Hydrological Simulation of Taizi River Basin with HSPF Model

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Abstract. With the development of economy and the increase of population, water resources are becoming more and more scarce. The total amount of water resources in the Taizi River Basin of Liaoning Province, China is 5.120 billion m³, and the per capita water resources amount is 845 m³. According to the United Nations standards, it is classified as a water shortage area. In order to better manage and protect water resources, this paper uses Hydrological Simulation Program-Fortran (HSPF) model to simulate runoff in the Taizi River Basin. The Parameter Estimation (PEST) procedure was used to calibrate the hydrological parameters. The results showed that the Nash-Sutcliffe efficiency (NSE) of the calibration period (2009-2011) was 0.78, the correlation coefficient ($R^2$) was 0.89; the Nash-Sutcliffe efficiency of the validation period (2012-2013) was 0.68, and the correlation coefficient was 0.85. It indicates that the HSPF hydrological model has good applicability in the Taizi River basin which will provide useful reference for future modeling research.

1. Introduction

Hydrological model is a means of describing and reflecting complex hydrological phenomena in nature by using mathematical methods. It is the product of the development of hydrology to a certain stage. The Hydrological Simulation Program-Fortran (HSPF) model was proposed by Robert Carl Johanson in 1981. It originated from the Stanford model[1] in 1966 and was a watershed hydrological model that applied mathematical methods to hydrological calculations and predictions. The HSPF model has been developed and improved and is currently in HSPF version 12.5, embedded in the Better Assessment Science Integrating Point and Non-point Sources (BASINS) system[2]. Developed by the US Environmental Protection Agency in 1988, BASINS is an integrated platform based on GIS technology. It incorporates hydrological models such as HSPF, SWAT and PLOAD, and auxiliary tools such as WDMUtil and GenScn.

Relying on BASINS system, HSPF can easily extract the data of terrain, landform, soil, vegetation and watershed needed by the model, and simulate the hydrology and water quality for a long time[3]. HSPF has been widely used in flood and drought disaster prevention, water environment monitoring, water resources development and utilization. HSPF model mainly includes hydrological and water quality simulation module in permeable area (PERLND, Pervious Land Segment), hydrological and water quality simulation module in impervious area (IMPLND, Impervious Land Segment) and hydrological and water quality simulation module of surface water body (RCHRES, Free-flowing Reach or Mixed Reservoir)[4]. HSPF model can simulate many hydrological phenomena such as precipitation, evaporation, surface runoff, basic flow, snow melting and so on by using these three modules.

Due to the influence of natural climate and human activities, the Taizi River Basin is short of water,
nutrients such as nitrogen and phosphorus are enriched, and water pollution is serious[5]. In this paper, the HSPF model is used to simulate the runoff in the Taizi River Basin, and the PEST automatic adjustment procedure is used to adjust the parameters. The evaluation results are obtained. The applicability of the HSPF model in the study area is preliminarily evaluated. The objection is to expound the variation law of hydrological cycle process in the basin and lay a foundation for the study of water quality pollution in the basin.

2. Study Area
The total length of the Taizi River is 464 km, and the basin area is 4000 km²[6]. It belongs to a large-scale river. The basin originates from the Liaodong mountainous area in the south of Fushun City. It flows through the Benxi, Liaoyang urban areas and the northern part of Anshan City, and merges with the Weihe River at the junction of Anshan City and Panjin City. After the confluence, the Da Liao River was formed into the Bohai Sea. The Taizi River Basin belongs to the temperate monsoon climate, with abundant rainfall in summer and less rainfall in winter[7]. The precipitation in the basin gradually increases from west to east, and the annual average precipitation increases from 500mm to 900mm. The study area map is shown in Figure 1.

3. Materials and Methods
3.1 Data collection
The HSPF model needs to input data including digital elevation model (DEM), river network, land use, meteorological data such as precipitation, evaporation, temperature, wind speed, relative humidity, solar radiation, dew point temperature, etc.[8]. According to the input data, the model automatically divides the watershed, determines the threshold area of 80 km², and finally generates 9 sub-watersheds. All data types and sources are shown in Table 1. DEM and land use are shown in Figure 2.
### Table 1. Data needed for HSPF model simulation

| Data type            | Data                  | Data sources                        |
|----------------------|-----------------------|-------------------------------------|
| spatial data         | DEM                   | http://www.gscloud.cn/              |
| land use             | http://westdc.westgis.ac.cn/ |
| meteorological data  | precipitation,        | http://data.cma.cn/                 |
|                      | evaporation, etc.     |                                     |
| hydrological data    | flow                  | Hydrological Yearbook               |

3.2 **PEST automatic calibration procedure**

Parameter Estimation (PEST) was developed by Dr. John Doheay of Watermark Numerical Computing Consulting company, Australia[9], a comprehensive software for model-independent parameter estimation and uncertainty analysis. PEST is based on the nonlinear evaluation method (Gauss-Marquardt-Levenberg method)[10]. This method concentrates on the advantages of the inverse Hessen method and the steepest descent method. It can converge the objective function quickly and efficiently, but the length of convergence time has a great dependence on the initial value of the model parameters. Therefore, on the basis of manual calibration, PEST automatic calibration is adopted, and the calculation speed of parameter calibration will be very fast. The PEST automatic calibration procedure can be combined with many models and achieve good results. Compared with the simplex method, SCE-UA algorithm, genetic algorithm and other automatic calibration algorithms, PEST algorithm is more efficient in parameter calibration of HSPF model.

4. **Results and discussion**

4.1 **Model parameter calibration**

The HSPF model has many parameters, each of which has a clear physical meaning. The purpose of parameter calibration is to obtain a set of optimal parameter values by adjusting the input parameter values so that the simulated values and measured values are as close as possible, so that the model can better reflect the true hydrological water quality process in the basin. According to the relevant literature research and the experience of the predecessors, this paper finally selects 11 sensitive parameters such as AGWRC, LZSN, UZSN and IRC[11]. The parameters are calibrated by manual calibration and PEST automatic calibration, and the optimal values of a set of parameters are obtained. Table 2 shows the main parameters of the HSPF model hydrology block.
Table 2. main parameters of the HSPF model hydrology block

| Parameter name | Meaning                                               | Range of value | Optimal value |
|----------------|-------------------------------------------------------|----------------|---------------|
| LZSN           | lower zone nominal storage                           | 2-15           | 2             |
| INFILT         | infiltration capacity of the soil                    | 0.001-0.5      | 0.10461       |
| KVARY          | behavior of groundwater recession flow               | 0-3            | 0.9           |
| AGWRC          | daily recession coefficient of groundwater           | 0.85-1         | 0.99093       |
| DEEPFR         | the fraction of groundwater inflow which will enter   | 0.001-0.5      | 0.27006       |
|                | (inactive) groundwater                               |                |               |
| BASETP         | evaporation coefficient of base flow                 | 0.001-0.2      | 0.001         |
| AGWETP         | groundwater evaporation coefficient                  | 0.001-0.2      | 0.17003       |
| UZSN           | upper zone nominal storage                           | 0.25-2         | 0.05          |
| INTFW          | interflow inflow coefficient                         | 1-10           | 6.64813       |
| IRC            | Interflow recession coefficient                      | 0.3-0.85       | 0.84849       |
| LZETP          | lower zone potential evaporation                     | 0.1-0.9        | 0.1           |

4.2 Runoff Calibration and Validation

Usually, there are many indicators for model evaluation. In this study, Nash-Sutcliffe efficiency (NSE) and correlation coefficient ($R^2$) are used as the indicators for model evaluation. The calculation formula is as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{i}^{obs} - Q_{i}^{sim})^2}{\sum_{i=1}^{n}(Q_{i}^{obs} - \bar{Q}^{obs})^2}$$  \hspace{1cm} (1)

$$R^2 = \frac{\sum_{i=1}^{n}(Q_{i}^{obs} - \bar{Q}^{obs})(Q_{i}^{sim} - \bar{Q}^{sim})}{\left[\left(\sum_{i=1}^{n}(Q_{i}^{obs} - \bar{Q}^{obs})^2\right)\left(\sum_{i=1}^{n}(Q_{i}^{sim} - \bar{Q}^{sim})^2\right)\right]^{1/2}}$$  \hspace{1cm} (2)

In formula: $Q_{i}^{obs}$ and $Q_{i}^{sim}$ are observed and simulated runoff values respectively; $\bar{Q}^{obs}$ and $\bar{Q}^{sim}$ are the average values of observed runoff and simulated runoff respectively.

Experience shows that the closer the values of NSE and $R^2$ are to 1, the closer the simulated values of the model are to the observed values[12]. The simulation results of the general model monthly scale NSE $\geq 0.65$ or the daily scale simulation results NSE $\geq 0.5$ indicate that the simulation results are acceptable[13]. Results showed that in the monthly scale simulation, $R^2$ of the calibration period (2009-2011) was 0.89, and NSE was 0.78. During the validation period (2012-2013), $R^2$ and NSE were 0.85 and 0.68 respectively. Figure 3 is a comparison of observed and simulated values of monthly average runoff. It can be seen from the figure that the fitting results of simulated runoff and observed runoff are better, and the percentage of excess runoff is within the controllable range. It shows that the HSPF model has good applicability in the Taizi River Basin, which can provide a favorable reference value for future hydrological investigation and research.
Figure 3. Comparison of observed and simulated values of monthly average runoff
(a1, a2, and a3 are calibration period; b1, b2, and b3 are validation period)

5. Conclusion
This paper chooses the Taizi River Basin, China as the research area. The spatial and attribute database is established by using the HSPF model, and the parameters are calibrated. Based on the calibrated parameters, the runoff process of the Taizi River Basin was simulated, and the applicability of the model was evaluated by selecting NSE and $R^2$. The NSE of the calibration period and the validation period are both above 0.65, and $R^2$ are both above 0.85. The results show that the hydrological simulation results of the model are ideal in the Taizi River Basin, which indicates that the HSPF model has good applicability to the runoff simulation of the basin.

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