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Simulation analysis of the influence of heavy rainfall on urban lake

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Abstract. Urban lakes play a role in flood control and storage, they are also important urban landscape, which have certain requirements for water quality. In addition to the impact on the lake water quantity, the short-term heavy rainfall runoff carries a large pollution and has a great impact on the water quality, especially for urban lakes with relatively small reserves. However, there are few studies on the effects of heavy rainfall on lake hydrodynamics and water quality. In this paper, taking the rainfall of typhoon Fitow as an example, EFDC was used to simulate the hydrodynamic water quality process of West Lake in Hangzhou China during the Fitow period, the water level and water quality monitoring values were used to validate the model during this period. The simulation shows that the heavy rainfall had a great influence on the water level of the West Lake. Water level of West Lake crossed warning mark about 71 hours, with Sudi and Baidi Causeways were flooded about 57 hours. According to the simulation, as the TP concentration of early runoff was high, the TP concentration at the inlets of each sub-basin increased above 0.1 mg/L. After the early runoff, the TP concentration at the inlets began to decrease. The high concentration area gradually migrated to the downstream, and decreased gradually until it was discharged from the Shengtangzha Outlet, and water quality gradually returned to normal. Since the water level of West Lake increased significantly during the period, the influence of different drainage discharges was analyzed. The analysis shows that the highest water level of West Lake during Fitow period would fall below warning mark in case of increasing the flood discharge capacity to 46.8m³/s, which was 29m³/s more than current discharge. Otherwise there's little effect on the spatial distribution of TP with the increasing of flood discharge. In conclusion, the main threat of short-term heavy rainfall to urban lake is flood control and drainage, meanwhile the impact of the heavy rain on water quality cannot be ignored. A perfect drainage and diversion system would make the water quality back to normal quickly after the heavy rainfall.

1. Introduction

In recent years, extreme weather (such as typhoon, heavy rainfall and hot temperature) happened frequently, which has a strong effect on social environment. Heavy rainfall as a kind of extreme weather also poses a great threat to urban water environment [1,2]. While urban lakes play a role in flood control and storage, they are also important urban landscape, which have certain requirements for water quality. According to research, the pollutant carrying by heavy rainfall runoff has a great effect on water quality of lake. Liu, Zheng and Yuan studied on the impact of rainfall on lake hydrodynamics and water quality [3,4,5], however the research about the heavy rainfall is seldom. In this paper, as an example of West Lake in Hangzhou China, the hydrodynamics and Total Phosphors processes were simulated in the heavy rain of typhoon Fitow period. Furthermore, the change



processes of water level and TP (total phosphorus) concentration (the major eutrophication factor) were simulated in different drainage capacity.

2. Study area

West Lake is a freshwater lake in Hangzhou, China. And it plays an important role in China's history and culture. It was made a UNESCO World Heritage Site in 2011. West Lake is divided into several small lakes by Sudi and Baidi Causeway (Figure1), there are Outer West Lake, West Inner Lake, Little Inner Lake and so on. The average water depth is 2.27 m. The annual water level is controlled at 7.18 m, the water area is 6.36 km², and the corresponding water storage capacity is 1.38×10^7 m³. The West Lake basin has an area of 27.25 km² and the multi-year average runoff is 1.46×10^7 m³. The tributaries mainly include Jinsha River, Longhong River, Chishan River and Changqiao River (Figure1).

At Oct 7th in 2013, heavy rain occurred in Hangzhou on account of the effects of the Typhoon Fitow. The weather station shows that the cumulative rainfall reached 246.4mm in 24 hours, which was a third of the average annual rainfall in Hangzhou. And West Lake was filled up rarely, that was an extreme storm case.

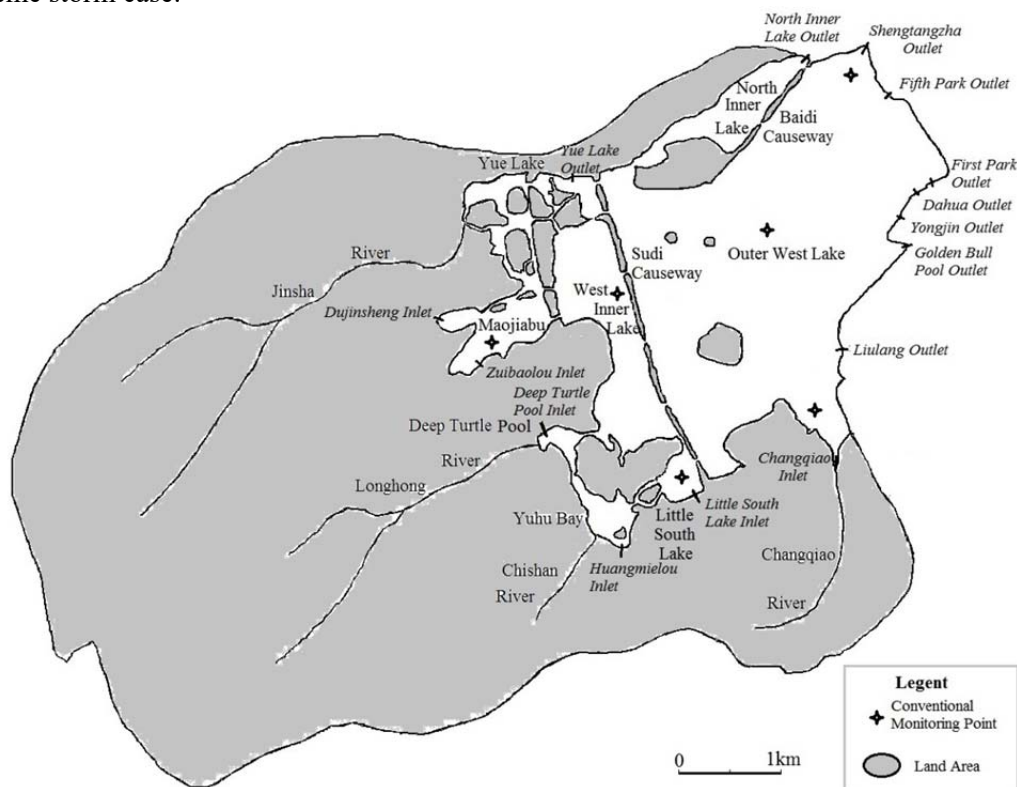


Figure 1. General situation of West Lake and its Watershed.

3. Calculation of inlets runoffs and pollutions

3.1. Discharge

In Fitow period, the water diversion had been stopped, and the main inflow was the runoff. As the inflow boundaries of West Lake, the runoff flow processes of 4 tributaries were calculated using the precipitation data per hour with deduction method (Figure 2). According to the runoff results, Jinsha River was the dominated tributary of West Lake, and the maximum discharge was 40m³/s. Considering the rainfall on the lake, the total water amount was about 4.73×10^6 m³ in Fitow period.

There are Shengtangzha Outlet, Yue Lake outlet and some little outlets around West Lake. Shengtangzha Outlet and Yue Lake Outlet reached the maximum discharges of $17.8\text{m}^3/\text{s}$ and $1.16\text{m}^3/\text{s}$ respectively in Fitow period, of which the total flow of other outlets was $1.4\text{m}^3/\text{s}$.

3.2. Water quality

Cause that there were no continuous TP concentration observations in the tributaries, which were needed in the water quality simulation. According to Tang's [6] observations in 3 different intensities of rainfall, the precipitations were 66.7, 81 and 153 mm, with the corresponding TP mean values were 0.83, 0.48 and 0.40 mg/L, respectively. However, the precipitation was more than 153mm in Fitow period, the TP mean value was extended to 0.3 mg/L. Meanwhile, according to Yin's [7] TP load distribution curve from times of observation and runoff discharge processes of 4 tributaries, the TP concentration processes of 4 tributaries were calculated (Figure 3).

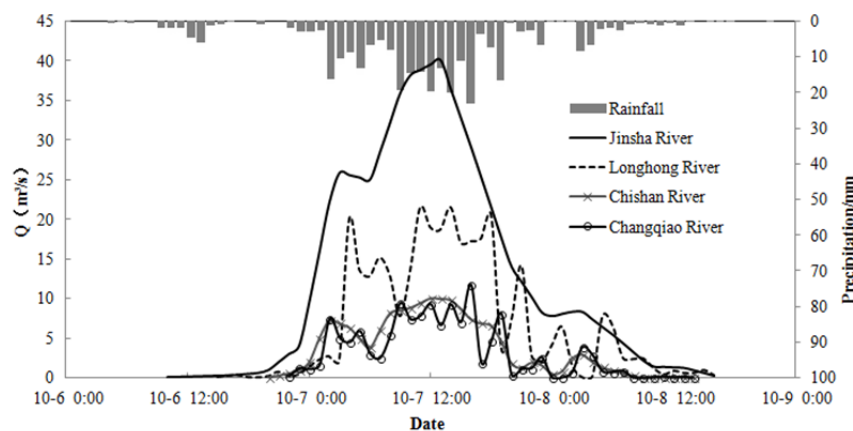


Figure 2. The precipitation and runoff discharge processes of 4 tributaries of West Lake.

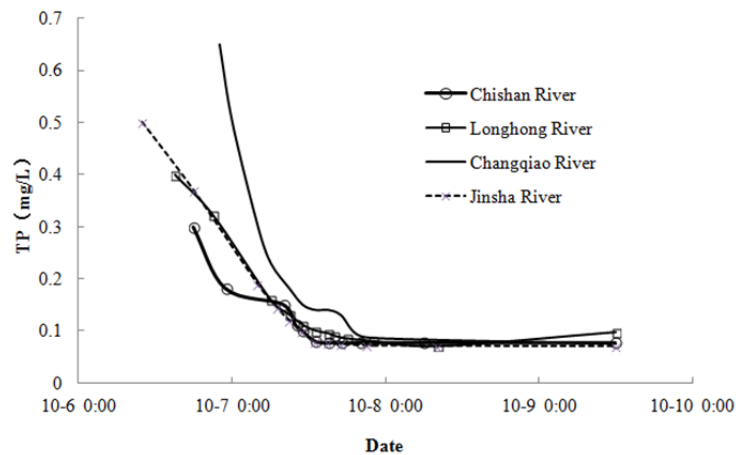


Figure 3. TP concentration processes of 4 tributaries in Fitow period.

4. Results

The West Lake hydrodynamic and water quality model was build using EFDC (Environmental Fluid Dynamic Code) [8]. The orthogonal curvilinear coordinates were used in the horizontal direction, allowing for a better representation of the complex shorelines and both considering model calculation time. There were 18578 computational cells in the horizontal plane of the model grid with cell lengths varying from 2 to 30 m. The model was verified in the regular atmosphere condition [9], water level and water quality results in Fitow period were verified in this paper.

4.1. Influence on water level

In Fitow period, the total water quantity was about $4.7 \times 10^6 \text{ m}^3$. Newspaper reported [10], up to 15:00 on October 7th, the cumulative precipitation was 201.9 mm in Hangzhou, and water level in West Lake raised up to 7.45 m, more than 0.27 m than normal water level. Meanwhile Shengtangzha Outlet reached the maximum discharge (about $17.8 \text{ m}^3/\text{s}$), flood was released about $1.5 \times 10^6 \text{ m}^3$ in 24 hours. The peak of water level was appeared at 0:11 on October 8th, which was 7.65 m, jumped 0.47 m, West Lake accumulated about $3 \times 10^6 \text{ m}^3$ of water, which was 1/5 of its capacity. At 8:00 on October 9th, water level was 7.52 m, it was down to 7.26 m at 12:00 on October 10th. Until to 15:00, the water level was down to 7.23 m, and then back to normal gradually. Compared to the description of water level in different time, the process of water level was show in Figure 4.

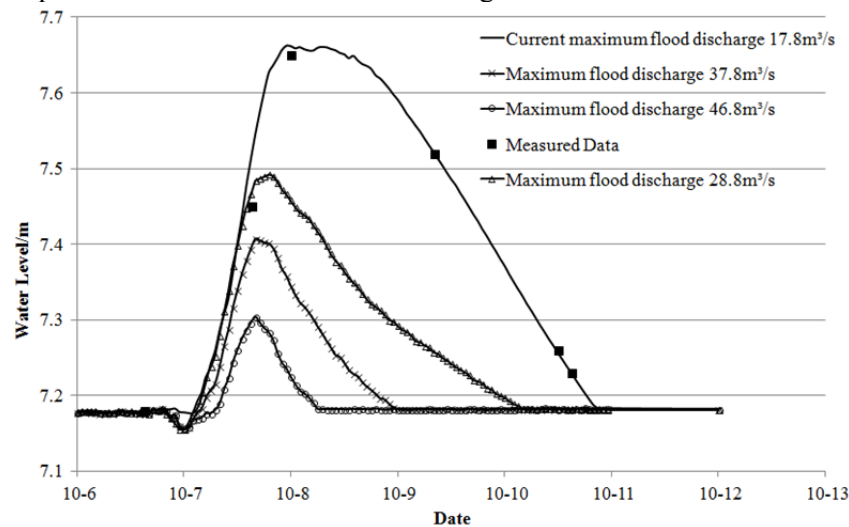


Figure 4. Water level of West Lake in Foitow period.

The validation results showed that the simulation values agreed well with the observations in Figure 4, suggesting that the model of West Lake could be used for simulating the water level process in the West Lake. The warning water level of West Lake is 7.3 m, some area of Sudi and Baidi Causeways is below 7.4 m. It's obviously that the water level of Outer West Lake was beyond the warning water level about 71 hours, and Sudi and Baidi Causeways were flooded about 57 hours.

4.2. Influence on water quality

According to the simulation, the TP concentration processes of different lakes were shown in Figure 5. It was obviously that the TP concentration of Yue Lake increased quickly, and the maximum concentration was above 0.24 mg/L , which was 2.6 times more than initial value. Oppositely, the TP concentration of Little South Lake increased slowly, and the maximum concentration was below 0.09 mg/L , which was 0.8 times more than initial value. The TP concentration at Outer West Lake and Shengtangzha Outlet measured points (location shown in Figure 1) changed a little, which decreased first and then increased, and the values were below 0.09 mg/L . According to the time of the maximum TP concentration appeared in each lake area, the fastest increase in TP concentration was Yue Lake, followed by Little South Lake, and the Outer West Lake was the slowest.

Due to the large catchment area of Jinsha River on the upstream of Yue Lake, and the area of Yue Lake is relatively small, the TP concentration of Yue Lake increased rapidly. Oppositely, due to the small catchment area of Chishan River on the upstream and Yuhu Bay as a buffer of Little South Lake, the TP concentration of Yue Lake increased gently. In summer, owing to the relatively large sediment release in Outer West Lake, TP distribution is higher in the west and lower in the east, and the maximum TP concentration is beyond 0.08 mg/L . In Fitow period, due to the large amount of water from west mountain, the water with low TP concentration from the west was pushed into Outer West Lake, which made the TP concentration of Outer West Lake decreased first and then increased.

Compared to the values measured on 9th Oct, the results showed that the simulation values agreed well with the measured values. Because of lack of measured values during the rainfall, the change process of TP was not verified.

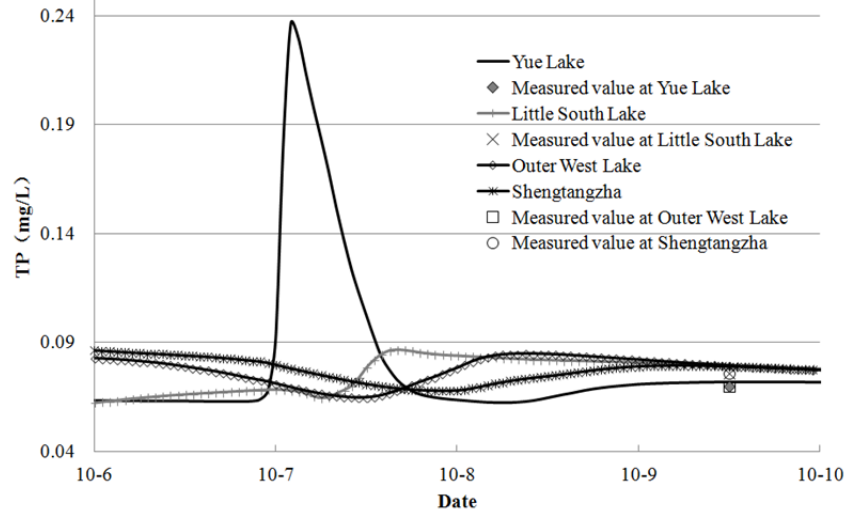


Figure 5. The processes of TP concentration in different lakes.

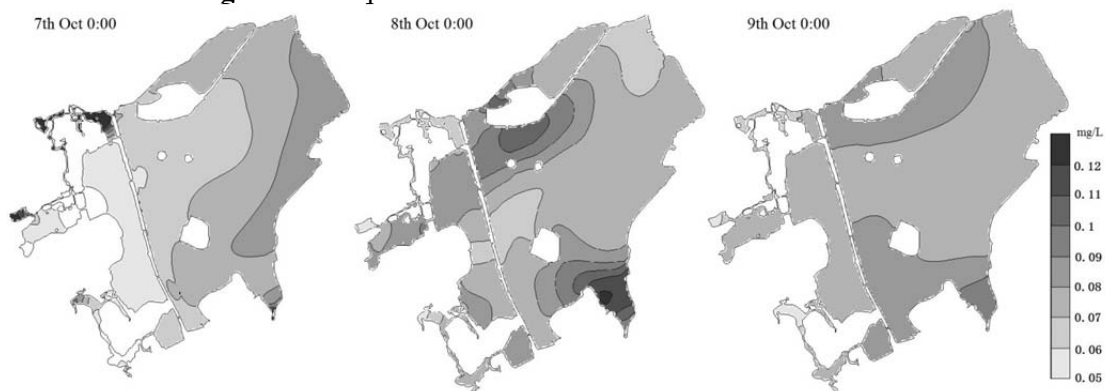


Figure 6. Distributions of TP concentration in West Lake at different times.

Different temporal and spatial distributions of TP concentration are listed in Figure 6. It can be seen that the spatial distributions of TP concentration changed a lot at different time. At the beginning of the rain on October 7th, the inlets of 4 tributaries increased obviously. The inflow of Jinsha River was already having effects on the whole of Yue Lake, TP concentration of Yue Lake was above 0.2mg/L essentially, and the high concentration area was transferred towards to Outer West Lake gradually. The runoff of other tributaries flowed into the corresponding lakes, and the TP concentration of these lakes began to rise up accordingly. Affected by rainfall runoff, TP distribution characteristics of higher in the west and lower in the east in the whole lake had changed, the low concentration area focused on Outer West Lake near Sudi Causeway and West Inner Lake, with the TP concentration was between 0.05 and 0.06 mg/L. At 0:00 on October 8th, water level reached the peak, and the TP concentration on runoff decreased gradually. West of Sudi Causeway, the TP concentration decreased below 0.1 mg/L. The high concentration area near Baidi Causeway was transferred towards to downstream gradually, and its area decreased. Affected by the north wind, the high concentration area near Changqiao River stayed in the bay, and the TP concentration was beyond 0.1 mg/L. At 0:00 on October 9th, water level of West Lake falled with rain stop, and the high concentration area near Baidi Causeway had been transferred to Shengtanzha Outlet, while the

concentration of Baidi Causeway was below 0.1 mg/L. The TP concentration near Little South Lake and Changqiao River was higher than that of other area, but the concentration was below 0.1 mg/L.

According to the temporal and spatial distributions of TP concentration in Fitow period, it's obviously that the early rainfall has a great influence on water quality in West Lake, and the water quality of mainstream area increases obviously. At the end of rainfall, the influence of heavy rainfall on water quality begins to decrease with the decreasing water quality of runoff. In addition, the integral diversion and drainage makes the water quality back normal quickly after the rainfall.

5. Discussion

In Fitow period, the total rainfall was 320 mm, and the total water amount was about $4.73 \times 10^6 \text{ m}^3$. The peak of water level was 7.65 m, Sudi and Baidi Causeways were flooded, which affected the pedestrians and traffic safety. However, only Shengtanzha Outlet has the potential to increase the flood discharge, and when Shengtanzha Outlet reached the maximum discharge, the water level of West Lake was still 2-3 m higher that of the downstream river. In order to meet the demand of flood control and drainage, Shengtanzha Outlet needs to increase the flood discharge. So the requirement of flood discharge was analyzed when the water level decreased to 7.5 m, 7.4 m and 7.3m when suffered the Typhoon Fitow again.

5.1. Influence of increasing discharge on water level

According to the simulation results, the water level processes of West Lake at different flood discharge was shown in Figure 4, and the time of water level beyond 7.4 m and 7.3 m at different flood discharge was counted in Table 1.

Table 1. Time of beyond different water level at different flood discharge.

Flood discharge (m^3/s)	Maximum water level (m)	Time of water level beyond 7.4m(hours)	Time of water level beyond 7.3m(hours)
17.8 (Current situation)	7.65	57	71
26.8	7.5	19	37
37.8	7.4	0	19
46.8	7.3	0	0

Results shown that the maximum of water level in West Lake was 7.65 m in current situation, which beyond the warning mark about 71 hours, and Sudi and Baidi Causeways (below 7.4 m) were flooded about 57 hours. With the increasing of flood discharge, the water level and time of water level beyond 7.4 m and 7.3 m decreased accordingly. If the maximum water level decreased to the warning mark, the flood discharge of Shengtanzha Outlet could be increased to $46.8 \text{ m}^3/\text{s}$, which was $29 \text{ m}^3/\text{s}$ more than current discharge. So, increasing flood discharge of Shengtanzha Outlet could reduce the influence of heavy rainfall on water level effectively in West Lake. 98 101

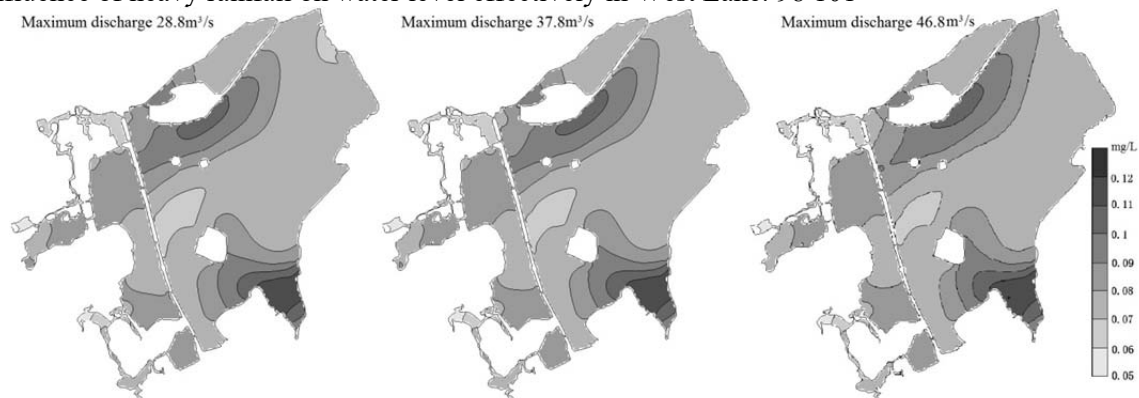


Figure 7. TP distributions of West Lake at increasing flood discharge cases.

5.2. Influence of increasing discharge on water quality

Compared the TP distributions at increasing flood discharge cases (Figure 7) with that of current discharge (Figure 6) at 0:00 on 8th Oct, the TP distributions at different cases were similar to each other, only the high concentration area near Baidi Causeway had slightly difference, which transferred towards to downstream with the increasing of flood discharge, but the migration distance was short. So the water from Jinsha River with large catchment was drained out more quickly than other tributaries. There was little influence of increasing discharge on TP distribution in West Lake.

6. Conclusions

In this paper, EFDC model was used to simulate the hydrodynamic water quality process of West Lake during the Fitow period. The validation results showed that the simulation values agreed well with the observations. According to the simulation, this paper studies the following conclusions.

(1) The heavy rainfall in Fitow period had a great influence on the water level of West Lake. Water level crossed warning mark about 71 hours, with Sudi and Baidi Causeways were flooded about 57 hours. The early rainfall has a great influence on water quality, the influence reduced with the decreasing of water quality in runoff.

(2) Increasing flood discharge could reduce the high water level and duration of high water level effectively. If the maximum water level decreased to the warning mark in Fitow period, the flood discharge of Shengtangzha Outlet could be increased to 46.8m³/s.

(3) There's little effect on the spatial distribution of TP with the increasing of flood discharge.

In conclusion, the main threat of short-term heavy rainfall to West Lake is flood control and drainage. The influence of short-term heavy rainfall on water quality is short in duration.

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References

- [1] Zhai Z N, Wang K Q, Su B, et al 2015 The change regulation of water quality in Jianshan River of Fuxian Lake watershed. *Ecological Science* **34**(2) 129–135
- [2] Zeng K, Huang T L, Ma W X, et al 2016 Impact of storm runoff on water quality of one stratified reservoir. *Chinese Journal of Environmental Engineering* **(9)** 4979-4986
- [3] Liu X D, Hu G Y, Zhou Y Y, et al 2015 Impact of rainstorm runoff on water quality of Wuli Lake. *Water Resources Protection* **(4)** 77-81
- [4] Zheng X Y, Zhang W S, Xu G H, et al 2016 Study on impact of storm on hydrodynamic and water quality of Liangzi Lake. *Yangtze River* **(9)** 17-21
- [5] Yuan Y, Han L X, Sun Y, et al 2014 Simulated research of reservoir water quality response under typical rainfall. *Journal of Safety and Environment* **(3)** 189-193
- [6] Tang M C, Yu Q H, Wang S X 2003 The effect of phosphorus of runoffs after heavy rains on the water quality in the West Lake and its countermeasures. *Environmental Pollution & Control* **25**(1) 12-15
- [7] Yin C Q 2009 Urban disuse pollution control principles & technologies. Beijing: China Architecture & Building Press
- [8] Hamrick J 1992 A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects. The College of William and Mary, Virginia Institute of Marine Science. *Special Report* **317**
- [9] Hua L, You A J, Han Z C, et al 2015 Total phosphorus model construction and analysis of internal circulation water transfer in West Lake. *Journal of China Hydrology* **35**(4) 27-32
- [10] Ban X D 2013 The water level of West Lake back to normal at yesterday afternoon [N]. *Hangzhou Daily*, 2013-10-11, B01