Water Science and Engineering, 2009, 2(3): 27-36
doi:10.3882/j.issn.1674-2370.2009.03.003

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Simulation of environmental change in response to operation of dams in Huaihe Basin

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Abstract: This paper describes the model simulation of a portion of the Huaihe Basin upstream of the river mouth at Hongze Lake, with an area of 130 520 km^2. The MIKE 11 modeling system was used to assess the flows and water quality in the Huaihe, Shayinghe, Honghe, Guohe, and Pihe rivers. The hydraulic part of the model was used to study the propagation of flows in the Huaihe River, which was calibrated with data from 2002-2003 and verified with data from 2004-2005. In general, there was agreement between measured and simulated discharges at all the hydrological stations. Except for some places close to large gates, there was reasonable agreement between measured and simulated water levels in the simulated rivers. The MIKE 11 WQ (water quality) model was used to study general sanitary parameters describing the river water quality in areas influenced by human activities. The water quality model simulated dissolved oxygen (DO), chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N). The difference between the simulated and observed concentrations was within the range that could be expected from water quality modeling, taking into account uncertainties such as pollution loads, and monitoring and sampling frequency. This model setup was also suitable for the subsequent scenario modeling of periods of water project operation. In the simulation of the Pihe River, increasing the discharge at Hengpaitou Dam was shown to cause a significant improvement in water quality downstream of Lu'an City. In the Shayinghe and Huaihe rivers, the effect was less visible. This suggests that the poor water quality in the Huaihe Basin is mainly caused by extensive discharge of domestic and industrial wastewater.

Key words: *Huaihe River; hydrodynamic model; water quality model; dam control*

1 Introduction

The Huaihe River is one of the seven largest rivers in China, which is located between the Yangtze River and the Yellow River. Its basin covers an area of 2.7×10^5 km^2. The river stretches across the four provinces of Henan, Anhui, Jiangsu and Shandong, originating in the Tongpo Mountains in Henan Province, in the western part of the basin, and then crossing

This work was supported by the National Natural Science Foundation of China (Grant No. 50709033), and the Key Project of the International Cooperation of the Natural Science Foundation of China (Grant No. 40721140020).
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Received Jun. 1, 2009; accepted Aug. 20, 2009

Anhui Province before flowing into Hongze Lake in Jiangsu Province and finally discharging into the Yangtze River. The main stream of the Huaihe River is about 1 000 km long, with 120 main tributaries. The average annual rainfall in the basin is about 900 mm, of which 70%-80% occurs during the summer. There is, therefore, considerable variability in the river flow. The Huaihe River has an average annual flow of 853 m^3/s, a discharge of over 1.1×10^4 m^3/s flood season, and a discharge that drops to nearly zero in the dry season. There are four main flood control gates on the Huaihe River, about 4 300 sluices, and over 5 000 reservoirs, of which 16 are major reservoirs. The estimated annual volume of water resources in the basin is about 8.54×10^{10} m^3, consisting of 6.21×10^{10} m^3 of surface water and 2.33×10^{10} m^3 of groundwater.

During the 1980s and the beginning of the 1990s, with rapid economic development in the basin, water pollution became more and more serious, causing many incidents of severe contamination of the river. According to the monitoring data, the total wastewater discharge in the basin reached 3.68×10^9 m^3 (including both industrial and domestic discharge from cities and towns) in 2000, with a total COD load of about 1.5×10^6 t. Organic matter causes most of the Huaihe Basin's water pollution. The Chinese Government presently pays great attention to pollution control in the basin.

Undoubtedly, the development of renewable hydropower resources is vital to social and economic development, in terms of water supply, flood control and power generation. It also helps maintain moderate local temperatures, humidity and the regional micro-climate. However, the construction and operation of large-scale reservoirs and sluices greatly changes the flow regime, water-sediment proportion and habitat, and the changes in the habitat of organisms living in or along the river affect the natural ecosystem and environment significantly (Liu and Xia 2004; Stone and Jia 2006; Wang et al. 2006; Xia and Chen 2001). The natural flow regime, sediment transport, estuary formation, and habitats of biological species also change to some extent due to dams' obstruction of flow and consequent hydraulic modifications (Scodanibbio and Mañez 2005; Le et al. 2007; Graf 2006).

In recent years, many researchers have considered flow regulation one of the important factors in the health of river ecosystems, since the flow always determines other key factors of aquatic habitats, such as velocity and depth (Jansson et al. 2000). Changes in natural runoff and water quality particularly affect the balance of the environmental ecosystem (Richter et al. 2003; Rosenberg et al. 2000; Kite 2001). Human activities have both direct and indirect effects on the global water system, including land-use change, river works, irrigation, water loss, and the disappearance and pollution of aquatic habitats (Vörösmarty et al. 2004). The impact of large water conservancy projects on the global water system and water security is very important (Alcamo et al. 2005). At present, the impact of human activities on natural ecosystems is one of the critical issues in hydrology and water resources research. The simulation of flow regime change and wastewater pollutant distribution, under the conditions of global climate change and continued operation of water conservancy projects, helps us to understand the

mechanisms of flood propagation and pollution accidents, as well as to establish the optimal operation mode of water conservancy projects for improving the regional environment.

2 Model simulation

The study area was the Huaihe Basin upstream of the river mouth at Hongze Lake. It has a surface area of 130 520 km^2, and includes Anhui Province, Henan Province, and small parts of Hubei and Jiangsu provinces, as shown in Fig. 1.

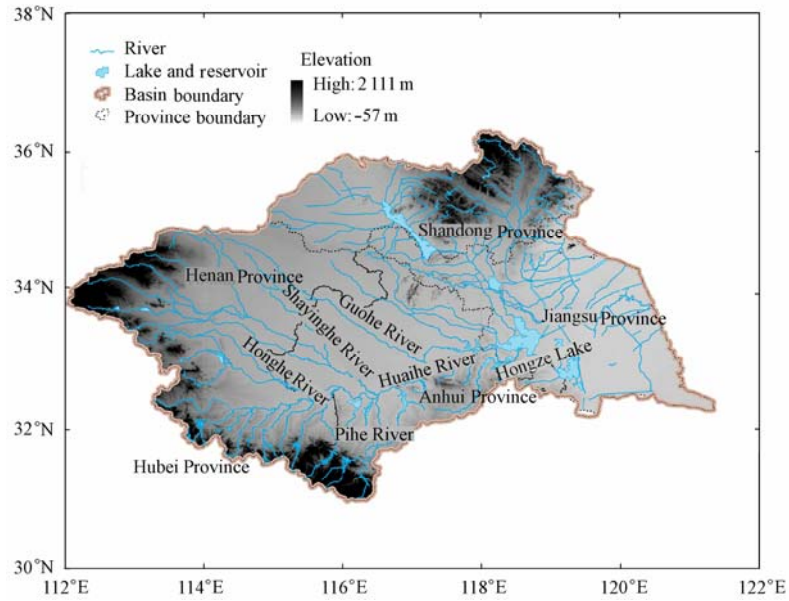

Fig. 1 Study area

The MIKE 11 modeling system was used to assess the flows and water quality of the Huaihe, Shayinghe, Honghe, Guohe, and Pihe rivers (DHI 2003a, 2003b). The hydraulic part of the model, however, is so general that it can be used to study the propagation of flows in the Huaihe River. The hydrodynamic model was calibrated with data from 2002-2003 and verified with data from 2004-2005. MIKE 11 WQ was used to examine general sanitary parameters describing the river water quality in areas influenced by human activities. The pollution of the Huaihe River is predominantly organic in nature. In this study, the water quality modeling focused on the simulation of DO, COD and NH_3-N.

The river model comprised the main stream of Huaihe River and the four major tributaries: the Shayinghe, Pihe, Guohe and Honghe rivers. Other major tributaries were only treated as lateral inflows. The model was split into a main stream model of only the Huaihe River (treating the other rivers as lateral inflows) and more detailed models of the four tributaries, all presently suffering from severe pollution (Fig. 2).

In the modeling system, a distance of approximately 1-2 km between grid points was selected for the main stream model, whereas distances depending on the data availability were

applied to the four major tributaries. The approach of splitting the model area into a number of sub-models was used to speed up the computations.

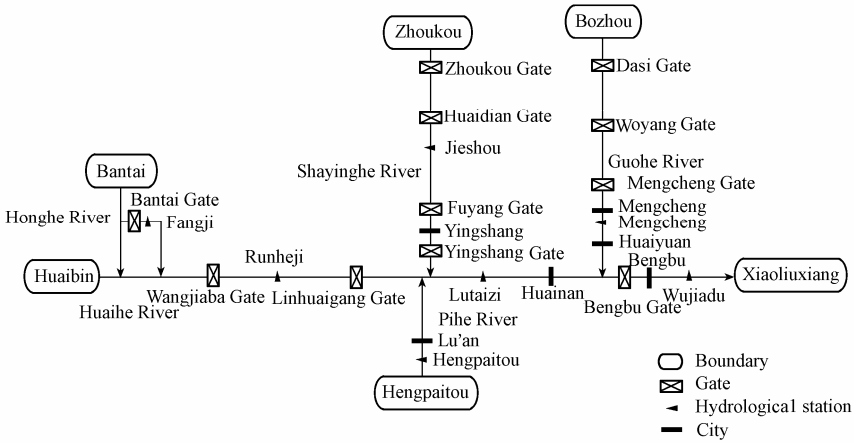

Fig. 2 Schematic diagram of model setup

The design of this model was as follows:

(1) The Huaihe River main stream model:

This model comprised the main Huaihe River from Huaibin County in Henan Province to the Xiaoliuxiang station in Anhui Province (Fig. 2). The model included the operation of Bengbu Dam control structure for combined hydropower, irrigation and flood control. It also included a description of the flood control compartments distributed along the river. The model was used to study the impact on water quality in the Huaihe River of changes in tributary loads and/or alternative modes of operation of Bengbu Dam.

(2) The Shayinghe River sub-model:

This model comprised the Shayinghe River from the upstream boundary near Zhoukou City to the confluence with the Huaihe River (Fig. 2). It included all major gates and a number of smaller irrigation diversion gates. It was used to investigate the effects of possible upstream flow regulation meant to increase the base flow in the river during the dry season.

(3) The Pihe River sub-model:

This model comprised the Pihe River from downstream of Hengpaitou Dam to the confluence with the Huaihe River (Fig. 2), and included the Hengpaitou diversion gate on the right bank of the Pihe River. Like that of the Shayinghe River, the Pihe River model was used to investigate the effects of different strategies with respect to possible flow regulation meant to increase the base flow in the river during the dry season.

(4) The Honghe River sub-model:

This model comprised the Honghe River from the upstream boundary near Bantai Dam to the confluence with the Huaihe River (Fig. 2). It included all major gates within the Honghe River and a number of smaller irrigation diversion gates.

(5) The Guohe River sub-model:

This model comprised the Guohe River from the upstream boundary near Bozhou City to the confluence with the Huaihe River (Fig. 2). It included all major gates within the Guohe River and a number of smaller irrigation diversion gates.

In addition, the four sub-models provided boundary conditions for the main stream model in terms of flows and pollutant concentrations.

3 Simulation results

The comparisons of calibrated and verified results with observed data (water level and discharge) at the main hydrological stations for the periods of 2002-2003 and 2004-2005, in general, show agreement (the maximum difference between measured and simulated cumulative discharges is less than 2% per year). Fig. 3 shows measured and simulated discharge at the Wujiadu station. However, the water level upstream of the gates could not be calibrated well, even though the discharge downstream of the gates had a very good fit with the observed value, since the small channel storage capacity, especially in the Shayinghe River, and large seasonal water level variation at the gate upstream were controlled by gate operation. Except for some places close to the large gates, there was reasonable agreement between measured and simulated levels in the rivers. As an example, the water level downstream of Bengbu Gate is shown in Fig. 4. The agreement in the main river is better than that in the Shayinghe River. It can be seen that the present hydrodynamic model setup provides a sound basis for water quality model setup and for simulation of water quality.

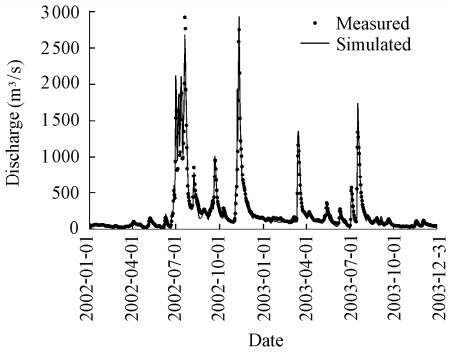

Fig. 3 Measured and simulated discharge at Wujiadu station

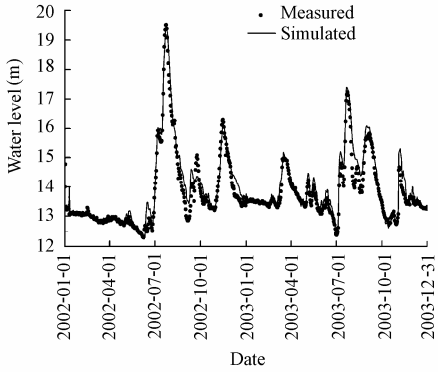

Fig. 4 Measured and simulated water level downstream of Bengbu Gate

During the calibration of the four sub-models, some general hurdles had to be overcome. From a water quality modeling point of view, this Huaihe River model setup is extremely difficult to implement and the calibration was a challenge. The Shayinghe River and the Guohe River systems in particular are so strictly controlled by gates that they are more a series of reservoirs than conventional rivers during the dry season. However, during the wet season, the

high discharge in the system generates a steady flow and a river-like situation. This transition between reservoirs and rivers complicates the calibration, as the two systems have different characteristics.

In a reservoir, the water is stagnant or very slow-flowing, creating favorable conditions for algae growth and internal production of organic matter. The internal production of organic matter generates a background level of organic matter. MIKE 11 WQ is in principle a river model and incorporates a very simple description of algae activity. This simple description does not account for organic matter produced within the system, and hence no background level of organic matter in reservoirs.

Compared to a river with constant flow, a reservoir is quite vulnerable to local discharge of wastewater. Even small discharges can have a significant negative local impact on the reservoir. In the present setup, point sources from cities are lumped into just one lateral input and total mixing in the river is assumed. A general distance between cross-sections of 1 000 m and a lack of detailed information on pollution loads does not allow a more detailed distribution of the point sources, and does not allow for the consideration of the discharge capacity of a large number of small plants during the pollution source survey. The location of industrial wastewater emission is difficult to determine, and the pollution load and monitoring of pollutant concentration have produced certain stochastic data or system errors. More non-point source pollution loads have been discharged, delivered into the rivers and simulated in the models than point source loads. However, the total annual pollution load has been estimated based on daily sampling data, which causes the deviation of simulation results of the water quality model. Nevertheless, the agreement between the simulated and observed concentrations was found to be within the range that can be expected from water quality modeling, taking all uncertainties into account. The present model setup was found to be suitable for the subsequent scenario modeling.

4 Scenario analysis

The present water quality of the rivers in the study area is much poorer than the target quality proposed in the Huaihe Basin Pollution Control Plan for 2010. In 2000, the northern tributaries were worse than Class V (according to the *GB3838-2002* standard of China), while the southern tributaries, except for the lower reaches of the Pihe River, were quite good. According to the Huaihe Basin Pollution Control Plan for 2010 (a baseline study), the target water qualities are Class III for the main Huaihe River and Class IV for the tributaries. However, the water quality of the Pihe River is affected by the following: (1) Most of the clean water from the upstream reservoirs is used for irrigation and transported to other areas. Therefore, there is little water going downstream through the Pihe River. (2) Wastewater from Lu'an City is directly discharged into the Pihe River.

The Huaihe River water is used for the municipal water supply of the cities of Bengbu and Huainan, and the upstream reaches of the Huaihe River and the southern tributaries are used for fishing, while few fishing activities occur in the northern tributaries. The river water from the northern tributaries is not used for municipal water supply because it is polluted; groundwater resources are used instead. For these water uses, the Huaihe River is critical. Considering the water quality status and the difficulty in water quality improvement, the most critical sections for water use are those around the cities of Bengbu and Huainan. The Pihe River water quality can be improved through wastewater treatment in Lu'an City.

The purpose of the scenario simulation was to analyze the present water quality situation and the effects of future water quality management in the study area. The target year of 2010 was set to define the socio-economic conditions related to the pollution control. It was therefore necessary to consider changes in pollution sources in the future due to some socio-economic changes in the basin, though this study did not prepare any regional development plan. The pollution control methods include industrial or municipal wastewater treatment; reduction of industrial wastewater through re-use; maintenance of river discharge in the dry season, either by saving irrigation water, storing floodwater (through gate operation), or transferring water from other rivers into the Huaihe River; and use of municipal and cattle breeding wastes for fertilizer.

The gate operation of the scenario analysis focused on the effect of increasing the discharge at Bengbu Gate, Zhoukou Gate and Hengpaitou Dam. The discharge levels were increased by 20% at Bengbu Gate and Hengpaitou Dam, respectively, and by 10% at Zhoukou Gate. The additional water in the dry season was assumed to be of water quality Class II, equivalent to the reservoir quality. The effect of reducing the load from agricultural and livestock activity by 30% was also considered in the scenario analysis.

The results of the scenario analysis can be found in Fig. 5. In the Pihe River, increasing the discharge at Hengpaitou Dam brought about a significant improvement in water quality downstream of Lu'an City. Only in two very short and wet periods in June and August could no improvement be identified. The concentration of COD was reduced to about half of the concentration in the dry season.

In the Shayinghe and Huaihe rivers (at Wujiadu station) the effect was less visible. The improvement could be seen in the second half-year of 2010. At Wujiadu station, the concentration of COD was reduced by 10%-25% from September to November. However, a high water discharge (73 m^3/s) was required to bring about this water quality improvement.

The sensitivity analysis of reduced livestock and agricultural loads shows a minimal improvement in water quality. This suggests that the poor water quality in the Huaihe Basin is mainly caused by extensive discharge of domestic and industrial wastewater.

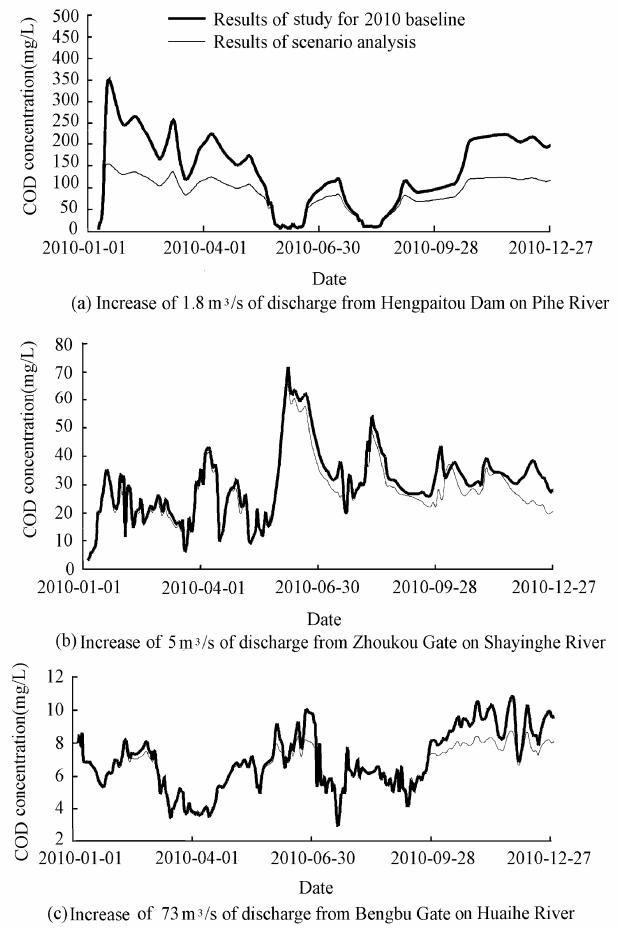

Fig. 5 Scenario analyses of increase of discharge downstream of gates

5 Conclusions

The Huaihe Basin is a complicated water system, with a large number of tributaries, many inter-provincial rivers, and highly artificial river water control. Human activities and excessive water and soil resources exploitation have significant effects on the ecological environment of the Huaihe Basin, of which the main problems are flood disasters, water resources shortages, and water pollution. The present study has put forward a water quality management model as a tool in the long-term water management process and pollution control plan for the Huaihe Basin.

The MIKE 11 WQ model was used to simulate flows and water concentration in the Huaihe Basin. The hydraulic part of the model has achieved good simulation accuracy at most hydraulic stations. However, the simulation accuracy of the MIKE 11 WQ model is not satisfying since it was used for studies of general sanitary parameters that describe the river water quality in areas influenced by uncertain factors. The subsequent modeling of

scenarios under water project operation shows that increasing the discharge at Hengpaitou Dam brings about significant improvement in the Pihe River water quality downstream of Lu'an City. The concentration of COD was reduced to about half of what it was in the dry season, whereas the water quality improvement effect has been less visible in the Shayinghe and Huaihe rivers.

At present, the impacts of human activities and climate change are critical issues for hydrologic and water resources research. In the future, studies will focus on the influences of climate change and human activities (such as construction and operation of water conservancy projects) on the ecological environment and the corresponding response, the status and changes of the ecological environment, the influence of climate change on the water circulation system, and the influence of construction of water conservancy projects on the local climate of the Huaihe Basin. Under the condition of global climate change and artificial control of water conservancy projects, the simulation of flow regime change and wastewater pollutant distribution should focus on the mechanisms of flood disasters and pollution accidents, as well as establishing the optimal operation mode for water conservancy projects, in order to improve the regional ecological environment.

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