Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2022.27810

245 (2022) 62–71
January

Assessment system of water conservancy project impact on environmental pollution based on HSPF model

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Received 26 August 2021; Accepted 23 September 2021

ABSTRACT

With the rapid development of water conservancy construction in recent years, the problem of uneven distribution of water resources has been solved to a certain extent, but at the same time, it also brings serious environmental pollution problems. In view of this, this study proposes to use HSPF model to analyze the environmental pollution of water conservancy projects. Through the collection of meteorological data, terrain factors, land use types and other data, the database and HSPF model were constructed, and the water hydrology, sediment and water quality were simulated by using HSPF model. The results show that the method proposed in this study has good simulation effect on hydrology, sediment and water quality of water area, which indicates that the HSPF model can accurately simulate the water area and judge the environmental pollution. Hope that through this study, can reduce the current rapid development of water conservancy projects under the environmental pollution problems to provide a certain reference.

Keywords: HSPF model; Pollution; Hydrology; Sediment; Water quality

1. Introduction

With the development of the times and the continuous progress of social economy, water conservancy projects play an increasingly important role in the growth of the national economy. For example, through the establishment of a water conservancy project that can control the water area in the water area, it can increase water storage, flood control, water supply, irrigation, shipping and aquaculture, and these effects have significant social effects economic performance [1]. Since the 1960s, with the rapid growth of world population and the rapid development of economy, more and more water conservancy projects have been built to resist floods, droughts and floods. According to the statistics of the World Commission on dams, up to 2003, there were 49,700 dams in the world, of which 25,800 were in China [2]. Water conservancy projects such as dams and reservoirs can not only resist floods, droughts and floods, but also solve the problem of uneven distribution of precipitation in time and space. Therefore, water conservancy projects have made great contributions to the production and development of people all over the world and national progress. However, at the same time, water conservancy projects also bring environmental pollution problems that cannot be ignored [3]. During the construction of water conservancy project, the survey and setting out, surface vegetation removal, pipeline excavation, road repair and material transportation and stacking will cause great damage and pollution to the ecological environment. In view of this, it is necessary to take corresponding measures to reduce the environmental pollution caused by water conservancy projects. This study proposes to study the water conservancy, hydrology and water quality through hydrological simulation model to analyze the impact of water conservancy projects on ecological environment. It is hoped that through this study, we can pay attention to the environmental pollution of water conservancy projects, and take corresponding measures to reduce the ecological environment pollution.

In order to understand the impact of water conservancy projects on environmental pollution, this study proposes to use HSPF model, and take a certain water area as the research object, collect the meteorological, hydrological and water conservancy data and water quality detection results of the water area, combined with field sampling and simulation experiments, and then analyze the environmental quality of the studied water area. The HSPF model used in this study has strong spatial analysis ability and data processing ability, which can realize continuous simulation of hydrology, surface pollution and point pollution in water area. It is hoped that this study can provide some reference for reducing the environmental pollution caused by water conservancy projects.

This research creatively proposes the research on environmental pollution of water conservancy project based on HSPF model. This method can effectively simulate the hydrology, sediment and water quality of the water area based on the hydrological and water conservancy, meteorological conditions, pollution sources and other data of the studied water area.

This study mainly consists of four parts. The first part mainly describes the research on HSPF model by domestic and foreign scholars. The second part mainly describes the principle of HSPF model and its establishment, and analyzes the uncertainty of the model. In the third part, based on the HSPF model, the influence of water quality on water quality of a certain water area is analyzed. The fourth part mainly describes some deficiencies in this study, hoping to be improved in the future.

2. Related work

Berndt et al. proposed to study sulfate in St. Louis River, Minnesota, and compare the measured river chemical elements with HSPF model. The results show that methyl mercury is associated with the active groundwater recharge in summer. The decrease of non-point source sulfate is related to the increase of methyl mercury, and the sulfate from mine is not related to the increase of methyl mercury [4]. Discussed the hydrological simulation program Fortran (HSPF) and BP neural network (BPNN), which represent the deterministic model and the probabilistic model respectively, and used the two models to study the prediction ability of surface runoff pollution. The results show that the prediction accuracy can be improved by adjusting BPNN neurons. On the contrary, HSPF limits the improvement of prediction accuracy [5]. Sobel et al. proposed to establish a tidal prism model (TPM) and a watershed runoff model to study the effects of tidal fluctuations and hydrochemistry on coastal water quality. The results show that the change of net attenuation rate has the greatest influence on TPM, followed by tidal load and runoff load. An inter related model has been developed to assess management assumptions to assess the impact of reducing runoff loads and improving the quality of wastewater treatment plants, and to identify areas where such reductions are urgently needed [6]. Amirhossien et al. proposed to evaluate the performance of hydrological simulation program Fortran (HSPF) as process model and ANN (data driven model) in runoff simulation. The results show that the Runoff Simulated by artificial neural network is closer to the observed value than that predicted by HSPF [7]. Liu et al. established a comprehensive watershed model–hydrological simulation program Fortran (HSPF), and combined with land use prediction model (CA Markov) and daily rainfall stochastic simulation model, the runoff of Dongjiang River Basin was quantitatively predicted. The calibration and validation results of HSPF show that the model is suitable for the simulation of monthly runoff in Dongjiang River Basin [8]. Luo et al. proposed the method of differential sensitivity analysis (DSA) to study the sensitivity of flow and nutrient parameters of HSPF in Xitiaoxi watershed. The results show that the groundwater flow is mainly affected by the related parameters of groundwater and evapotranspiration. DEEPFR (recharge part of groundwater flow into depth), LZETP (lower evapotranspiration parameters) and AGWRC (decline of basic groundwater) have negative and nonlinear effects on groundwater flow. In addition, nutrient composition is usually affected by land process parameters [9,10]. Zhou et al. proposed to use the watershed hydrological simulation program FORTRAN cat (climate assessment tool) model system in Jianfengling tropical montane rainforest of Hainan Island to determine the impact of potential rainfall changes on the hydrological process of the basin in the future. The results showed that the runoff, surface runoff and outflow increased by 1.3 times when the rainfall increased by 10%. The potential humid climate in the future may have a profound impact on the hydrological process of JFL basin, while the potential future arid climate has little impact on the runoff, surface runoff and water outflow of the same basin [11]. Sarkar et al. proposed a new linked modeling system for the prediction of key watershed sources by combining the advantages of two widely accepted watershed management models soil and water assessment tool (SWAT) and hydrological simulation program FORTRAN (HSPF). The model shows that about 66% of the total sediment load comes from the eastram source, which is consistent with other studies in the area and can be used to support the identification of these channel source segments and terrestrial source segments and further improve target management [12,13]. Quan et al. proposed a method of combining water quality monitoring with modeling to realize water quality management. In this study, a hydrological simulation program FORTRAN (HSPF) model was established to carry out experiments. The results show that the contribution of point source and diffusion source to nutrient load can be clearly identified by monitoring, and the water quality sampling in flood process is the key to evaluate pollution source, especially diffusion pollution source [14]. Zhao et al. proposed a water resources risk assessment model based on subjective and objective combination weighting method to control environmental water pollution. Taking Hanjiang Basin as an example, the risk assessment model was established and verified, and the actual data and simulation data were applied. The results show that the risk of water resources is controlled at a certain level. This is consistent with the facts [15].

Ranatunga proposed to analyze the time and space of hydrological response using the hydrological models of LMR and LVW. The results show that LMR basin is highly sensitive to groundwater related parameters, while LVW basin is mainly sensitive to near surface parameters and seepage control parameters. High and medium flow rate is greatly affected by most parameters. Low flow pattern is highly sensitive to groundwater related parameters [16].

Through the research and analysis of domestic and foreign scholars, it can be seen that HSPF model is often used in hydrological research, and has achieved quite good results, but there are few studies on the environmental pollution caused by water conservancy projects. This study proposes to analyze the environmental pollution caused by water conservancy projects on the basis of HSPF model, hoping that this study can make a certain reference for reducing environmental pollution of water conservancy projects [17].

3. Environmental pollution analysis based on HSPF model

3.1. HSPF model

HSPF (hydraulic simulation program FORTRAN) model is a method based on Stanford model in 1966, which combines mathematical method and hydrological calculation, and can be used to simulate hydrological series, point source pollution and basin pollution in water basin. HSPF hydrological simulation model mainly includes four parts: watershed hydrological model (WinHSPE), GIS integrated analysis tool (BASINS GIS), decision support analysis tool (GenScn) and tool analysis software (WDMUtil, HSOEParm). Among them, GIS integrated analysis tool system can combine hydrological model with GIS core plug-in, and then realize automatic extraction of water area, length and other information, which makes the model simulation have certain spatial attributes. WDMUtil can represent the observation time series data of water area in the form of. WDM file, and form new time data to meet the requirements of model data input. However, HSPF can make all meteorological data imported into the system have corresponding data sets, and the coding rules of its digital serial number and data set are shown in Table 1.

WinHSPF is a component in HSPF model, which is the running interface of software to by combining with Windows. WinHSPF can complete the simulation by generating and modifying UCI files and operations.

Fig. 1 shows the structure of HSPF model. It can be seen from Fig. 1 that HSPF model can be divided into three modules, namely impervious surface hydrological and water quality simulation module (IMPLND), permeable section hydrological water quality simulation module (PERLND) and surface water body simulation module (RCHRES). Among them, PERLND module is mostly applicable to the permeable part of the sub basin of HSPF model. The module can simulate the runoff, pollutant concentration and load, and the simulation of water quality and sediment also needs to be carried out on its basis. Therefore, PERLND module is the basis and key of HSPF model operation. The impervious module of IMPLND is mainly applicable to the areas with little or no water permeability. The pollutants in the section are basically stored on the surface. IMPLND can simulate the changes of water balance, sediment accumulation, temperature, hydrology and atmospheric density, and water quality. However, channel and reservoir modules are mostly used to simulate closed water bodies such as HUPO and reservoir. HSPF model can simulate various chemical substances in soil and water to judge the current water pollution.

When using HSPF model to simulate water hydrology, the main steps can be divided into three steps. Firstly, WDMUtil is used to transform time series data into. WDM file, which can meet the data input format requirements

Table 1
Digital sequence number and WDM data set coding rules

Meaning of parameters	Digital serial number	Data set	Dataset field
Hourly temperature	(11,31,51,...,191)	ATEM	1
Hourly wind speed	(12,32,52,...,192)	WIND	2
Hourly cloud cover	(13,33,53,...,193)	CLOU	3
Daily minimum temperature	(14,34,54,...,194)	TMIN	4
Average daily cloud cover	(15,35,55,...,195)	DCLO	5
Daily solar radiation intensity	(16,36,56,...,196)	DSOL	6
Hourly evaporation	(17,37,57,...,197)	EVAP	7
Potential evaporation per hour	(18,38,58,...,198)	PEVT	8
Hourly rainfall	(19,39,59,...,199)	TMAX	9
Hourly solar radiation	(20,40,60,...,200)	TMIN	10
Hourly dew point temperature	(21,41,61,...,201)	DWND	11
Daily maximum temperature	(22,42,62,...,202)	TMAX	12
Daily surface evaporation	(23,43,63,...,203)	DEVP	13
Daily dew point temperature	(24,44,64,...,204)	DPTP	14
Average daily wind speed	(25,45,65,...,205)	DWND	15
Daily potential evapotranspiration of soil water	(26,46,66,...,206)	DEVT	16

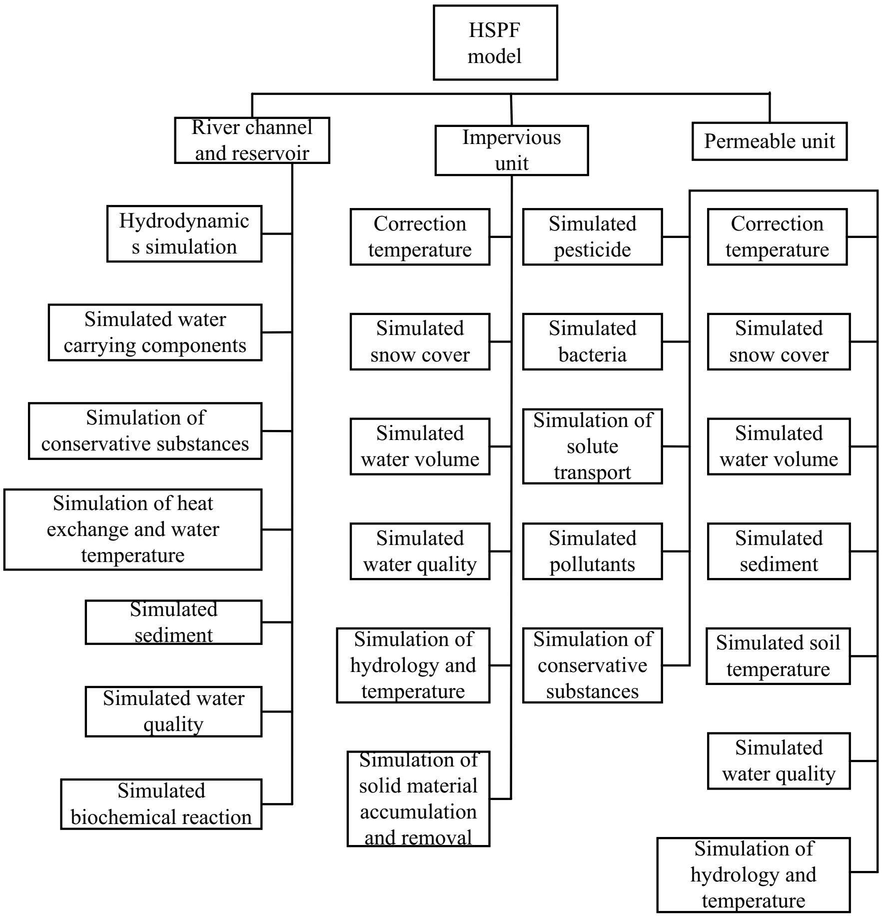

Fig. 1. HSPF model structure.

of HSPF model. Secondly, input spatial geographic data through Map Window GIS to enhance the simulation efficiency and accuracy of the results. Finally, on the basis of GenScn program, the running results of HSPF model can be viewed. Besides the first time, GenScn can be used to compare and analyze the running results of HSPF model in different situations.

3.2. Establishment of HSPF model and database

In order to realize the hydrologic simulation research of water area, the topographic factors are very important. Digital elevation data (DEM) is a parameter to determine regional geomorphology, river length, width and other parameters. In order to analyze the environmental pollution of water conservancy projects based on HSPF model, this study takes a certain watershed A as the research object, and obtains the DEM map of the region through the geospatial data cloud service system.

Fig. 2 is the DEM schematic diagram of basin A. through the DEM map, the terrain characteristics of the area can be reflected, and the surface morphology information of the basin grid unit can be extracted to determine the length of the river and the water boundary. By extracting the surface information, we can get the area proportion of elevation value in Table 2.

There is a close relationship between the hydrological change of water area and regional land use, and the hydrological change is greatly affected by human hydraulic engineering activities, so it is of great significance to study it. In this study, combined with electronic map and field survey, the land use types of the region are divided into woodland, construction land, and wasteland and water area. At the same time, because of the different soil permeability of various land use types, forest land, water area and wasteland are divided into permeable ground, and construction land and urban land are divided into impermeable ground.

Fig. 3 shows the land use map of basin a selected in this study. In the selected watershed, the proportion of woodland area is 85.4%, the water occupation area is 2.4%, the wasteland area is 0.8%, the construction land area is 3.9%, and the cultivated land area is 7.5%.

In addition to digital elevation data and land use data, observation data is also indispensable for the establishment of HSPF database, and the observation data mainly includes hydrological data, meteorological data and water quality data. The meteorological data include daily precipitation, daily average wind speed and so on. The storage of meteorological data adopts the WDM format file used in the previous paper. In this study, hydrological data, meteorological data, water quality data and GIS data are input to make the simulation results consistent with the actual

Table 2
Digital sequence number and WDM data set coding rules

Parameter	DEM < 200	200 ≤ DEM < 500	500 ≤ DEM < 5000	1,000 ≤ DEM
Measure of area (m^2)	747,533.658	26,854,126.52	12,586,210.34	27,458,624.37
Proportion (%)	0.43	16.88	68.21	14.33

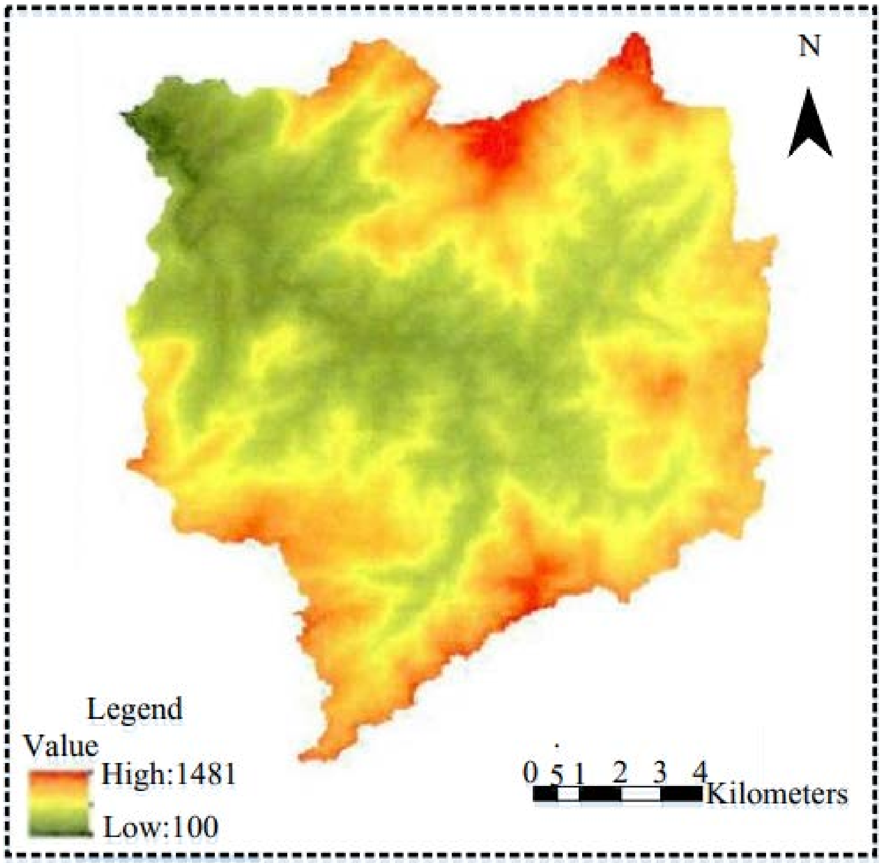

Fig. 2. DEM map of basin a.

measurement results. After the preparation of basic data, the basin is divided automatically by using BASINS software. The results are shown in Table 3.

Table 3 shows the information of sub basins, which are divided into seven sub basins in this study. After the watershed division is completed, WDMUtil tool is needed to input meteorological data, and in order to make WINHOPF and BASINS applicable, the meteorological data unit needs to be converted to the U.S. meteorological unit. After the preparation of basic data, the preprocessing of spatial information, the establishment of time series and the division of sub basins, the research has ensured the conversion from BASINS to WinHSPF. After the construction of HSPF model, it needs to be verified. This study will use HSPF model to simulate watershed A, and verify it by comparing the simulation results with the measured results. In this study, discriminant coefficient (R^2), relative error (Re) and Nash efficiency coefficient (ENS) were used to verify the HSPF model. Where ENS and Re can be expressed by Eq. (1):

$$\begin{cases} \text{Re} = \dfrac{S_i - O_i}{O_i} \times 100\% \\ \text{Ens} = 1 - \dfrac{\sum_{i=1}^{n}\left(S_i - O_i\right)^2}{\sum_{i=1}^{n}\left(O_i - O_{\text{ave}}\right)^2} \end{cases} \tag{1}$$

In Eq. (1), O_i is the actual observed value, S_i is the simulated value of HSPF model, and O_{ave} is the average value of actual observation value. When the relative error is close to 0, it means that the closer the simulation result is to the actual measurement result, the higher the accuracy is. When the Nash efficiency coefficient is closer to 1, the higher the simulation efficiency, the better the effect. The criteria for judging the simulation results in this study are shown in Table 4.

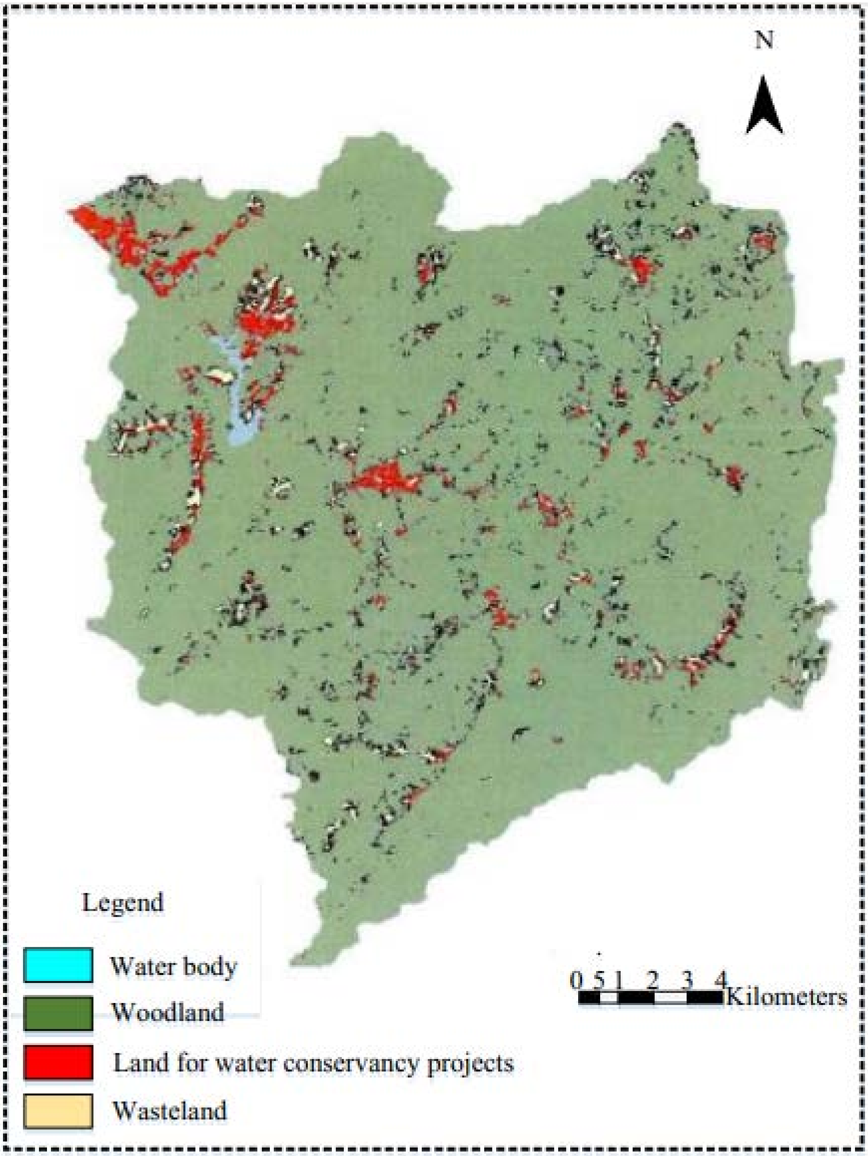

Fig. 3. Land use map of basin a.

Table 3
Sub basin details

Basin number	1	2	3	4	5	6	7
River number	2	3	5	7	4	6	1
River length (m)	16,537	10,284	6,324	2,547	968	2,799	1,652
Measure of area (m^3)	35,716,950	35,716,950	35,716,950	35,716,950	35,716,950	35,716,950	35,716,950

4. Experimental design and analysis

4.1. Hydrological simulation results based on HSPF model

The size of water runoff is directly related to the nutrient content and sediment content of water quality. Therefore, the simulation of water runoff is of great significance for the normal operation of water quality simulation and sediment simulation. In this study, the runoff of the selected waters from 2013 to 2019 is analyzed and simulated, and the period from 2013 to 2015 is taken as the model rate period, and the period from 2016 to 2019 is taken as the model validation period. In order to ensure the preciseness and scientificity of the research, it is necessary to keep the simulation results close to the actual measurement

Table 4
HSPF model simulation criteria

Judge category	Effect judgment	Very nice	Good	Reasonable
Re (%)	Hydrological simulation	<10	10–15	15–25
	Sediment simulation	<20	20–30	30–45
	Water quality simulation	<20	20–30	30–40
Ens (%)	Difference	Commonly	Good	Very nice
	<0.5	0.5–0.7	0.7–0.9	>0.9

results as far as possible. Therefore, three time scales of day, month and year are used in the simulation test of this study. The results of annual runoff are shown in Table 5.

Table 5 shows the comparison results of runoff observation value and simulation value from 2013 to 2019. Through the table, we can see that during the calibration period from 2013 to 2015, the relative errors of the three years are –21.9%, 3.3% and –14.2%, and the annual total relative error of the calibration period is –14.6%, and the simulation results are good. In addition, it can be seen that the simulation relative errors during the verification period from 2016 to 2019 are 0%, 6%, –23% and –14% respectively, and the relative error of total annual runoff in the four-year verification period is –10%, and the simulation effect is better than that in the calibration period.

Fig. 4 shows the comparison results of monthly runoff observation value and simulation value from 2013 to 2019, where (a) is the comparison of monthly runoff observation value and simulation value during calibration period, and (b) is the comparison of monthly runoff observation value and simulation value during verification period. During the calibration period, the relative error discrimination coefficient between the actual test results and the simulation results is 0.836, and the Nash coefficient is 0.76. Combined with the judgment standard, it can be seen that the simulation effect is better. During the verification period, the relative error discrimination coefficient between the actual test results and the simulation results is 0.75, and the Nash coefficient is 0.72. Combined with the judgment standard, it can be seen that the simulation effect is better than that during the calibration period, and the simulation effect is good.

Fig. 5 shows the comparison results of daily runoff observation value and simulation value from 2013 to 2019. The main factors influencing the daily runoff are IRC and INTFW. Among them, IRC will affect the size of water flow, and its adjustment can affect the speed of falling into the water. If the value of INTFW is adjusted, the flow in soil can be adjusted, and the slope flow can be controlled. According to Fig. 5, the total discrimination coefficient is 0.58 and the total Nash coefficient is 0.58 during 2013–2019, which can basically meet the requirements of simulation. It can be seen that the method proposed in this study can effectively simulate the hydrological situation of water area.

4.2. Sediment simulation results based on HSPF model

In the process of water conservancy project construction, surface clearing, sediment excavation and soil material discarding make a large amount of sediment enter the river and water area with the flow of water. As the most common material in surface erosion, sediment carries a lot of pollutants and toxic substances, which is one of the main factors leading to the decline of water environment quality.

Table 6 shows the comparison results between the observed and simulated sediment values from 2013 to 2019. It can be seen from Table 6 that the relative errors between the simulated and actual values of sediment during the calibration period from 2013 to 2015 are –35%, 35% and –22%, respectively, and the total relative error of three years is –29%. Combined with the judgment standard of HSPF model in Table 4, it can be seen that the simulation result is effective. In addition to the first time, it can be seen from Table 6 that during the verification period from

Table 5
Comparison results of annual runoff observation value and simulation value from 2013 to 2019

Simulation category	Particular year	Analog value (thousand m^3)	Observations (thousand m^3)	Relative error (%)
Calibration period	2013	18,895.33671	24,221.29366	–21.9
	2014	9,667.138055	9,350.193096	3.3
	2015	20,220.74237	23,590.94064	–14.2
	Total	48,783.21714	57,162.4274	–14.6
Validation period	2016	13,764.07	13,781.69	0
	2017	16,321.32	15,418.73	6
	2018	16,454.91	21,373.87	–23
	2019	27,566.50	32,202.88	–14
	Total	74,106.60	82,777.18	–10

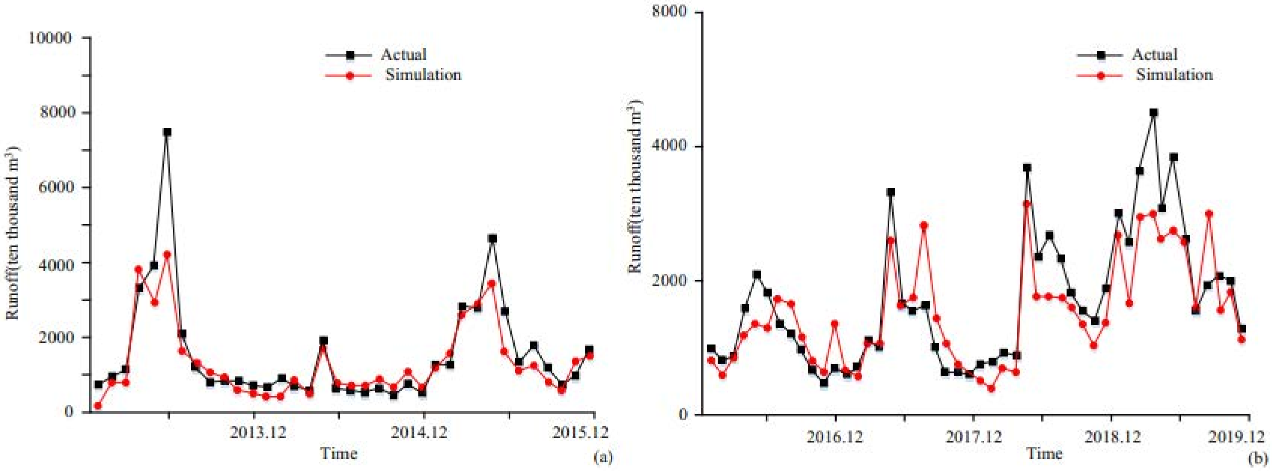

Fig. 4. Comparison results of runoff observation value and simulation value from 2013 to 2019.

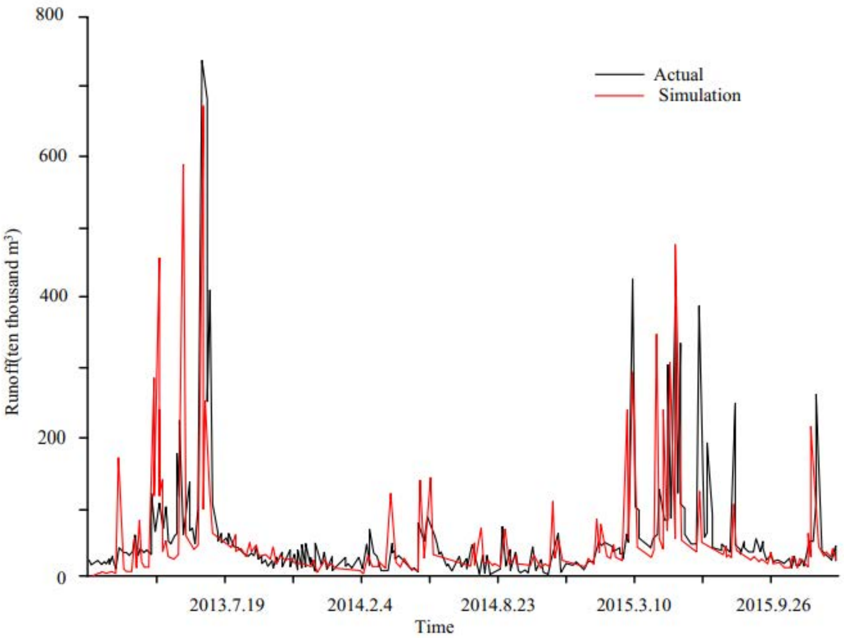

Fig. 5. Comparison results of daily runoff observation value and simulation value from 2013 to 2019.

2016 to 2019, the relative errors between the simulated and actual sediment values are 57%, 15%, –18% and –11% respectively, and the total relative error of four years is –5%. Combined with the judgment criteria of HSPF model in Table 4, it can be seen that the simulation results are very effective. Therefore, the HSPF model proposed in this study can accurately and effectively simulate and judge the sediment situation in the water area.

4.3. Water quality simulation results based on HSPF model

After the completion of hydrological simulation and sediment simulation, water quality can be simulated and verified on the basis of it. Biochemical oxygen demand BOD, do, orthophosphate PO_4–P, nitrate nitrogen NO_3–N and bacteria are the main objects that HSPF model can simulate. In order to analyze the water quality in the water area, TP and TN were selected as the research focus. For the simulation of TP, because the organic phosphorus mainly exists in the organism, the main simulation object of this study is the simulation of adsorption of inorganic phosphorus. For TN simulation, because HSPF model can not directly simulate it, so the total amount of nitrite nitrogen, nitrate nitrogen and ammonia nitrogen will be calculated to get the output of TN.

Fig. 6 shows the comparison results between the observed and simulated values of TP monthly average concentration values from 2013 to 2019, where (a) is the

Table 6
Comparison results of observed and simulated sediment values from 2013 to 2019

Simulation category	Particular year	Analog value (t)	Observations (t)	Relative error (%)
Calibration period	2013	64,166.66	41,112.17	–35
	2014	1,924.43	2,638.87	35
	2015	32,097.36	24,701.01	–22
	Total	98,188.45	68,452.05	–29
Validation period	2016	6,498.57	10,349.87	57
	2017	15,492.88	17,694.53	15
	2018	36,599.97	29,703.21	–18
	2019	40,857.74	26,799.87	–11
	Total	99,449.16	84,547.48	–5

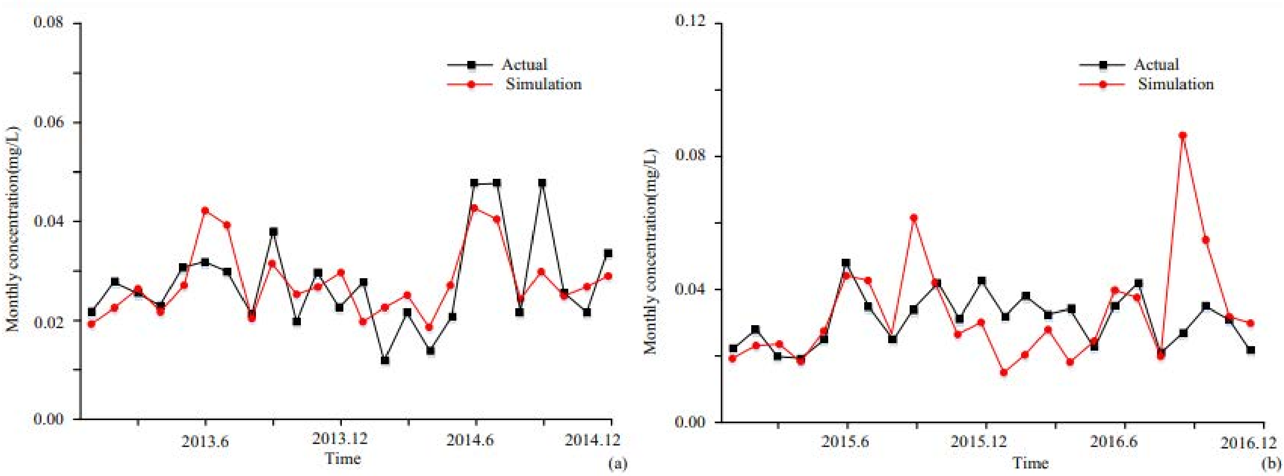

Fig. 6. Comparison results of monthly mean TP concentration values observed and simulated from 2013 to 2019.

comparison results of monthly average TP concentration values during the calibration period from 2013 to 2015, and (b) is the comparison results between the observed and simulated TP monthly average concentrations during the verification period from 2016 to 2019. It can be seen from Fig. 6 that 80% of the total months are occupied by the months with the monthly mean deviation of TP < 30% during the calibration period. Combined with Table 4, it can be seen that the simulation results are good. It can also be seen that during the validation period, 45% of the total months accounted for the months with the monthly mean deviation of TP < 30%. Combined with Table 4, the simulation effect is good.

Fig. 7 shows the comparison results between the observed and simulated values of TN monthly average concentration values from 2013 to 2019, where (a) is the comparison results of monthly average TN concentration values and simulated values during the calibration period from 2013 to 2015, and (b) is the comparison results between the observed and simulated values of monthly average TN concentrations during the verification period from 2016 to 2019. It can be seen from Fig. 7 that the monthly average concentration deviation of TN during the calibration period is less than 40%, and the months with average deviation less than 30% account for 96%. Combined with Table 4, it can be seen that the simulation results are good. During the validation period, the monthly average concentration of TN in each month was less than 40%, in which the monthly average deviation was less than 30%, accounting for 92%. According to Table 4, the simulation effect is good. It can be seen that the method proposed in this study can accurately simulate and judge the water quality.

5. Conclusion

In recent years, the rapid development of water conservancy projects has brought great impact on environmental pollution. In order to study the impact of water conservancy projects on the environment, this study proposes to study it on the basis of HSPF model. Combined with meteorological factors, land use types and terrain factors, the HSPF model database and HSPF model were constructed, and the effects of using HSPF model to simulate hydrology, water quality and sediment were determined. The results show that the HSPF model has good simulation effect on hydrology, water quality and sediment, which indicates that the method proposed in this study can be used in water area simulation, and the simulation effect is very good. However, there are

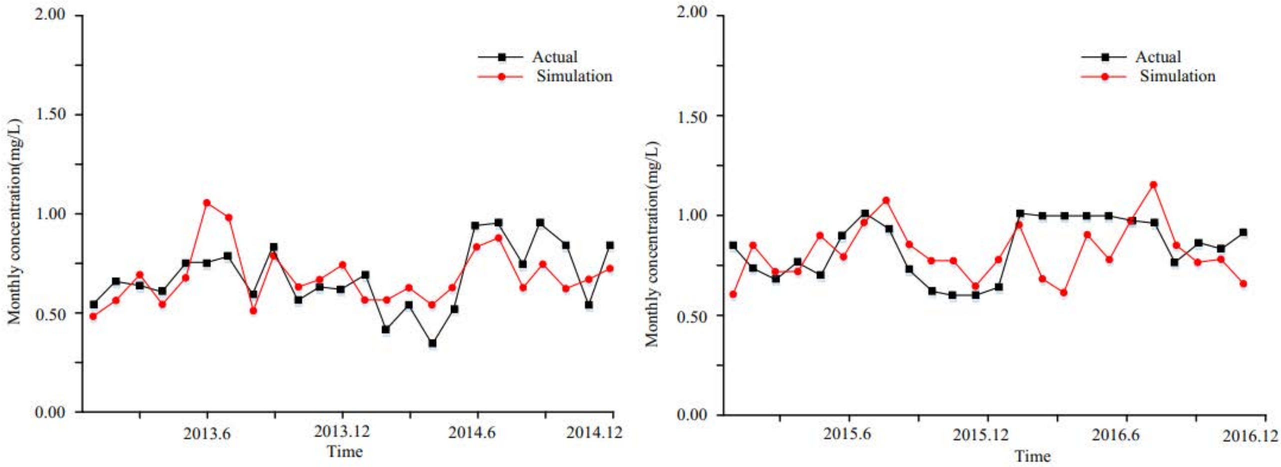

Fig. 7. Comparison results of monthly average TN concentration value observation value and simulation value from 2013 to 2019.

still some problems in this study. For the detection of water quality, nitrogen and phosphorus are mainly analyzed, and the rest of the elements are not analyzed. It is hoped that this study can be improved in the future.

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