water MDPI

Supplementary Materials

Simulation and Analysis of Water Quality Improvement Measures for Plain River Networks Based on Infoworks ICM Model: A Case Study of Baoying County, China

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Methods

S1. The construction of water quality model

S1.1 Type of the surface source pollution

The formulae for calculating the processes related to surface source pollution is as follows:

S1.1.1 Accumulation of pollutants on the surface

Equation for calculating sediment mass at the end of the surface contaminant accumulation period:

$$M_0 = M_d e^{-K_1 N_J} + \frac{P_s}{K_1}(1 - e^{-K_1 N_J}) \quad \text{(S1)}$$

Where M_0 is the mass of sediment at the end of the accumulation period or at the end of each step (kg/ha); M_d is the initial mass of sediment (Kg/ha); K_1 is the decay factor (./day); N_J is the duration of the non-rainy day, or the length of the calculation step (days); P_s is the accumulation factor (kg/ha.day).

For the calculation of the initial accumulation, this value was taken from the catchment sediment data defined in the Rainfall Event Editor. If this value was not set, InfoWorks calculated it as 0; for each calculation step, this value was the sediment mass at the end of the previous calculation step. Typical cumulative factor values for each land use were shown in Table S3.

S1.1.2 Surface pollutant washout processes

(i) Sediment erosion

The mass of eroded sediment from the surface is a function of rainfall intensity and total sediment mass at the surface.

$$\frac{dM_e}{dt} = K_a M(t) - f(t) \quad \text{(S2)}$$

Where M(t) is the mass of pollutants deposited on the surface (kg/ha); Ka is the erosion/dissolution factor (1/s) related to the rainfall intensity (1/s).

$$K_a(t) = C1_i(t)^{C2} - C3_i(t) \quad \text{(S3)}$$

Where i(t) is effective rainfall; C1、C2、C3 are factors.

(ii) Sediment scouring

Scour modelling is based on the Desbordes model (single linear reservoir confluence model)

$$Me(t) = Kf(t) \quad (S4)$$

Where Me(t) is the mass of dissolved or suspended pollutants; f(t) is the flow rate of pollutants per unit area (kg/(ha.s)); K is the linear reservoir coefficient (s), and the software uses the K value in the Desbordes model.

(iii) Attached pollutants

The mass of each pollutant attached to the sediment and flushed into the pipe network is calculated using the efficiency factor. The efficiency factor depends on the rainfall intensity. These efficiency factors (K_{pn}) relate the mass of surface sediment to the mass of surface pollutants and are calculated using the efficiency factor formula. The specific formula is shown in (5).

$$K_{pn} = C1(IMKP - C2)^{C3} + C4 \quad (S5)$$

Where IMKP is the maximum rainfall intensity within 5 minutes (mm/hr); C1, C2, C3, C4 are coefficients.

It was obvious from the above formula that the greater the rainfall intensity, the greater the proportion of pollutants attached to the sediment. ICM assumed that the effectiveness factor of a rainfall sub-event is constant. The coefficients in the effectiveness factor formula were edited in the surface pollutant editor and depend on the land use type; and all effectiveness factors are constant in a simulation. The ICM used equation (6) to calculate the mass of pollutants attached to the sediment.

$$fn(t) = K_{pn}(i)f_m(t) \quad (S6)$$

Where $f_n(t)$ is the pollutant flow rate per unit area (kg/(ha.s)); K_{pn} is the efficiency factor; $f_m(t)$ is the total suspended solids (TSS) flow rate (kg/(ha.s)).

S1.2 Type of the point source pollution

Point source pollution was achieved by coupling the inflow event with the pollutant process line event. The corresponding domestic sewage flow and pollutant concentration in the rivers near villages and towns were set to represent the direct discharge of sewage. According to the special planning instructions for village domestic sewage treatment in Baoying County, the direct discharge of rural domestic sewage in the five major rivers in the Yundong area was shown in Table S4. The key parameters of point source pollution were shown in Table S5.

S2. Model boundary

The model is constructed in the above way, and combined with a series of boundary data, it can be calculated and simulated. Due to the lack of historical measured rainfall data, this study analyzes the effect of water quality improvement measures by changing the water quality of the river under the condition of short-duration design rainstorm. Since water quality research usually targets non-extreme rainfall, this study selected the local 2-hour short-duration design rainstorm with a return period of 0.25 years. The specific formula is shown in (7).

$$i = \frac{30.651387(1 + 0.683933lgT)}{(t + 15.274126)^{0.938054}} \quad (S7)$$

The 2-hour rainfall process line simulated by Infoworks ICM was shown in Figure S1. Since the study area was in the plains river network area and the river was connected to other water systems both upstream and downstream, certain boundary conditions need to be set for it. The direction of water flow in this area was that the Grand Canal flows from north to south, while other water systems flow from west to east, and finally concentrate in the northeast corner to flow out of the study area. The largest external water source in this model was the north end of the Grand Canal inflow, due to the lack of measured information, it was assumed here that the flow velocity in the Grand Canal was 0.1

m/s, the width of the river was 70 m, the depth of the water was 10 m, and a channel section of 700 m^2 was obtained by the calculation, so the boundary inflow was 70 m^3/s.

S3. Calibrated parameter model

The key parameters of the InfoWorks ICM model were shown in Table S6. In the water quality parameters, the point source pollutant data were made into model input items using a combination of research and specification, and the point source pollutant parameters were shown in Table S7 and the pollutant flows from point sources after calibration are shown in Table S8.

The rate determination results showed that the surface source pollution is the biggest factor influencing the water quality condition of the river in this study area, so the surface source parameters were corrected according to the measured river pollutant concentration, and the correction results were shown in Table S9.

Table S1. *China Environmental Quality Standards for Surface Water* (*GB3838-2002*) mg/L

Index \ Class	I	II	III	IV	V
DO ≥	7.5	6	5	3	2
NH_3-N ≤	0.15	0.5	1	1.5	2
TP ≤	0.02	0.1	0.2	0.3	0.4
Permanganate index ≤	2	4	6	10	15
BOD ≤	3	3	4	6	10
COD ≤	15	15	20	30	40

Table S2. Pollutant concentration measurements at Huangtugou section

	COD (mg/L)	NH_3-N (mg/L)	TP (mg/L)	Nitrate nitrogen (mg/L)
Before the rain	12	0.177	0.13	2.64
5 min	12	0.2	0.13	1.56
10 min	17	0.219	0.13	1.49
15 min	15	0.256	0.14	1.48
30 min	22	0.234	0.15	1.54
1 h	18	0.16	0.12	1.68
2 h	11	0.18	0.1	1.75
4 h	12	0.19	0.11	1.33
6 h	13	0.2	0.13	1.18

Table S3. Pollutant concentration measurements at Huangtugou section

Land usage	Surface accumulation factor (kg/ha/day)	Source
Residential areas (dense)	25	French Calibration

Residential areas	6	French Calibration
Downtown	25	American Calibration
Industrial zone	35	American Calibration
Mixed Suburbs	6	French Calibration

Table S4. Statistics of domestic sewage direct discharge points and drainage flow

River	Town	Village	Total amount of domestic sewage discharged from villages (t/d)
Daxi river	Jinghe	Huangpu	205.63
	Economic development Zone	Xiaoduo	196.48
	Caodian	Cuibao	189.5
	Sheyang	Weidang	97.04
	Anyi	Dongsheng	103.8
		Guozhuang	188.74

		Guoqiang	215.36
		Junshi	151.94
Baoshe river	Wang zhigang	Heping	124.61
		Dashu	180.42
		Pailou	187.36
		Jifeng	156.86
	Sheyang	Liushu	104.64
		Gaoxia	193.98
Datong river	Sishui	Xinmin	209.98
	Xiaji	Guoqiao	200.9
		Shuangtang	218.24
		Jiangbao	159.04
Dasanwang river	Sheyang	Qiaonan	318.07
		Shenan	279.87
		Youfang	217.34
	Guangyang	Hewan	181.53
		Yanqiao	175.68
	Liubao	Zhengdu	280.26
		Liubao	176.56

Table S5. Key parameters of point source pollution

	COD (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)
Total mass of wastewater (g/m·d)	22	2.7	3.5	0.13
Quantity of waste water (L/m·d)			80	
Concentration (mg/L)	275	33.75	43.75	1.625

Table S6. The key parameters of InfoWorks ICM model

Hydraulic parameters	Model setup values
Pipe roughness	0.013
Pipeline local water loss coefficient	1-8
River channel roughness	0.02

Table S7. Concentration of pollutants at point sources after rate-setting

Pollutant indicators	COD	NH_3-N	TN	TP
Concentration (mg/L)	275	33.75	43.75	1.625

Table S8. Pollutant flows from point sources after calibration

River	Town	Village	Total amount of domestic sewage discharged from villages (t/d)
Daxi river	Jinghe	Huangpu	205.63
	Economic development Zone	Xiaoduo	196.48
	Caodian	Cuibao	189.5
	Sheyang	Weidang	97.04
Baoshe river	Anyi	Dongsheng	103.8
	Wang zhigang	Guozhuang	188.74
		Guoqiang	215.36
		Junshi	151.94
		Heping	124.61
		Dashu	180.42
		Pailou	187.36
		Jifeng	156.86
	Sheyang	Liushu	104.64

		Gaoxia	193.98
Datong river	Sishui	Xinmin	209.98
	Xiaji	Guoqiao	200.9
		Shuangtang	218.24
		Jiangbao	159.04
Dasanwang river	Sheyang	Qiaonan	318.07
		Shenan	279.87
		Youfang	217.34
	Guangyang	Hewan	181.53
		Yanqiao	175.68
	Liubao	Zhengdu	280.26

Table S9. Pollutant flows from point sources after calibration

Model parameter	Type of operation	Parameters after calibration
Maximum pollution load from urban surface sources	Revised	25 (kg/ha.day)
Maximum pollution load from rural surface sources	Revised	6 (kg/ha.day)
COD flushing coefficient for surface pollution C1	Default	1.800
COD flushing factor for surface pollution C2	Default	0
COD flushing factor for surface pollution C3	Default	-0.419
COD flushing factor for surface pollution C4	Default	0
NH_3-N flushing factor for surface pollution C1	Revised	0.025
NH_3-N flushing factor for surface pollution C2	Default	0.800
NH_3-N flushing factor for surface pollution C3	Default	-0.600
NH_3-N flushing factor for surface pollution C4	Default	0.001
TP pollution indicator	New	TPH
TP flushing factor for surface pollution C1	Revised	0.003
TP flushing factor for surface pollution C2	Revised	0.1
TP flushing factor for surface pollution C3	Revised	-0.300
TP flushing factor for surface pollution C4	Revised	0

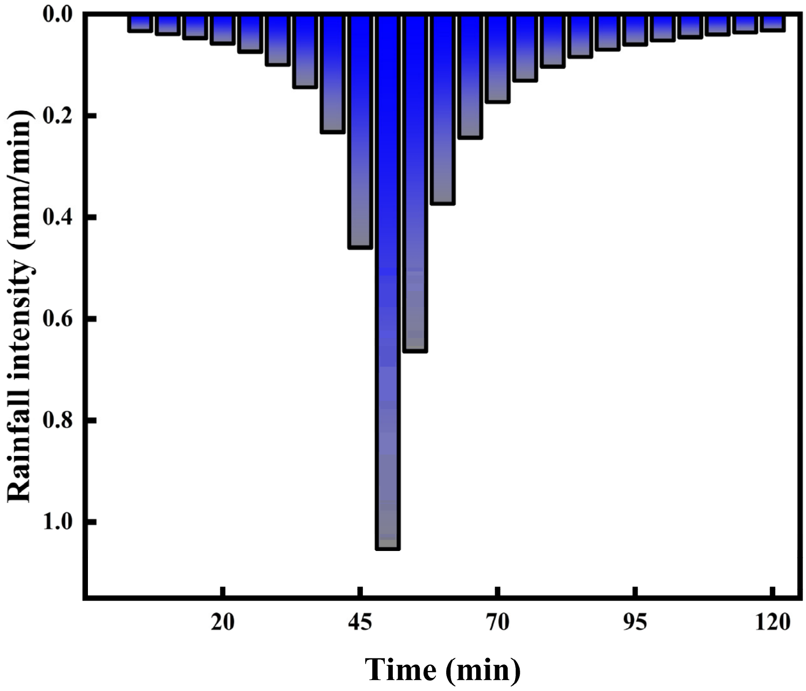

Figure S1. Simulation of 2-hour rainfall process