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Runoff Simulation in Semi-humid Region by Coupling MIKE SHE with MIKE 11

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Abstract: The paper used the coupling of distributed hydrological model MIKE SHE and the hydrodynamic model of MIKE 11, to establish watershed-based rainfall-runoff mode in the sub-humid area of the north China. The hydrologic process of Xiaoling river basin was simulated with the input data, including DEM altitude, weather, vegetation, soil, land uses, etc. Through the sensitivity analysis, the soil roughness factor of overland flow, roughness of runoff, saturated hydraulic conductivity were chosen for main calibration parameters. The simulation consequences showed that the daily runoff simulation, Nash-Suttclife coefficient in the rate of regular (1990-1994/Jinzhou station) and the validation period (1995-1999/Jinzhou station) were 0.636 and 0.582, the correlation coefficient reached 0.839 and 0.788,the rate of regular Ens and R was 0.794,0.863;0.961,0.960 of month scale simulation; verification period of two stations Ens and R for 0.740,0.820;0.911,0.917. The model was practical and reliable in the basin. The simulations showed that correlation coefficients and Nash coefficient (Ens) of long series of the simulation had good accuracy in the model. In median water year, the simulation results would be better.

Keywords: Hydrology models, MIKE SHE, MIKE 11, Correlation coefficient, Nash-Sutcliffe coefficient.

1. INTRODUCTION

SHE model is a typical distributed hydrological model, which was jointly developed by DHI (Danish Hydraulic institute), the British hydrology institute and SOGREAH consulting companies in France during 1986-1995. Abbrot [1-2], Bathurst [3] developed and improved the model, so it has become one of the most widely used and knew distributed hydrological model. SHE model is a tight coupling of the hydrological model with physical basis.

In the early 1990's, MIKE SHE was further developed from the SHE model by the Danish Institute of hydraulics (Danish Hydraulic Institute, DHI). MIKE SHE can solve the problem of all hydrological on river basin in principle, including watershed management and planning, soil and water management, land use and impacts of climate change [4-5], groundwater management, ecological impact assessment [6], the combined apply of groundwater and surface water [7], map of groundwater aquifer vulnerability, agricultural activity research, etc. Although the structure of the model itself and the input data is relatively complex, but MIKE SHE can simulate the whole basin's hydrologic cycle, vegetation, soil, etc. So in recent years, the application study of MKESHE also gradually increases at home and abroad [8-12].

Obvious deficiency existed in MKE SHE river hydrodynamic simulation. Because its water level and flow of runoff is to calculate by relatively simple diffusion wave of Saint Venant equation approximately. The paper calculated based on the complex river network and the runoff process, using a complete Saint-Venant equation -MIKE 11. That was more appropriate. Furthermore, runoff part of MIKE SHE does not support the simulations of hydraulic structures such as weir, culvert and sluice. For the usually rivers which contains the hydraulic structure, using MIKE SHE only may influence the simulation effect. Thompson J R [13] combined MIKE 11/MIKE SHE to recreate the seasonal variation of groundwater and the water from ditch, proved that the close connection existed between the floods, groundwater and water level of the channel; Singh [14] analysis the agricultural irrigation management system of Indian Mahanadi by using coupling model simulation; Thompson [15] established the coupling model based on MIKE SHE and MIKE 11, simulated the impacts of climate change on wetlands; Liu H L [16] used coupling model to simulate the flood season of 112 - day average water balance calculation, and provided a method which was suitable for the dry areas of water management.

In domestic, usage of watershed hydrological lumped model -XAJ model, half-distributed model –TOPMODEL, and loosely coupled distributed model-SWAT are the most research fields [17-22]. The distributed model could be divided into two structural styles, including tight coupling and loosely coupling. MIKE SHE is a tight coupling hydrologic model. In the model, the hydrological processes could be described by the differential forms of partial differential equations of quality, energy, or conservation of momentum, which is the main characteristic. The model uses continuous equation and motion equation to establish the relationship of time and space where adjacent grid cells or the elements be-

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tween sub-catchments, to solve the questions by numerical method. This paper established the model for Xiaoling river basin where locals in the semi-humid region in western Liaoning Province, China. The main research is to analysis the hydrology and runoff of middle-size basin based on distributed hydrological model-MIKE SHE and one dimensional hydrodynamic model- MIKE 11, and establish the watershed runoff model of coupling MIKE SHE and MIKE 11. It also discussed the applicability of MIKE SHE in Xiaoling river basin.

2. THE STUDY AREA AND DATA SOURCES

2.1. The Study Area Profile

Xiaoling river is one of the major rivers in western Liaoning Province. The river basin is located in the semi-humid region in western Liaoning, belongs to the Liao river, east longitude 120 ° 06 '~ 121 ° 21', north latitude 40 ° 55 '~ 41 ° 21'. Xiaolingriver is in the west of Liugu river, in the south of Xingcheng and Lianshan rivers. Its north and east parts abuts Daling river. The river originates from Bo Mountain, where locates in the border region of Jianchang County and Chaoyang County. It flows through the county or city of Jianchang, Chaoyang, Nanpiao, Linghai, Jinzhou, etc. And it flows into Liaodong Bay at the south of Niangnianggong town. The main stream length of the river is 206km, watershed area is 5153 km^2.

Table 1. The hydrological stations controlled area in Xiaoling river basin

	Hydrometric Station	Control Area（km^2）
1	Gangyaokou	2251
2	Jinzhou	3172

2.2. Data Source

Terrain data comes from SRTM (Shuttle Radar Topography Mission), we took the DEM data of 90mresolution (http://srtm.csi.cgiar.org/), and djusted the coordinate system, so the resolution was improved to 1000m.

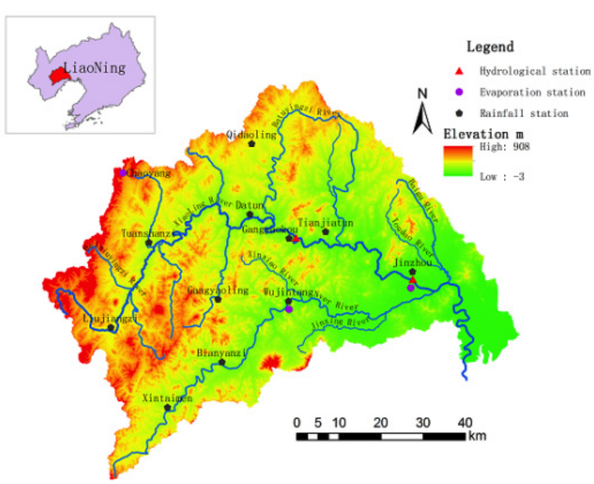


Fig. (1). Xiaolinghe river basin and stations.

Land Cover/use data derived from MCD12Q1 of MODIS products' 1999 data. Land Cover data of MODIS includes different types programs of land cover data extracted from the observation data of Terra and Aqua. Its resolution is 500m. The projection type of the data is sinusoidal projection. By using MODIS Reprojection Tool (MRT) to transform the projection and combine the data, to process data into the common Geotiff format, so we can use other tools to process the data. There are many different land cover classification system, our analysis used the University of Maryland (UMD) vegetation classification scheme. Most of our study area is rural area. Human didn't pay much disturbance to the area during 1990-1999. The land use of the area is stable, so there has not big change. It is suitable to simulate the model under the land use data in 1999.We incorporated the original land use types became a new classification system. There were 12 original classes at first, after reclassification, in the system, there are 7 different types. Woodland (evergreen coniferous forest, evergreen broad-leaved forest, deciduous coniferous forest, deciduous broad-leaved forest, mixed forests) 0.63%; brush (dense thickets, sparse thickets) accounted for 1.04%; city and buildings account for 1.90%; agricultural land accounted for 67.78%; grassland accounted for 28.58%; sparse vegetation accounted for0.04% and water accounted for0.03%. VIC model test data was direct quoted under the cover of leaf area index (LAI).

Soil type data was cited from HWSD (Harmonized World Soil Database Viewer) version 1.21.Global soil taxonomy of FAO and UNESCO was adopted to class the soil type data. According to the HWSD1.21, we obtained soil types and codes in study area, queried the soil parameters, and calculated the soil water dynamics related parameters through the Soil Water Characteristics (6.02.74) software. There were two layers in the original soil classification data, the upper layer (0 ~ 30 cm) and the lower layer (30-100 cm) according to the thickness of the soil. Vertical soil differences of unsaturated layer were not considered in the study, only the upper layer was analyzed. And the soil types were reclassified in the study area (Fig. **2**, Table **2**).

Ground water level data of the study was calculated from the measuredvalue of ground water depth in 1999 supplied by Hydrographic Office of Liaoning Province by using anti-distance difference. The data of rainfall, runoff and other groundwater were obtained from Hydrographic Office of Liaoning Province. And meteorological data were obtained from the Weather Bureau of Liaoning Province.

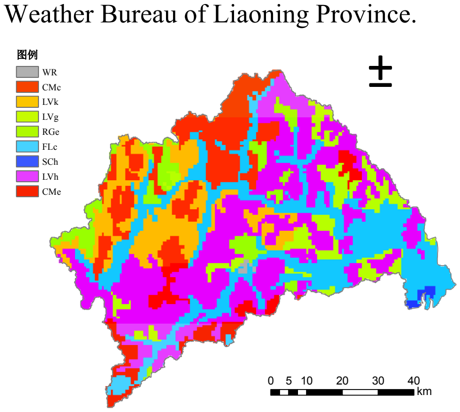


Fig. (2). Soil type of Xiaoling river basin.

3. HYDROLOGICAL MODELING

3.1. MIKE SHE/MIKE 11 Coupling

According to the study area, 1km^2 area computational grid was chosen. So the study area was divided into 114×95 cells. For data pretreatment and subsequent data supplement,all calculation data unified coordinate system were transformed into the WGS 1984 UTM Zone 51 n.

MIKE 11 channel connections coupled with adjacent MIKE SHE grid, the link was determined automatically by point coordinates of the river channel which defined by hydrodynamic model of MIKE 11.Linkswere only defined at the coupling reach in the hydrodynamic model. Although MIKE 11 was taken for building a complete river model, and MIKE SHE only had water exchange in coupling reach, but coupling of MIKE SHE and MIKE 11 is completely dynamic .In the process of simulation, the water levels of coupling reach were transferred from the calculation points of MIKE 11 (Fıg. **3**, H point) to the adjacent river connections of MIKE SHE. In reverse, MIKE SHE passed the calculations of adjacent grids and river to every river link. These conditions as the next time step nod of next calculation, as the lateral inflow or outflow, were returned to the calculation water level points of MIKE 11 [23]. The input files of MIKE 11 model including files such as river net, cross section data, boundary conditions, the hydrodynamic parameters and hot start data. River network data based on watershed DEM's data extraction, then as a SHP file imported into MIKE 11 river network module. River cross section data was obtained by measuring river channel cross section and generalization of the terrain data. The simulation of water in MIKE 11 was the rainfall runoff from ground. Therefore, the upstream boundary must be given a small amount of water, ensure that during the period of free rain, MIKE 11 model could run. Lower boundary had a long distance from the model checkpoint-Jinzhou station, so the influence was light. The influence of river mouth's sea level to flood was ignored in the simulation. And we took the stage-discharge relation of the boundary cross section which estimated by the average slope and experienced roughness as the lower boundary of the model. The default Settings were used by hydrodynamic parameter.

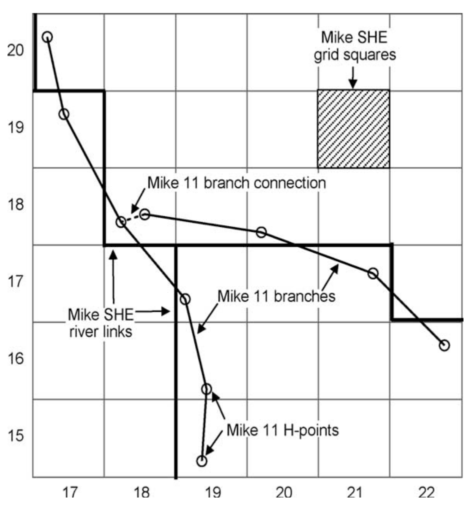


Fig. (3). MIKE 11 river links in MIKE SHE hydrological model grid.

3.2. Calibration and validation of model parameters

Refsgaard and Storm [24] suggested that, the numbers of parameters to adjust should be as less as possible in a MIKE SHE distributed hydrological model calibration process. For example, Khudhairy *et al*. [25] calibrated the parameters of Bells Creek watershed in MIKE SHE, they only calibrated the saturated hydraulic conductivity, the Manning coefficient of runoff and drainage time constant. In MIKE SHE/MIKE 11 coupling model, they have the same parameters to be calibrated, so these parameters are unified in the whole river. The characteristic of the coupling models is that, calibrating the parameters could be done at the same time in MIKE 11 and MIKESHE. Because the parameters once were changed in one model, the outcome of another changed simultaneously. Several parameters are common calibrated parameters, such as roughness, intercept amount of surface ground, roughness of runoff, saturated hydraulic conductivity and experienced constant parameters of water characteristic curve in soil. In the study, we selected roughness of surface slope (M), river roughness (RM), river leakage coefficient (LC) and soil saturated hydraulic conductivity rate (KS) were carried out as the calibrated model parameters through sensitivity analysis. The measured runoff value from Jinzhou station and Gangyaokou station (Fig. **1**) on the main stream of XiaoLing river were chosen as reference. The correlation coefficient (R) was adopted to tell the correlation of measured runoff value and simulated values. Nash coefficient (*Ens*) was used to evaluate the fitting degree of the simulation value and the measured values.

$$R = \frac{\sum_t (Calc_{i,t} - \overline{Calc_i}) \cdot (Obs_{i,t} - \overline{Obs_i})}{\sqrt{\sum_t (Calc_{i,t} - \overline{Calc_i})^2 \cdot \sum_t (Obs_{i,t} - \overline{Obs_i})^2}}$$

$$Ens = 1 - \frac{\sum_t (Obs_{i,t} - Calc_{i,t})^2}{\sum_t (Obs_{i,t} - \overline{Obs_i})^2}$$

In the equation, Obs_i 、 $Calc_i$ are measured value and calculated value at the point i, $\overline{Obs_i}$ and $\overline{Calc_i}$ are their mean values. Based on the experience [26], when *Ens*> 0.75, the simulation result is well; 0.36≤*Ens*≤0.75, the simulation result is desirable; *Ens*<0.36, the simulation result is not well. When R>0.8, there is a strong linear dependence between simulated value and calculated value.

4. RESULTS AND ANALYSIS

4.1. Calibration and Verification

The data of Jinzhou station and Gangyaokou station during 1990-1994 were used for calibration. The two stations weighting factor was 1:1. Data during 1995-1999 were used for verification. Model parameters calibration usually adopted in two ways, manual and automatic. It is very necessary using automatic calibrating, because there are many parameters and parameters needed calibrated in distributed hydrological model. The paper adopted the manual and automatic ways combined to calibrate the parameters. First, we analyzed their sensitivity by using manual trial-and-error of the calibration parameters, thus to estimate the possible value

Table 2. The calibrated parameters.

Calibrated parameter	Start value	Calibrated value
Roughness of slope surface M($m^{1/3}s^{-1}$)	5	1.23
Channel roughness RM($m^{1/3}s^{-1}$)	30	24.2
Riverbed leakage coefficient CL(s^{-1})	1.00E-06	4.45E-06
Saturated soil hydraulic conductivity KS(m s^{-1})		
calcaric fluvisol FLc	4.64E-08	7.6E-08
calcareous chao soil CMc	3.81E-08	7.22E-08
Luvic calcisols LVk	3.71E-08	4.89E-09
eutric regosols RGe	5.06E-08	6.25E-08
active luvisols LVh	3.69E-08	3.83E-08
eutric cambisol CMe	3.73E-08	5.46E-08
orthic solonchaks SCh	2.75E-08	6.43E-08
gleisoil LVg	3.24E-08	4.56E-08

Table 3. Model performance for the simulation of streamflow.

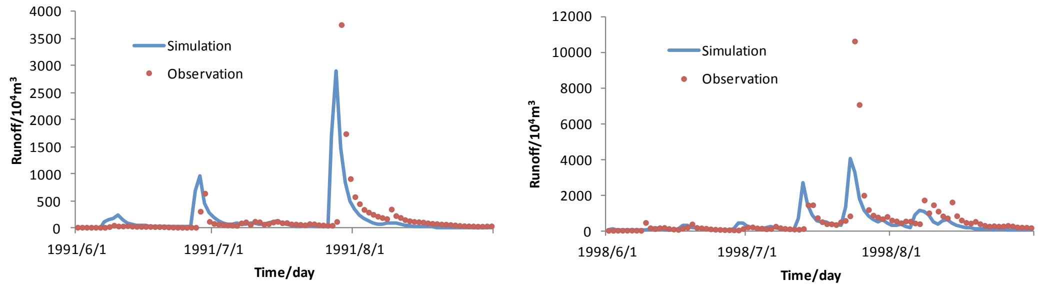
Period	Hydrometric Station	R (Correlation)		*Ens* (Nash_Sutcliffe)	
		Day	Month	Day	Month
Calibration Period（1990-1994）	Jinzhou station	0.839	0.961	0.636	0.794
	Gangyaokou station	0.808	0.960	0.618	0.863
Verification Period（1995-1999）	Jinzhou station	0.788	0.911	0.582	0.740
	Gangyaokou station	0.761	0.917	0.575	0.820

space, then we calibrated the parameters by automatic tools (*.auc) of MIKE SHE. Automatic calibration tool uses the Shuffle Complex Evolution (SCE), it is a overall situation random search algorithm, which achieved nice results in the parameter model's calibration [23, 27]. The calibrat ed parameters were in Table **2**.

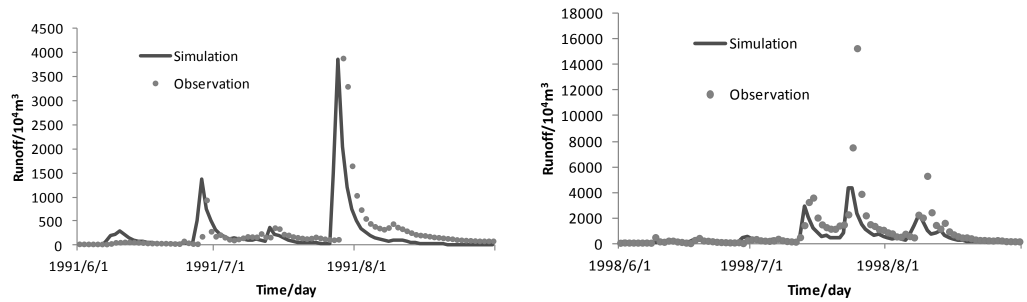
4.2. Runoff Simulation Analysis

We simulated the daily runoff process of the study area from 1990 to 1999 by using coupling model of MIKE SHE/MIKE 11. The analysis（Fig. **3**）of calibration and verification of the simulation showed that in daily simulation, Ens of Nash efficiency coefficients were all above 0.55 either in the period of calibration and verification at Jinzhou station and Gangyaokou station. The correlation coefficient of two stations were all higher than 0.75. The study had chosen the runoff process in 1998, which had a heavy runoff, and 1991, which was a median water year, for concrete analysis. In Fig. (**4**), we can see the runoff process of 1991 and June-August of 1998 at two stations.

From the simulation results of the model, the model can simulate the runoff process, and the simulation runoff and the observed runoff are in good agreement in general. In the median water year 1991, the model shows a high alignment in flood volume and simulation runoff and the time of propagation of flood peak, etc. But there also has some deviation in the simulations for the heavy runoff situations. A great peak flow will be underestimated. The month runoff simulation obviously better than the daily runoff simulation, R=0.961 while Ens=0.794 at Jinzhou station; R=0.960 while Ens=0.863 at Gangyaokou station in calibration period. In verification period, R=0.911 while Ens=0.740 at Jinzhou station; R=0.917 while Ens=0.820 at Gangyaokou station. So we considered that month runoff simulation had a better result in the model. Fig**. (5)** respectively shows that the comparison of monthly simulation runoff and observed runoff at Jinzhou station and Gangyaokou station in the Xiaoling river basin from 1990 to 1999. From the specific data, there is a relatively consistent trend of the two stations on monthly simulation values and observation values in calibration period and verification period. Xiaoling river basin is located in the semi-humid region in northeast China. The rainfall concentrated in June-August each year, so does the floods. The minimum error exists in this period of each year between simulation data and observation data. The flood simulation

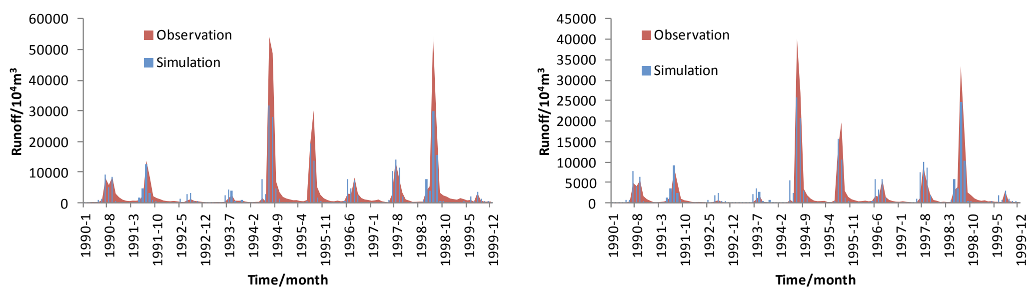


Gangyaokou Station



Jinzhou Station

Fig. (4). Simulated daily runoff.



Jinzhou Station Gangyaokou Station

Fig. (5). Comparison between simulated and observed monthly runoff.

by using monthly runoff simulation model for 1994, 1995 and 1998 are also very accurate. Although runoff in the low water period was overrated by simulation of the model, and the flood flow in wet season was underestimated. But by the simulation of long sequential, the correlation coefficient of the model and Nash efficiency coefficient all satisfied the requirement precision of the model.

4. DISCUSSIONS AND CONCLUSIONS

The parameters in the model have physical meaning. After calibrating, parameters must comply with their practical significance, avoiding to be parameterized. In-depth study of relevant profession will play a great role to improve the precision of model. The study area is located in the sub-humid area of the north China. On the one hand, rainfall is uneven distributed in time and space, underlying surface faces complex conditions, the local runoff phenomenon is widespread. On the other hand, time scale of model plays is a factor affected on the precision elements. In the basin, it is primary that excess infiltration transforming into flow. In the curve of rainfall infiltration, infiltration intensity attenuation with time is very fast. For the measured data of time scale is large, so homogenization phenomenon is very obvious of the infiltration intensity of time frame. These all made directly affects on the precision of model calculation.

The study coupled the distributed hydrological model MIKE SHE and MIKE 11, to simulate middle-sized basin-Xiaoling river basin in the sub-humid area of the north China. The variation of rainfall in time and space makes much affection to the runoff simulation. The simulation process and result were:

1) By calibrations of Jinzhou station and Gangyaokou station, the model calculated a reasonable solution, including river roughness (MIKE 11), roughness of slope surface, riverbed leakage coefficient and soil parameters. These were all verified. The applicability could be affirmed in the study area. The method laid a good foundation to the hydrological simulation of the semi-humid zone.

2) We simulated the monthly runoff process of sub-humid basin of the north China from 1990 to 1999 by using coupling model of MIKE SHE/MIKE 11, and validated the simulation results using the observation values of the hydrometric station located in the midstream and downstream. The results showed that in a long series of simulation had good accuracy in the model. For relevancy and fitting degree of Jinzhou station and Gangyaokou station, monthly simulations were better than daily simulations. Correlation coefficients of daily simulation were 0.788 and 0.761, and Nash coefficient were 0.582 and 0.575. And correlation coefficients of monthly simulation were 0.911 and 0.917, Nash coefficient were 0.740 and 0.863.

3）The simulation had a best result when it was median water year, daily runoff characteristic could be simulated mainly. In wet year, simulation effect also can achieve satisfactory, so the model has a good application prospect in the assessment of flood in semi-humid region. Monthly runoff simulation had a better effect in the model. It can be adopted in water resources assessment in semi-humid region of north China.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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