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Hydrological simulation and prediction for environmental change

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Abstract A strong environmental change has been recognized in China with the impacts of climate change and intensive human activities on land use. In this paper, first environmental changes in China, such as those caused by human activities, land use, climate change, and social and economic development, are presented. Secondly, the hydrological prediction models and systems and their application in China are briefly introduced. Finally, it is pointed out that new hydrological prediction models, such as distributed hydrological models based on geographical information, should be developed because long-time data series will be invalid for traditional model calibration due to changing current and future environmental conditions.

Key words environmental change; hydrological prediction; PUB

INTRODUCTION

Due to its special geographical location and climate conditions, China has frequently been hit by floods and suffered from flood disasters. China has formed a flood control engineering system which has provided basic guarantee for economic and social development. Meanwhile, non-structural measures, such as hydrological monitoring and forecasting, have played a very important role for the mitigation of flood disasters, especially in the case of over-standard floods in China. However, with the impacts of climate change and intensive human land use activities, a remarkable environmental change has been recognized in China. This kind of change has made the long-term gauged data in many basins invalid for parameter calibration of models used for predicting current and future hydrological processes. On the other hand, the rapid social and economic development makes strong demands for the hydrological prediction of ungauged basins, especially in the western parts of China. Therefore, methods for hydrological prediction of basins with no or few data become very important, not only for scientific reasons, but also for practical applications. This article discusses the new challenges to hydrological prediction caused by environmental condition changes.

ENVIRONMENTAL CHANGES

The environmental changes can be classified into those caused by human activities, climate change processes, social and economic developments and mixed impact (Fig. 1).

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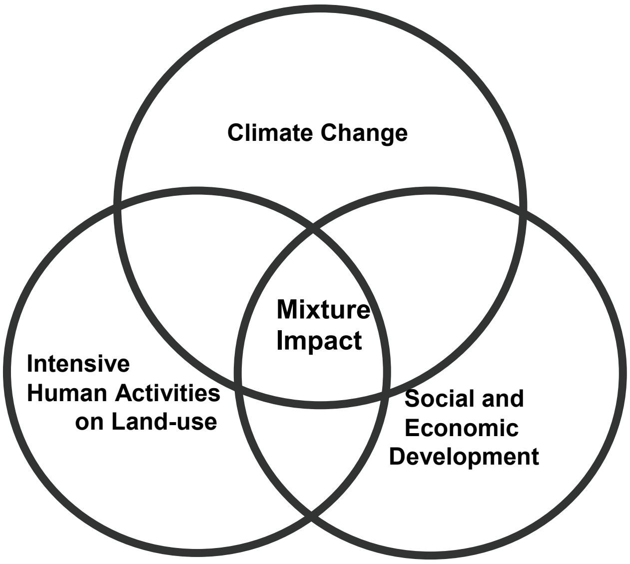

Fig. 1 Environmental change processes and their interactions.

Human activities

Since 1949, a total length of 277 000 km of river embankments has been built to protect 531 million people and 43.9 million ha of farmlands. Meanwhile, river dredging and training works have been carried out together with the opening of new flood diversion passages to the sea for the Huaihe, the Haihe and other rivers.

Reservoirs Over 85 000 large, medium and small reservoirs have been completed with a total storage capacity of 554 billion m^3 and a flood-control storage capacity of 100 billion m^3. The 460 large-sized reservoirs with a total storage capacity of 414.7 billion m^3 have played a significant role in flood control.

Flood detention and storage basin There are 97 flood detention and storage basins for the major rivers with a storage and retardation capacity of 103 billion m^3 to handle the floodwater exceeding the design standard capacity. These flood control systems are capable of controlling the ordinary flood (standard flood) for the major rivers in China. When big floods occur, the flood disasters in the plain areas are restricted within the planned flood detention and storage basins, which greatly mitigate the flood damage of the basin, particularly in middle and downstream areas.

Soil and water conservation By the end of 2004, the total area of comprehensive management activities employed for soil erosion control and water conservation had amounted to 920 000 km^2, of which small watersheds occupied 360 000 km^2. Real-time monitoring system were implemented in key areas such as the Jialing River basin, the source area and areas of rich sand or coarse sand of the Yellow River basin and the Haihe River basin.

Climate change

Climate change and its impacts on hydrology and water resources is becoming a more important research area (IPCC, 2001). Observations show that the temperature of the

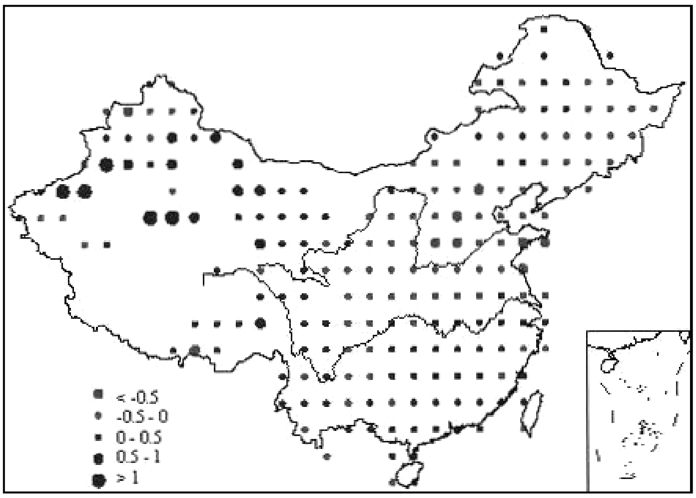

Fig. 2 Change of precipitation during 1951–2002 in China (% per year).

global land-surface increased 0.4–0.8°C over the last 100 years; precipitation over the Northern Hemisphere increased by about 5–10 %; and the frequencies and intensities of both flooding and drought events have increased. Figure 2 shows the annual change of precipitation (% per year) in China over last 50 years, 1951–2002 (Pan, 2002). Increasing trends in the northwest and southeast regions are clearly seen while decreasing trends can be observed in the Yellow River basin, the Huaihe River basin and the Haihe River basin.

HYDROLOGICAL PREDICTION IN CHINA

Chinese hydrologists have developed empirical forecasting schemes for more than 500 forecasting points on seven major rivers which function as the basis for hydrological forecasting. The modelling techniques have been under development since the early 1950s and are based on conventional methods for runoff yield analysis and flood routing. In particular, the Xinanjiang model developed by Chinese experts in the 1960s has been widely applied in large river basins, especially in the humid basins. Other models like API, SCLS, Sacramento, Tank, SMAR, and Muskingum routing models are also widely used in many river basins.

Empirical correlation methods developed before the 1970s

Empirical Forecasting Schemes (EFS) developed in the 1950s–1970s were based on empirical correlation curves (Fig. 3), P ~ R + UH, by which runoff (R) is given according of the depth of precipitation (P), and discharge at the outlet of the basin can be obtained by routing of runoff using the Unit-Hydrograph (UH). These were widely applied for operational flood forecasting in all of the main rivers with appropriate accuracy for operational application. The empirical correlation methods are effective for most studies related to peak streamflow forecasting.

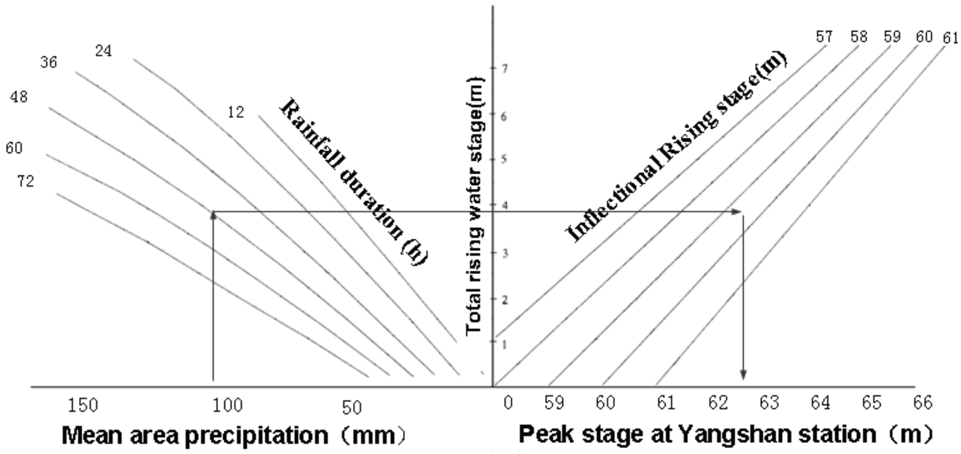

Fig. 3 Empirical correlation method based on multiple factors (precipitation, rainfall duration and water stage) for peak flow estimation

Watershed hydrological models developed in the 1970s and 1980s

The Xinanjiang (denoted as XAJ) model is widely used as a watershed hydrological model to generate the outflow hydrograph of all sub-basins. The generated runoff is routed into the discharge using the UH or Nash-IUH (Nash Instantaneous Unit-Hydrograph) at the outlet of each sub-basin, and then the discharge at the outlet of the whole basin can be obtained by routing the discharge of each sub-basin using the Muskingum method.

The simulation of outflow of each sub-basin consists of four parts: (1) the evapotranspiration (*E*) generates the deficit of the soil storage which is divided into three layers: upper, lower and deep layer; (2) the runoff (*R*) which produces the runoff according to the rainfall and soil storage deficit; (3) the runoff separation which divides the runoff into three components: surface runoff (*RS*), subsurface runoff, also denoted interflow (*RI*), and groundwater runoff, also denoted baseflow (*RG*); and (4) the flow routing which transfers the local runoff (*T*) to the outflow (*Q*) of each sub-basin to form the outflow of the whole basin (*TQ*).

Most of watershed hydrological models (WHM) can get good simulation results in humid areas. The soil moisture accounting models, such as the traditional API model, XAJ, SMAR and Sacramento models, are suitable for most areas in China. In arid and semi-arid areas, there are some difficulties in hydrological simulation and forecasting, the reasons for this being related to shortage of flood-event data for model calibration and inadequate model structure to represent the practical conditions.

Hydrological forecasting systems developed since the 1990s

In the early 1980s, the first generation of the real time Flood Forecasting System (FFS) was developed on a VAX machine and for single PCs. During the 1990s, the second generation of the FFS was developed in cooperation with American and European countries. Since the end of the 1990s, a National Flood Forecasting System (NFFS) has been developed in China based on the new achievements in computing and network technology, GIS, and databases (DB).

In 1998, the Bureau of Hydrology (BOH, Water Resources Information Centre) of the Ministry of Water Resources (MWR) began a project to design and develop the NFFS. The NFFS is going to be applicable to the hydrological forecasting sectors of BOH in 31 provinces and seven large river authorities as well as 244 local hydrological information centres in China.

The system is built in a Client/Server(C/S) structure, relying on a real-time flood information database (see Fig. 4). It has developed based on the standard and advanced software and hardware environment with a modularized and open structure. Therefore, it has a databank of common forecasting models and methods. The model calibrating sub-system can perform manual trial-and-error and/or automatic mathematical optimization. The forecasting process system can be interfered through a man–machine interface in the form of graphs and tables. To obtain a more accurate forecast, model inputs (such as precipitation and evaporation, rainfall forecast, etc.), model parameters (including UH, rating curve parameters, etc.) and states (such as the soil moisture) can be adjusted according to the operational experience using the user-interface of the system. The system provides automatic real-time forecasting and warning of floods, and data pre-processing and management.

NFFS adopts a completely modular structure so that modules can be independent of the system, i.e. any new suitable model can be easily nested and applied by the system. Many forecasting models and methods (Liu & Zhang, 2005) have been employed in the system (see Table 1). Normally, the empirical rainfall–runoff method is used for runoff estimation; the API, XAJ (Zhao *et al.*, 1980; Zhao, 1992; Zhao & Liu, 1995),

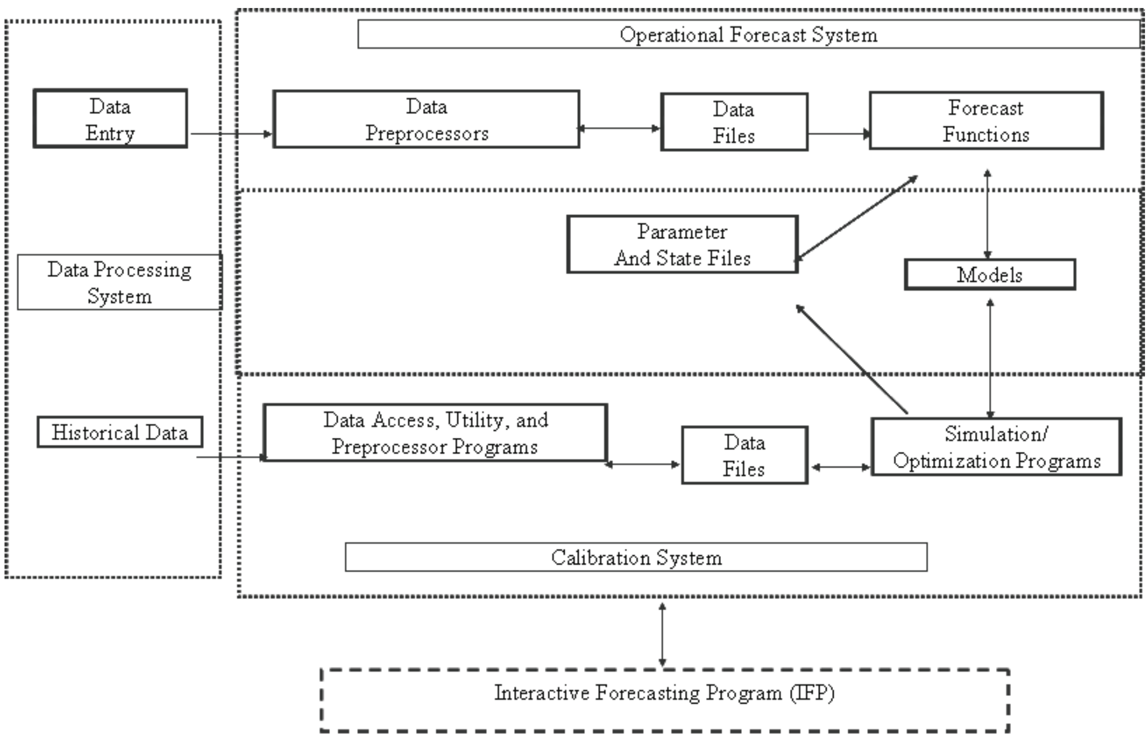

Fig. 4 The basic components of the National Flood Forecasting System.

Table 1 The hydrological forecasting models used in China.

1	Xin'anjiang Model	10	SMAR Model
2	API Model	11	NAM Model
3	Jiangwan Runoff Model	12	Tank Model
4	Hebei Storm Flow Model	13	Sacramento model
5	Shanbei Model	14	SCLS Model
6	Xin'anjiang Model for semi-arid areas	15	Index Recession Model
7	Liaoning Model	16	Recession Curve Method
8	Double Attenuation Curve Model	17	Unit Hydrograph
9	Double Excess Runoff Yield Model		

SMAR (Zhang, 1994; Tan, 1996), and SCLS (Wang, 2005) models can be used for rainstorm flood forecasting; the Muskingum successive routing method and empirical storage curve method can be used for flood routing in the river reach; and the corresponding water level method can be used for downstream flood peak forecasting.

NEW CHALLENGES TO HYDROLOGICAL PREDICTION

As the data pattern changes in response to intensive human activities and land-use change, many basins must be considered as ungauged basins or as basins with insufficient available data. For these basins, new models or/and new techniques are required to set up and calibrate the model parameters. PUB (Predictions for Ungauged Basins) becomes an important scientific initiative to improve hydrological predictions in ungauged or poorly gauged basins (Fig. 5). The most interesting PUB scientific challenges include: (1) hydrological prediction approaches for the large poorly-gauged basins; (2) prediction of hydrological responses to human activity and climate change in ungauged basins; and (3) prediction of eco-environmental responses to human activities, such as soil erosion and non-point source water pollution in ungauged basins.

To address these scientific issues, seven PUB working groups have been formed and many Chinese hydrologists and researchers are engaged in the PUB research activities. The seven PUB working groups involving Chinese researchers are:

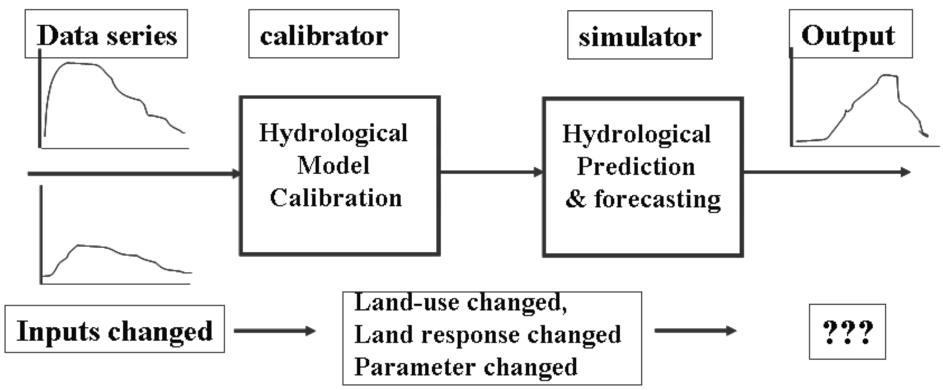

Fig. 5 PUB: a challenge for hydrological prediction.

(1) Hydrological modelling and water resources assessment in Northern China under high water-stress; (2) Evaluation and prediction of groundwater development in northern China; (3) Flood forecast and damage estimation in southern China; (4) Prediction of water resources and its consumption in the arid region of northwest China; (5) Study on the ecologically vulnerable basins in China; (6) Development of the coupled model of the hydrological cycle and water quality in urbanized river basins; and (7) Application of new technologies, theories and methods to hydrological prediction in ungauged basins in China (Yang *et al*., 2005).

CONCLUSIONS

The intensification of human activities on land use destroy the representativity of long-time series of hydrological data. As a consequence, many gauged basins must now be regarded as ungauged basins because the existing data are not useful for model parameter calibration. However, given fast social and economic development, more accurate hydrological predictions are required, particularly in remote ungauged basins. New models, such as the distributed hydrological model, and new methodologies, such as the DEM (Digital Elevation Model) and methods for model parameter calibration with which model parameters can be estimated based on geographical information, such as soil type, stream length, basin shape and channel slope, instead of on long-term monitoring data, are all urgently required. These models, methods, and geographical data can be efficiently managed by Geographical Information Systems.

REFERENCES

IPCC (2001) *Climate Change 2001: Impacts, Adaptation,and Vulnerability*. Cambridge University Press, Cambridge, UK.

Liu, J. & Zhang, J. (2005) Development and prospects of hydrological forecasting technique in China. *J. Hydrol. (Chinese)* **25**(6), 1–5.

Pan, X. H. (2002) Changes in temperature and precipitation in China during the last 50 years. Master Thesis, The Chinese Academy of Meteorological Sciences, Beijing, China.

Tan, B. Q., O'Connor, K. M. & Liu, Z. C. (1996) Application of a distributed form of the SMAR model. In: Proceedings of the International Conference on Water Resources & Environment Research: Towards the 21st Century (October, Kyoto, Japan (at Heian Kaikan)), vol. 1, 46–52.

Wang, J. M. (2000) *The Flood Forecasting Model of SCLS*. Yellow River Conservancy Press, Zhengzhou, China.

Yang, D., Li, C., Ye, B., Hu, H., Zhang, H., Liu, Z. & Xia, J. (2005) Chinese perspectives on PUB and the working group initiative. In: *Predictions in Ungauged Basins: International Perspectives on the State of the Art and Pathways Forward* (ed. by S. Franks, M. Sivapalan, K. Takeuchi & Y. Tachikawa), 26–29. IAHS Publ. 301. IAHS press, Wallingford, UK.

Zhang, S. L. (2002) Design and development of China National Flood Forecasting System. *J. Hydrol. (Chinese)* **22**(1), 28–32.

Zhang, J. Y., O'Connor, K. M. & Liang, G.C. (1994) A software package for river flow forecasting based on the SMAR model. In: *Hydraulic Engineering Software V*, vol. I, *Water Resources and Distribution* (ed. by W. R. Blain & Katsifarakis), 163–170. Computational Mechanics Publications, Southampton, UK.

Zhang, J. Y., *et al.* (1998) Hydrological prediction model based on Geographical Information System. *Adv. Water Sci.* **9**(4).

Zhang, J. Y., Wang, G. S., Zhang, J. X. & Sun, C. P. (2005) Flood forecasting and regulating system based on Web: development and application. *Water Resour. Hydropower Engng* **36**(2), 67–70.

Zhao, R. J. (1992) Xinanjiang model applied in China. *J. Hydrol.* **135**, 371–381.

Zhao, R. J. & Liu, X. R. (1995) The Xinanjiang Model. In: *Computer Models of Watershed Hydrology* (ed. by V. P. Singh), 215–232. Water Resources Publication, Littleton, Colorado, USA.

Zhao, R. J., Zhuang, Y. L., Fang, L. R., Liu, X. R. & Zhang, Q. S. (1980) The Xinanjiang Model. In: *Hydrological Forecasting* (Proceedings Oxford Symposium), 351–356. IAHS Publ. 129. IAHS Press, Wallingford, UK.