4200 m$^3$/s. The water level at Jiujiang Station can be evaluated from the fitted line in Figure 5a, and that at Pengze Station can be obtained from the fitted line in Figure 5b. Furthermore, discharge series in five inflow rivers are from gauging stations, and their flow boundary conditions are not influenced by the regulation of TGD.

![Figure 3. Daily averaged velocities at four cross sections (22th Sep. 2012).](image-url)
2.2.3. With/without the flushing of TGD

After the completion of TGD, stored water during the impoundment period will be sluiced during the lake dry season. The supplied water volume during the flushing period can reach 10 billion tonnes[14, 15].

Runoff data with flushing of TGD could be obtained from the gauging stations distributed in the Yangtze River and lake inflow rivers. Assume that the additional flushing discharge (from the Three Gorges Reservoir to the downstream Yangtze river reach) during the flushing period is equal to the discharge difference $\Delta Q$ between the outflow and inflow of Three Gorges Reservoir. So $Q_1(t)$ in the Yangtze River without the flushing of TGD could be obtained by subtracting $\Delta Q$ from the measured runoff series at Jiujiang Station. The water level at Jiujiang Station can be evaluated from the fitted line in Figure 6, and that at Pengze Station can be obtained from the fitted line in Figure 5b. Meanwhile, as the regulation of TGD has little influence on inflow rivers to Lake Poyang, their flow boundary conditions are the same in cases with/without the flushing of TGD.

**Figure 4** Lake water levels at two stations (2011).

**Figure 5.** (a) The relation between water level and discharge at Jiujiang Station during the impoundment period in 2011 and (b) The relation on water level between Jiujiang Station and Pengze Station in 2011.
Figure 6. Relations between water level and discharge at Jiujiang Station during the flushing period in 2011.

3. Results

3.1. Lake water level change based on field data

Based on analysis of field data on lake water level during 1950-2012, the characteristics of water level in Lake Poyang during the dry season are summarized in Table 1:

(1) The start time of low water level occurrence is brought forward. Before the completion of TGD (during 1956-2002), the averaged start date of 10 m low water level at Xingzi Station is November 11th; however after the completion of TGD, it is October 14th, 28 days forward. Before the completion of TGD (during 1956-2002), the averaged start date of 8 m low water level at Xingzi Station is December 2nd; however after the completion of TGD, it is October 29th, 34 days forward.

(2) The duration time of low water level is increased. As listed in Table 2, the duration time of 10 m low level is 127 days during 1956-2002, while it increases to 175 days during 2003-2012. Moreover, the duration time of 8 m low level is 72 days during 1956-2002, while it increases to 106 days during 2003-2012. The completion of TGD extends the duration time of low lake water level.

(3) The lake water level is decreased by the impoundment of TGD. After the completion of TGD, a large amount of water is stored during the impoundment period, which leads to relative lack of water downstream. Particularly, during the impoundment period, in October, water levels at Hukou Station, Xingzi Station, Duchang Station, Kangshan Station and Tangyin Station have remarkable descending trends with decrement about 1.27-2.20 m. On the other hand, during the flushing period from January to March, the flushing water will help to raise the lake water level at Hukou Station up, but water levels at most of the lake regions are still 0.1-1.0 m lower than they were before the completion of TGD.

| Gauging Stations | Sep.  | Oct.  | Nov.  | Dec.  | Jan.  | Feb.  | Mar.  |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Hukou            | -0.80 | -2.20 | -1.60 | -0.54 | +0.25 | +0.38 | +0.67 |
| Xingzi           | -0.80 | -2.17 | -1.64 | -0.77 | -0.40 | -0.55 | -0.22 |
| Duchang          | -0.81 | -2.14 | -1.67 | -1.12 | -1.03 | -1.06 | -0.60 |
| Tangyin          | -0.77 | -1.81 | -1.05 | -0.64 | -0.63 | -0.38 | -0.05 |
| Kangshan         | -0.52 | -1.27 | -0.29 | -0.29 | -0.32 | -0.29 | -0.08 |

Varied value listed above is the difference between the averaged water level during 2003-2012 (after the completion of TGD) and the averaged water level during 1956-2002 (before the completion of TGD) in each month.
Table 2. Duration time of low water level at Xingzi Station after the completion of TGD.

| Series       | 10m low level | 8m low level | 6m low level |
|--------------|---------------|--------------|--------------|
|              | \( T \) | \( t_{1st} \) | \( t_{ave} \) | \( T \) | \( t_{1st} \) | \( t_{ave} \) |
| 1956-2002    | 127          | Sep/1        | Nov/11       | 72     | Oct/14        | Dec/2         | 11     | Dec/9         | Dec/21       |
| 2003-2012    | 175          | Aug/22       | Oct/14       | 106    | Sep/28        | Oct/29        | 20     | Dec/11        | Dec/15        |

\( T \) means the duration time (days); \( t_{1st} \) means the first start date; \( t_{ave} \) means the averaged start date.

3.2. Lake water level change based on numerical simulations

3.2.1. During the impoundment period After the impoundment of TGD, discharge and water level in the downstream Yangtze River reach decreases, leading to more outflow from Lake Poyang pouring into the Yangtze River. Besides, the discharge decrement in inflow rivers during September to October reduces the water level of the lake further. It is concluded that the decrease magnitude in latter half of September is the largest, while it is relatively small in the former half of October. In terms of degree of water level decrease, Hukou Station is the largest, while those in the middle of Lake Poyang are smallest. With the regulation of TGD, water level at Hukou Station is decreased by 0.52-1.65 m, and water levels at Xingzi Station and Duchang Station are decreased by 0.41-1.60 m and 0.21-1.50 m, respectively (see Figure 7).

With the impoundment of TGD, the downstream river water level is decreased, leading to more outflow from Lake Poyang to the Yangtze River. Hence the lake dry season is promoted to start early, about 4-5 days forward, and the lake water level is decreased accordingly.

3.2.2. During the flushing period Simulated results with/without the regulation of TGD during the flushing period are shown in Figure 8. With the flushing from the Three Gorge Reservoir, discharge and water level in the downstream river reach are increased. With the river water level higher than the lake water level, the Yangtze River is blocking the outflow from Lake Poyang, leading to the increment of lake water level. Except in the end of January and the start of February, lake water level is increasing at a notable rate. In terms of magnitude of lake water level increment, Hukou Station is the largest, while other stations inside the lake are relatively small. With the regulation of TGD during the flushing period, water level at Hukou Station is increased by 0.29-1.27 m, while water levels at Xingzi Station and Duchang Station are increased by 0.26-0.93 m and 0.10-0.43 m respectively.

With the flushing of Three Gorges Reservoir, water level in Lake Poyang is increased, which helps to make a relief to the lake drought during the dry season.

4. Conclusions

Based on analysis of field data and numerical simulation, water level change in Lake Poyang regulated by the Three Gorges Dam (TGD) during the dry season is investigated. Major findings are summarized as follows:

1) With the regulation of TGD, the dry season in Lake Poyang is promoted to start earlier, and its duration time is extended while lake water level is decreased.

2) With the impoundment of TGD, discharge in the downstream river reach is decreased, leading to more outflow from Lake Poyang pouring into the Yangtze River. The dry season of the lake is brought forward by 4-5 days. With the regulation of TGD, lake water level is decreased, and water levels at Hukou Station, Xingzi Station and Duchang Station are decreased by 0.52-1.65 m, 0.41-1.60 m and 0.21-1.50 m, respectively.
Figure 7. Lake water levels with/without regulation of TGD during the impoundment period in 2011.

Figure 8. Lake water levels with/without regulation of TGD during the flushing period in 2011.

(3) With the flushing of TGD, discharge in the downstream river reach is increased, leading to backflow from the Yangtze River to Lake Poyang. With the regulation of TGD, lake water levels are increased, and those at Hukou Station, Xingzi Station and Duchang Station are increased by 0.29-1.27 m, 0.26-0.93 m and 0.10-0.43 m respectively. The increment of lake water level will make a relief to the lake drought during the dry season.

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