Preliminary Research and Application of MIKE SHE Model in Jialingjiang River Basin

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Abstract. Introduce the model structure, principle and characteristic of MIKE SHE hydrological model. Advances in research and application of MIKE SHE model are summarized in 3 aspects: applicability study of the model, basic process research of the model and further application research of the model. Probes into the modelling and application process of MIKE SHE model in Jialingjiang river basin. The development direction of MIKE SHE model in the future is analysed and forecasted, according to the research progress of MIKE SHE model in China.

1. Introduction
Hydrological model, as a tool and method for hydrologists to study complex hydrological phenomena, has always been the focus of research in hydrology. With the development of hydrology, Hydrologists have understood the mechanism and process of hydrological in depth, and accelerated the development of hydrological models. Hydrological models can be broadly divided into two categories: Lumped hydrological models and distributed hydrological models [1]. Lumped hydrological model simulates the runoff formation process as a whole. The model structure of lumped hydrological model is relatively simple and the data requirements are low, but the physical mechanism of hydrological process is not studied in depth, so it can not simulate the hydrological process close to “real”. Therefore, the distributed hydrological model that can fully consider various physical mechanisms has become the focus of modern hydrological model research [2].

As a typical distributed hydrological model, MIKE SHE describes hydrological and physical processes based on partial differential equations of mass and momentum conservation [3]. It has high calculation accuracy and strict requirements on data accuracy. With the development of information technology such as GIS and RS, the acquisition of high-precision data is less difficult, and the application and research of MIKE SHE model become extensive in China. The research on MIKE SHE model in China has the following aspects: First, the applicability of MIKE SHE model in different research areas; second, the basic process research of MIKE SHE model, including the uncertainty analysis and parameter sensitivity analysis of the model, model scale effect, etc. [4]; Third, further application of MIKE SHE model: including hydrological response research under land use and climate change, research of the application of MIKE SHE model coupled with other models.

According to the topography, climate, topography, vegetation, ecological hydrological system characteristics and human economic activities in China, the whole country can be divided into 36 eco-hydro regions [5]. The flow generation process and distribution of the watershed in different hydro regions will be greatly different due to the different conditions of underlying surface and climate. The integrity, continuity, accuracy and collection difficulty of hydrometeorological data of different eco-
hydro regions are also very different. Tian, K.D., Shen, B. et al. [6] studied the applicability of MIKE SHE model in the runoff simulation of Bahe River Basin. The results shown that MIKE SHE model has good applicability to the annual runoff simulation of the Bahe River Basin. The simulation effect of daily runoff remains to be further studied. Liu, J., Liu, T. et al. [7] used remote sensing data of precipitation, temperature and potential evapotranspiration as the model input, established the MIKE SHE model of Yarkant River Basin, and simulated the basin daily runoff, the result shown good, Nash efficiency coefficient reached 0.7, and the correlation coefficient reached 0.8. Lu, D.B., Shi, Z.T. et al. [8] simulated the hydrological process in Bajiang River Basin by MIKE SHE. The results shown that the model is able to simulate temporal evolution of water flow.

MIKE SHE model has powerful hydrological simulation functions and a good physical foundation. It can simulate and output every step of the hydrological cycle in the basin and even simulate water quality changes, but the model still has limitations in some functions. By coupling with other more professional models, we can further explore the application potential of MIKE SHE. Wang, S.P., Zhang, Z.Q. et al. [9] used MIKE SHE model coupled with the modified soil erosion model MUSLE to simulated and evaluated the spatial distribution of erosion and sediment yield in the typical small watershed of the Loess Plateau. The results shown that the coupling of MIKE SHE with MUSLE can effectively simulated the spatial distribution of soil erosion in the basin. However, based on this method, it is necessary to further considered the coupling mechanism of channel gravity erosion, and the simulation precision of MIKE SHE model needs to be further improved. This paper summarizes the research and application of MIKE SHE model in China, and analyses the case of application in Jialingjiang River Basin, and the future development of MIKE SHE model in China.

2. Study area and data
Jialingjiang River is one of the important tributaries of the upper reaches of Yangtze River. It is the largest river in the Yangtze River tributary. Its origin located in the northern foot of the Qinling Mountains in Shanxi. The river passes through the three provinces of Shanxi, Gansu and Sichuan. It merges with Beijiang River and Qujiang River, eventually flowed into Yangtze River in Chongqing. The total length of the river is 1120 km and the drainage area is about 160000 km$^2$. The Jialing River Basin is shown in Figure 1.

![Figure1. Jialingjiang River Basin](image)

Before modelling MIKE SHE model, it is necessary to pre-process the required terrain data, meteorological data, land use and soil type data.
Terrain data is downloaded from the Geospatial Data Cloud Platform of the Chinese Academy of Sciences Computer Network Information Center (http://www.gscloud.cn/).

The meteorological data is derived from China Surface Climate Data Day Value Dataset (V3.0) downloaded from the China Meteorological Data Network (http://data.cma.cn), using Thiessen polygon method divides the watershed into 13 parts through 13 meteorological stations in the basin.

The soil data is China Soil Dataset (v1.1) based on the World Soil Database (HWSD) [10], derived from the Heihe Plan Data Management Center (http://westdc.westgis.ac.cn); land use data Downloaded for the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). According to the research needs, the soil types were reclassified into 10 categories, and the land use types were reclassified into 6 categories. The soil type and land use distribution are shown in Figure 2.

![Figure 2. Soil type data and land use data in Jialingjiang River Basin](image)

3. Methodology

3.1. Structure and principle of model

MIKE SHE model divides the watershed into a unit grid horizontally for discrete calculation of complex terrain. Relationship of grid codes is established by solving the continuity equation and the motion equation. In the vertical direction, a soil column is formed on each cell, and the difference in soil properties is indicated by different horizontal layers on the soil column. MIKE SHE model is calculated by three modules: water body motion module (WM), water quality module (WQ) and water balance tool, in which the water body motion module simulates the water body migration process through different calculation sub-modules, including snow melting module (SM), Overland Flow Module (OL), Rivers and Lakes Module (OC), Evapotranspiration Module (ET), Unsaturated Flow Module (UZ), and Saturated Flow Module (SZ). The relationship between each sub-module and the calculation method involved in each sub-module are shown in Figure 3. When applying the MIKE SHE model to different watersheds, corresponding modules can be selected according to the range size, underlying surface conditions and model research purposes of different watersheds to further obtain more accurate results. The data required for MIKE SHE model is shown in Table 1.
3.2. Characteristic of model

MIKE SHE model is an integrated hydrological simulation system based on actual physical mechanism with powerful analog computing functions. There are many applications in the model, including: water resources planning and management, flood risk map, interaction calculation between surface water and groundwater, ecological evaluations, environmental impact assessment, groundwater hydrological assessment, etc. MIKE SHE model has the following characteristic compared to other models:

- MIKE SHE model software has a simple and clear user interface and is easy to operate.
- The model is simulated by six sub-modules, and the calculation methods of different sub-modules can also be selected. Different module combinations and algorithms can be selected according to the actual research conditions, so that the MIKE SHE model has higher flexibility.
- Each sub-module of the model can be calculated by independent step size. For the response rate of the hydrological process corresponding to different sub-modules, a limited computing resource can be allocated more reasonably.

Table 1. Data required for MIKE SHE model

| Data Type         | Contains                                                                 |
|-------------------|--------------------------------------------------------------------------|
| Basic data        | Simulation area                                                          |
|                   | Terrain data                                                             |
|                   | Spatial distribution and time series of precipitation                   |
| Meteorological    | Spatial distribution and time series of Reference Evapotranspiration     |
| data              | Spatial distribution and time series of temperature                     |
|                   | Spatial distribution and time series of shortwave radiation (for SM)     |
| Land use data     | Spatial distribution and characteristics of vegetation                   |
|                   | Spatial distribution and irrigation water demand                         |
| Soil data         | Spatial distribution of soil                                             |
|                   | Soil hydraulic characteristic curve                                      |
| Groundwater data  | Spatial distribution of geological lens                                  |
|                   | Recharge of groundwater                                                  |
|                   | Discharge of groundwater                                                 |
The model has a good physical basis. In theory, the simulation accuracy of the model is improved with the accuracy of provided basic data and parameters. However, after the simulation accuracy reaches a certain level, the model construction and calibration process will become very lengthy.

4. Application in Jialingjiang River Basin

The terrain data is converted to ASCII format by Arcgis 10.2, and then the ASCII code is converted to DFS2 format by the MKIE Zero tool. The conversion result is shown in Figure 4. A comparison chart of monthly runoff and Precipitation observations in the basin is shown in Figure 5. The summary of annual runoff is shown in Table 2.

![Figure 4. Terrain data applied in MIKE SHE model](image)

![Figure 5. Comparison chart of monthly runoff and rainfall observations](image)

| Year | Annual runoff (million m³) |
|------|---------------------------|
| 2009 | 67191.03                  |
| 2010 | 76239.01                  |
| 2011 | 76720.69                  |
| 2012 | 76031.48                  |
| 2013 | 70502.65                  |
| 2014 | 63513.07                  |
| 2015 | 50339.58                  |
After loading the pre-processed data into the MIKE SHE model. The output can be selected in the Detailed timeseries output and Grid series output, as shown in Figure 6. The output can be viewed in MIKE SHE Detailed Time Series and Gridded Data Results, as shown in Figure 7.

5. Results and discussion

5.1. Research of basic process in model
The basic process of MIKE SHE model includes: model scale selection, construction model, parameter calibration, model verification, result analysis, and model uncertainty analysis. Studying the impact of these basic processes can further deepen the understanding of MIKE SHE model and help to improve the research and application of MIKE SHE model in China. Wang, S.P., Zhang, Z.Q. et al. [12] used MIKE SHE model as a tool to analyze the influence of grid size and time step changes on the model simulation results by using the measured sub-rainfall-runoff in the Lv’ergou watershed as the input data. The results shown that the grid size change had an effect on the peak value and the total amount of simulated runoff; the time step change only affected the peak simulation and had no effect on the total runoff. Zheng, Z., Zhang, J. et al. [13] used the runoff data of the hydrological station of East Bridge of Guishui River Basin to analyze the uncertainty of MIKE SHE model parameters based on the GLUE method. The results shown that the parameters of larger uncertainty include PER, SP, C1, C2, C3 and the smaller parameters include KsF, KsI, IT and TD.

5.2. Research of further application of MIKE SHE
After the simulation accuracy of MIKE SHE model reaches a certain level, the further application of MIKE SHE model can be developed. For example, changing some conditions in the basin to study the hydrological response in the basin under these conditions. Under the background that global warming has become the focus of the world, the hydrological response of climate change has become the frontier and hotspot of distributed hydrological model research [14]. Luo, M., Liu, T. et al. [15] used the MIKE SHE model to simulate the hydrological process in the Hetian River Basin, and studied the Hydrological response of Hetian River Basin under four emission scenarios of RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in CMIP5. The results shown that the surface runoff in Hetian River Basin increased under different emission scenarios in the future, while the runoff from July to August decreased, the snowmelt period is further advanced, and the snowmelt in spring increased significantly.
6. Conclusion
The research of MIKE SHE model in China has gradually deepened compared with the earlier years. MIKE SHE, as a distributed hydrological model with a strong physical foundation, has far more research and application potential. MIKE SHE model can be further strengthened from the following aspects:

- Research on uncertainty of model: Uncertainty is inevitable during hydrological modelling due to the complexity of the hydrological process. Although there is uncertainty research on the MIKE SHE model in China, it is still limited. Using more uncertainty analysis methods to study in more watersheds is also a direction for further research on the MIKE SHE model in the future.

- Application research of MIKE SHE model in scarce data areas: The nature of the MIKE SHE model determines that the simulation accuracy of the model depends on the accuracy of the input data. How to improve the simulation accuracy of the model as much as possible in the research area with high data acquisition difficulty and insufficient data accuracy will be a major challenge in the MIKE SHE model research. Seeking more data sources, such as combining the latest remote sensing data and remote sensing interpretation methods to fill the gaps in the data required for the MIKE SHE model [16].

- Extend the Application of MIKE SHE: MIKE SHE hydrological model has a number of sub-modules, each of which represents a different stage in the hydrological process. Therefore, MIKE SHE can output data at different stages of the hydrological process. Making full use of these data and applying it to different fields of hydrology and water resources research can develop a wider range of functions of MIKE SHE model.

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