Supplementary information

High-efficiency control strategies for urban composite non-point source pollution: optimization of source and process control facilities

Bingquan Lin, Chen Zhao, Yuxuan Liu, Yahong Gao, Xinqi An, Bin Qiu, Fei Qi, Dezhi Sun (✉)

Beijing Key Lab for Source Control Technology of Water Pollution, Engineering Research Center for Water Pollution Source Control & Eco-remediation, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, China

Acknowledgements

This research was financially supported by the National Key Research and Development Program of China (No. 2021YFC3201504).

✉ Corresponding author

E-mail: sdzlab@126.com

Contents

Text S1 Model Set-up

(1) Import of pipe network data

To meet the requirements of modeling, it is often necessary to simplify complex pipe network systems. This simplification typically involves disregarding some branch pipes and their auxiliary inspection wells to focus on the primary pipelines, which significantly influence the simulation results and are functionally critical. Simplification also enhances modeling efficiency. However, it is essential to ensure that the retained pipe and their adjacent inspection wells maintain accurate connections, preserving the spatial topology and hydraulic characteristics of the actual pipe network.

Finally, the YC-C study area was generalized to 32 drainage pipes, 31 nodes, and 3 outfalls (Fig. S1); the JT-C study area was generalized to 30 drainage pipes, 32 nodes, and 8 outfalls (including 3 overflows, Fig. S1); and the JT-S study area was generalized to 61 drainage pipes, 70 nodes, and 9 outfalls (Fig. S1).

(2) Sub-catchment division

The Tyson polygon method, combined with a manual division strategy, was used to divide sub-catchment areas. First, the traditional Tyson polygon method was applied using the ArcToolbox spatial analysis tools in ArcGIS. This method preliminarily divides the sub-catchments based on the distribution of nodes within the study area. Next, the preliminary results are refined through manual adjustments, incorporating specific local conditions such as surface slope, building roof slopes, road layouts, and the arrangement of rainwater pipe networks. These adjustments ensure the scientific accuracy and rationality of the division.

Finally, the YC-C study area was divided into 27 sub-catchment areas, the JT-C study area was divided into 29 sub-catchment areas, and the JT-S study area was divided into 63 sub-catchment areas. Detailed information for each sub-catchment is showed in Tables S2-S4.

(3) Parameter initialization and calibration

The runoff coefficient method was used to determine the hydrological and hydraulic parameters of the SWMM model. The comprehensive runoff coefficients for each study area were calculated as weighted averages of the empirical runoff coefficients for different land use surfaces. Monitored rainfall data were input into the SWMM model to simulate surface runoff for each rainfall event, allowing for the calculation of simulated runoff coefficients. Parameters were adjusted iteratively using the trial-and-error method to minimize discrepancies between the simulated and actual runoff coefficients. The results, shown in Table S5, indicate that the error for each rainfall event is within 15%, demonstrating the success of the parameter calibration. These calibrated parameters ensure that the SWMM model accurately represents the hydrological conditions of the study area, as summarized in Table S6.

The water quality parameters were calibrated based on actual monitored pollutant concentrations at the pipe network outfall. The saturation cumulative function and the exponential wash off function were employed as YC-C pollutant model. The simulation scenario used a typical rainfall event at July 19, 2023, characterized by moderate rainfall and a uniform distribution. Parameter calibration was performed iteratively using the trial-and-error method to make the model simulation results close to the actual monitoring data. The results, presented in Fig. S2, show that the Nash-Sutcliffe coefficients for pollutant indices in the SWMM model of YC-C aera are all above 0.7 (0.703~0.881), indicating that the model is accuracy and reliability after calibration. The water quality parameters are showed in Table S7.

The pollution models of JT-C aera and JT-S aera all used exponential functions to quantify the buildup and wash off of pollutants. The simulation scenario used a typical rainfall event at March 17, 2023 with a rainfall of 12.0mm as the simulation scenario. Water quality parameters were calibrated using measured pollutant concentrations from pipe network outfalls. The parameters were iteratively adjusted through the trial-and-error method to make the simulated pollutant concentrations close to the measured values. The calibration results, shown in Fig. S3 and Fig. S4, indicate that the Nash-Sutcliffe coefficients for pollutant indexes in the SWMM models of JT-C aera and JT-S aera are above 0.7, ranging from 0.807 to 0.875 and 0.780 to 0.922, respectively. These results confirm the accuracy and reliability of the constructed SWMM models. The final calibrated parameters are presented in Tables S8 and S9.

Text S2 The calculation process of Group decision-making

After using AHP to calculate the individual weights of each expert, the HCA method is used to integrate the individual weights of the experts into the group-decision making weights through weighted average, and the similarity of the individual weights of each expert is used as the standard for HCA. The formula for calculating similarity d_{xy} is:

$$dxy=\frac{\sum_{i=1}^{n} XiYi}{\sqrt{\sum_{i=1}^{n} Xi^2 \sum_{i=1}^{n} Yi^2}}$$

Where, the closer the similarity d_{xy} is to 1, the greater the similarity of individual weights between experts; X and Y are the individual weights of two experts, X= $(X_1, X_2, ..., X_n)$ and Y= $(Y_1, Y_2, ..., Y_n)$, where n represents n indicators.

The calculation formula for the proportion of each expert in group decision-making is:

$$\lambda_k=\frac{\varphi_k}{\sum_{i=1}^{m} \varphi_i}$$

Where, λ_k is the proportion of the k-th expert in group decision-making; k is the number of experts in the cluster where the k-th expert belongs; m is the number of experts participating in the scoring process.

Text S3 Detailed process of ideal point method for identifying the optimal solution

First, since the original data for each objective function varies in magnitude, normalization is required. The formula for normalization is as follows:

$$\mathrm{M_{value}}=\frac{\mathrm{M_{raw}}\text{-}\mathrm{M_{min}}}{\mathrm{M_{max}}\text{-}\mathrm{M_{min}}}$$

Where, M_{value} is normalized value; M_{raw} is actual value; M_{min} is ideal objective value; M_{max} is anti-ideal objective value.

Next, construct the function $\mathrm{f_i(x)}$ for each objective, where the optimal solution for each function is denoted as f_i^*. These optimal points collectively form the set $f^* = (f_1^*, \cdots, f_p^*)^T$, which represents the ideal point of multi-objective optimization. However, obtaining this ideal point directly in multi-objective optimization is often challenging. Therefore, a function is constructed to identify the solution f_i that is closest to the ideal point f_i^*, serving f_i as an approximation of f_i^*. The constructed function is as follows:

$$Z(X) = \sqrt{\sum_{i=1}^{p} \mu_i [f_i(x) - f_i^*]^2}$$

Solve the minimum value of the above equation to get the optimal solution x^*, which represents the optimal solution of the multi-objective function. μ_i is the weight of sub-objectives to the total objectives.

Text S4 Scoring criteria

Among the indexes of Fig. 2, C1–C9 are quantitative indexes, while C10 and C11 are qualitative indexes. Specifically, C1–C3 represented the economic inputs during the scheme design, construction, and operation phases, respectively. The economic costs of each scheme were determined through market research (Table S17). C4–C9 represented the pollution reduction benefits of each scheme, which were derived from the SWMM model simulation results in Section 3.1.1 (Fig. 1). Scores for C1–C9 were assigned based on the quantitative data following the established criteria (Table S18). C10 and C11 represent the technological maturity and operational stability of the schemes, respectively. Based on current technology applications and operational experiences, the technological maturity scores for permeable paving, green roofs, rain gardens, and sunken green spaces were assigned as 7, 6, 6, and 6, respectively. Technology stability scores were 6, 5, 5, and 5, respectively. These scores were then combined with the deployment area of each facility to calculate the final scores of C10 and C11 for each scheme (Table S18).

Text S5 The simulation results of CSO volume and pollution load under different n_0 in JT-C

CSO volume reduction (Fig. 5(a)): With the increase in n0, both the interception volume and interception rate exhibited varying degrees of growth. When n_0 increased from 2 to 5, the corresponding interception rates were 18.6%, 28.0%, 33.2%, 36.2%, 39.0%, 41.6%, and 42.9%, respectively. Notably, as n_0 increases from 2 to 3, the interception volume and rate increased significantly, with the interception rate rising by approximately 36.5%. However, when n_0 increased from 3 to 5, the rising rate just 8.3%. This indicates that when $n_0>3$, the improvement in interception rate with the increase of n_0 will decrease, suggesting that the relationship between the interception rate and n_0 is nonlinear.

CSO pollution load reduction (Figs. 5(b)-5(f)): The most significant increase in the interception rate for pollutant loads occurred when n0 was raised from 2 to 3, the increases rate of interception rate of SS, COD, NH_3-N, TN, and TP were 12.5%, 13.1%, 7.2%, 8.1%, and 9.6%, respectively. In contrast, when n0 was further increased from 3 to 5, the corresponding increase rate were only 4.5%, 3.9%, 3.3%, 2.9%, and 3.0%. Similar to CSO volume reduction, the pollutant reduction rate and n_0 do not exhibit a simple linear relationship.

Text S6 Calculation of construction costs for different interception multiples

It leads to a rise in the original intercepting pipe flow, necessitating recalculations of the intercepting pipe sewage conveyance capacity and possible expansion. Additionally, the increase of n_0 requires upgrades to the sewage elevation pumping stations and wastewater treatment plants (WWTP). Therefore, the total cost function G(x) encompasses costs related to the renovations of interception pipe, pumping stations, and WWTP.

(1) The cost of intercepting pipe under different interception ratio

According to the fifth volume of the *Jiangsu Province Municipal Engineering Valuation Table* (2021 edition), *Municipal Pipe Network Engineering*, ductile iron pipes are used for the pipe network. The interception pipe is laid along the JT-C aera section of the DanjinliCaohe River. For various interception ratio, it was assumed that the burial depth of each pipe section remains unchanged and only the diameter of the interception pipe was adjusted. Therefore, only the construction costs associated with changes in diameter was considered. The estimated construction costs for ductile iron pipes with different diameters are shown in Table S22. Then it can be inferred that the costs of interception pipes under different interception ratio. (Table S23)

（2）The cost of wastewater pumping station under different interception ratio

Combined drainage systems are usually equipped with a wastewater pumping station, which allows the intercepted stormwater and sewage flow to reach the wastewater treatment plant naturally via gravity. Variations in interception ratio will affect the volume of water requiring lifting by the pumping station, and then affect the scale of the wastewater lifting pump station. The *Water Supply and Drainage Design Manual* (Book 10), *Technical Economics*, provides comprehensive cost for wastewater pumping stations (Table S24). Based on Table S24, a linear relationship was derived between the design flow and the comprehensive cost of wastewater pumping stations (Fig. S7). Whereby the comprehensive cost of the wastewater pumping station under simulated flow can be calculated using this relationship, with the linear fitting formula expressed as follows:

$$y=22237-15.95x+0.004x^2$$

Where, y——The comprehensive cost of the wastewater pumping station, yuan.

x——design flow of wastewater, L/s.

From this, it can be inferred that the total construction cost of the wastewater pump station under different interception ratios (Table S25).

（3）The cost of wastewater treatment plant under different interception ratio

Different interception ratio will result in differences in the volume of water volume entering the wastewater treatment plant. *The Water Supply and Drainage Design Manual* (Volume 10) *Technical Economics* provides comprehensive cost for wastewater treatment plants (Table S26). According to Table S26, the relationship between the design flow and the comprehensive cost of the wastewater treatment plant is derived from a linear fit (Fig. S8), whereby the cost of the WWTP at the simulated flow can be obtained, and the linear fit equation is as follows:

$$y=1350.33-54.98x+1.33x^2$$

Where, y——The comprehensive cost of the wastewater treatment plant, yuan.

x——design flow of wastewater treatment plant, m^3/d.

From this, it can be inferred that the total construction cost of the wastewater treatment plant under different interception ratios (Table S27).

YC-C **JT-C** **JT-S**

Fig. S1. SWMM model generalization

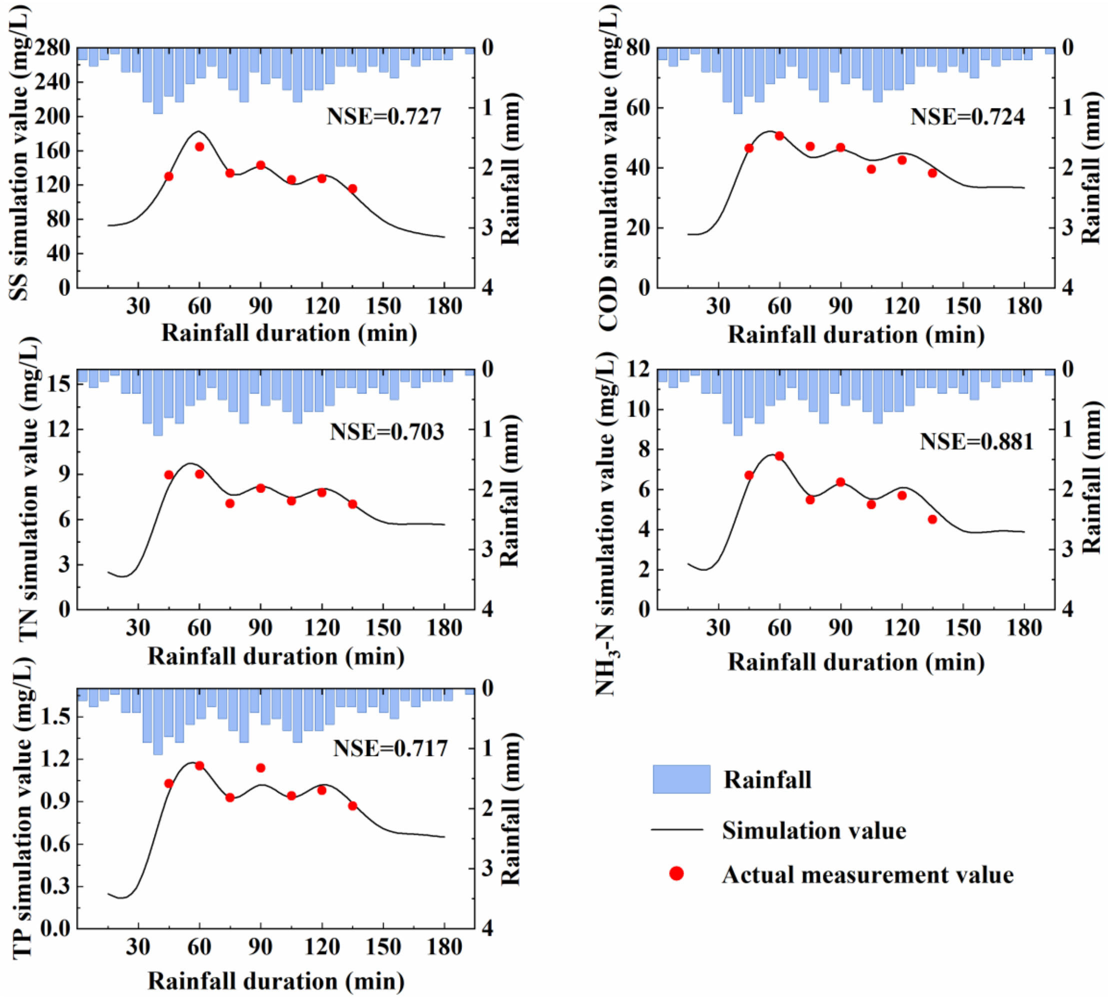

Fig. S2. Actual values and model values of outfall pollutant sin YC-C study area

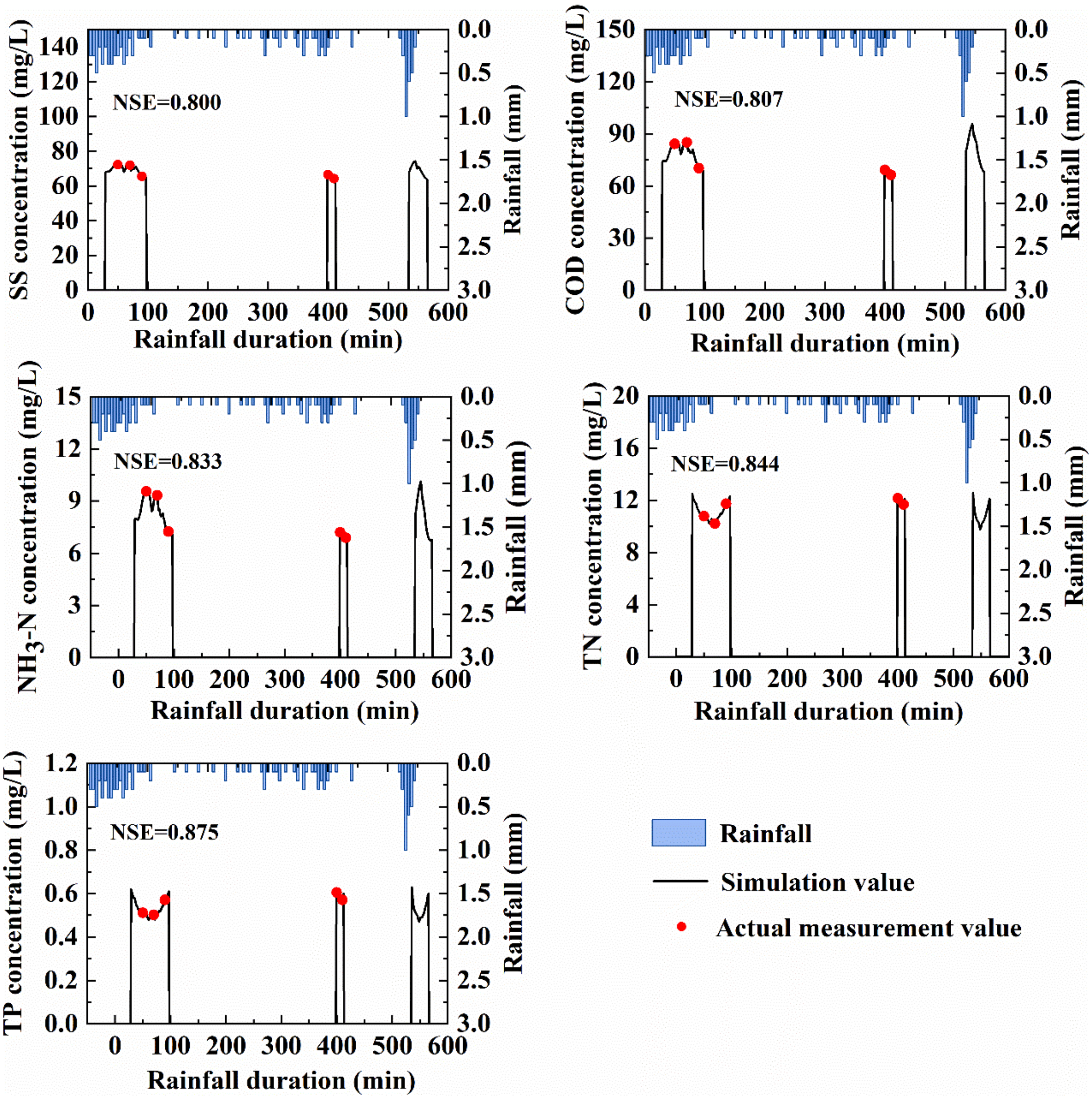

Fig. S3. Actual values and model values of outfall pollutant sin JT-C study area

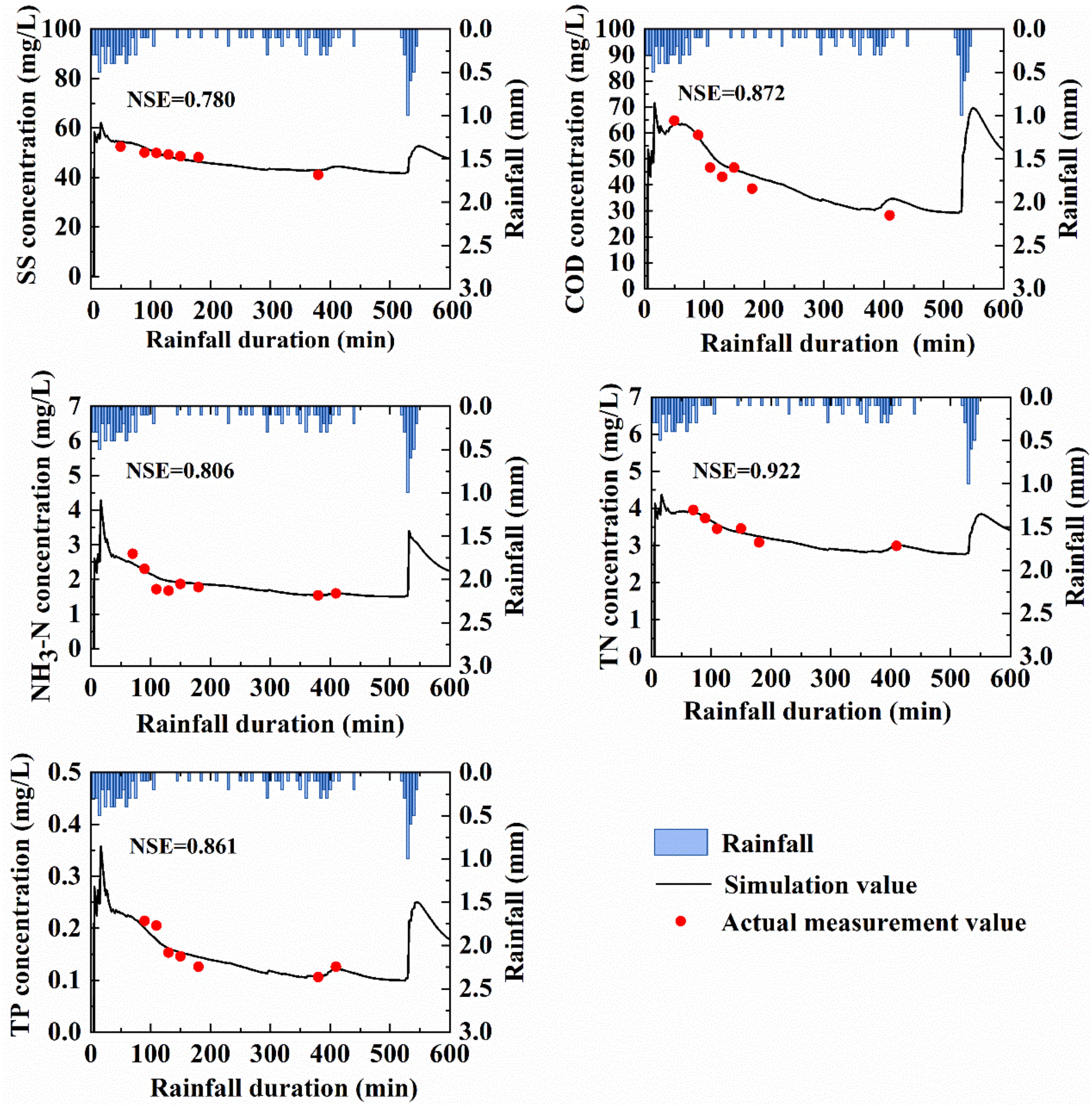

Fig. S4. Actual values and model values of outfall pollutant sin JT-S study area

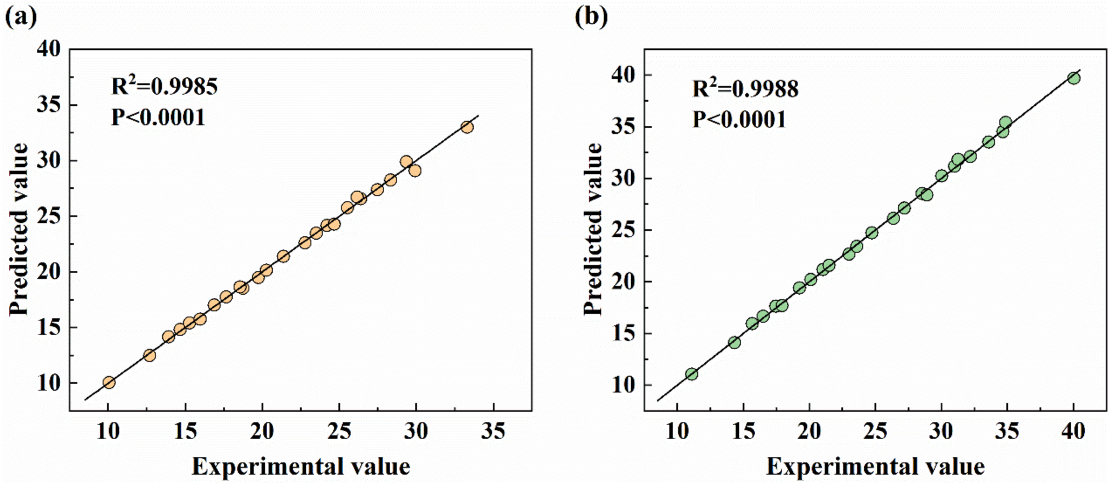

Fig. S5. Comparison between the predicted values of the fitting equation and the simulated values of the SWMM model. (a) runoff reduction rate, (b) SS load reduction rate

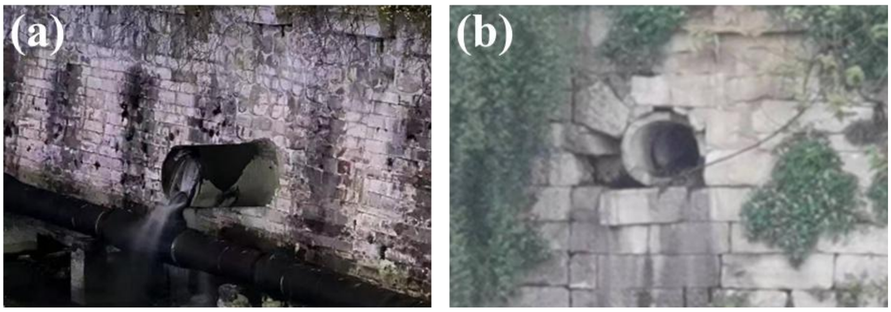

Fig. S6. Overflow outfall-1 and overflow outfall-2 in JT-C. (a) Outfall-a, (b) Outfall-b

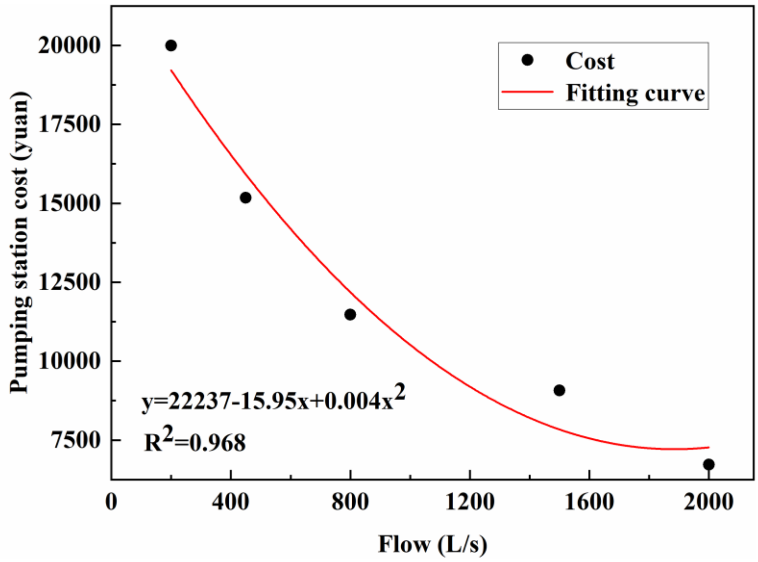

Fig. S7. Fitting curve of comprehensive cost for wastewater pumping station

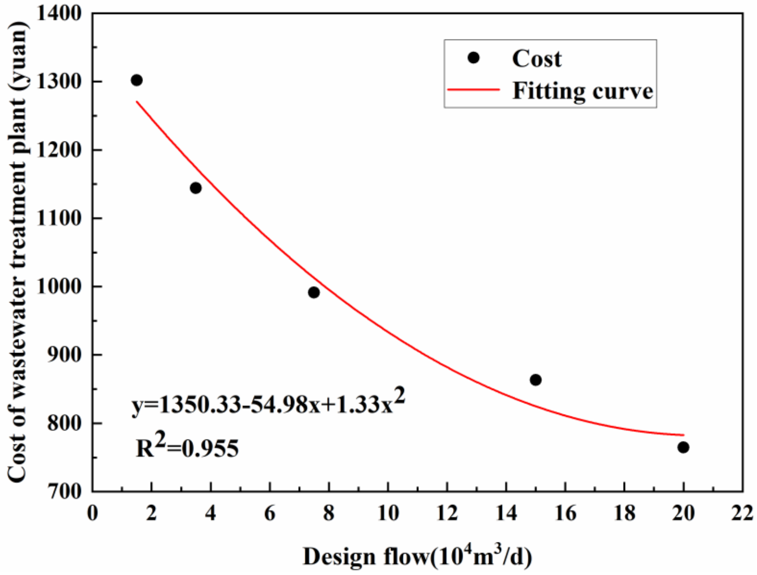

Fig. S8. Fitting curve of comprehensive cost for wastewater treatment plant

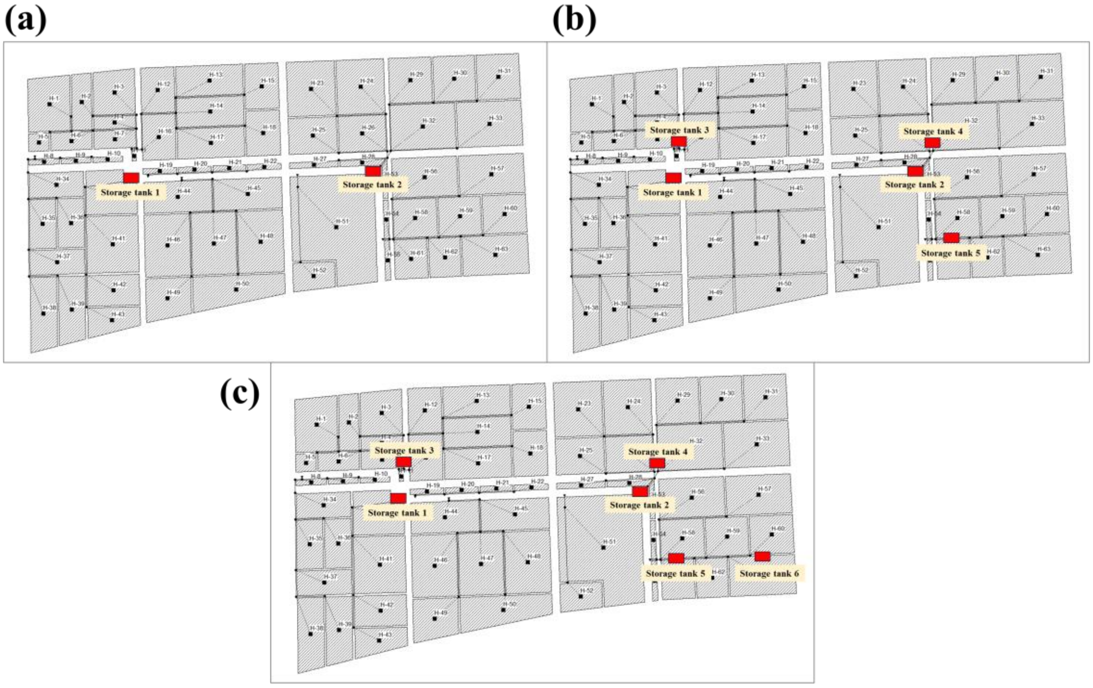

Fig. S9. Layout scheme for initial rainwater storage tank. (a) scheme 1, (b) scheme 2, (c) scheme 3

Table S1 Location of research area and sampling points

Study aera	Range coordinates	Sampling point coordinates
JT-S	（119°34′60″, 31°45′80″），（119°34′14″, 31°45′70″）， （119°34′19″, 31°45′17″），（119°34′26″, 31°45′18″）， （119°34′37″, 31°45′11″），（119°34′38″, 31°44′57″）， （119°34′38″, 31°44′50″），（119°34′42″, 31°44′35″）， （119°34′25″, 31°44′25″），（119°34′22″, 31°44′31″）， （119°33′56″, 31°44′45″）	（119°34′10″, 31°44′42″）， （119°34′19″, 31°44′51″）， （119°34′22″, 31°44′55″）
JT-C	（119°35′30″, 31°43′49″），（119°36′27″, 31°43′52″）， （119°36′29″, 31°43′29″），（119°36°00″, 31°43′28″）， （119°35′30″, 31°43′21″）	（119°36′11″, 31°43′34″）， （119°36′11″, 31°43′40″）， （119°35′31″, 31°43′42″）
YC-C	（105°52′33, 29°21′51″），（105°63′10″, 29°21′51″）， （105°53′10″, 29°21′41″），（105°53′14″, 29°21′35″）， （105°53′15″, 29°21′22″），（105°53′21″, 29°21′22″）， （105°53′22″, 29°21′16″），（105°53′17″, 29°21′10″）， （105°53′14″, 29°21′12″），（105°53′10″, 29°21′90″）， （105°53′43″, 29°21′19″），（105°52′21″, 29°21′22″）， （105°52′25″, 29°21′41″），（105°52′33″, 29°21′43″）	（105°52′50″,29°21′19″）， （105°53′80″,29°21′21″）
YC-OB	（105°52′30″, 29°22′50″），（105°52′32″, 29°22′20″）， （105°53′15″, 29°22′60″），（105°54′30″, 29°21′55″）， （105°54′24″, 29°21′49″），（105°54′40″, 29°21′59″）， （105°54′56″, 29°21′43″），（105°54′47″, 29°21′39″）， （105°54′51″, 29°21′10″），（105°54′51″, 29°20′44″）， （105°55′10″, 29°20′42″），（105°54′57″, 29°20′38″）， （105°55′10″, 29°20′18″），（105°54′47″, 29°20′18″）， （105°55′60″, 29°19′44″），（105°53′53″, 29°20′50″）， （105°53′34″, 29°19′56″），（105°52′40″, 29°20′60″）， （105°51′48″, 29°20′18″），（105°51′49″, 29°21′46″）	The same with YC-C.

Table S2 Overview of catchment area in YC-C study area

Sub catchments	Area (ha)	Proportion of impermeable area (%)	Proportion of permeable area (%)	Sub catchments	Area (ha)	Proportion of impermeable area (%)	Proportion of permeable area (%)
1	4.69	27.1	73.0	15	7.16	92.7	7.3
2	3.21	100.0	0.0	16	7.83	91.5	8.5
3	10.22	58.0	42.0	17	6.09	99.0	1.0
4	4.73	71.3	28.7	18	1.91	99.4	0.6
5	4.36	91.1	8.9	19	5.03	94.8	5.2
6	3.55	87.7	12.3	20	5.48	98.7	1.3
7	4.29	90.4	9.6	21	2.16	75.3	24.7
8	2.27	77.4	22.6	22	2.82	83.5	16.5
9	4.36	76.8	23.2	23	2.04	94.9	5.1
10	6.56	95.8	4.2	24	1.00	98.4	1.6
11	1.85	94.9	5.1	25	1.51	95.3	4.7
12	2.25	93.7	6.3	26	2.12	92.4	7.6
13	1.01	84.7	15.3	27	5.49	100.0	0.0
14	10.84	87.4	12.6				

Table S3 Overview of catchment area in JT-C study area

Sub catchments	Area (ha)	Proportion of impermeable area (%)	Proportion of permeable area (%)	Sub catchments	Area (ha)	Proportion of impermeable area (%)	Proportion of permeable area (%)
1	6.69	20.9	79.1	16	2.19	79.4	20.6
2	1.64	69.9	30.1	17	7.00	77.0	23.0
3	3.62	76.9	23.1	18	4.04	77.9	22.1
4	2.71	66.1	33.9	19	6.85	73.4	26.6
5	4.13	70.3	29.7	20	2.38	77.5	22.5
6	2.65	74.7	25.3	21	5.39	72.8	27.2
7	3.70	55.2	44.8	22	1.89	77.5	22.5
8	9.81	60.0	40.0	23	1.08	80.7	19.3
9	1.62	75.0	25.0	24	1.53	76.0	24.0
10	0.44	74.2	25.8	25	2.77	81.5	18.5
1	3.84	74.2	25.8	26	2.88	77.5	22.5
12	1.06	79.2	20.8	27	2.99	78.2	21.80
13	0.20	82.8	17.2	28	6.12	37.6	62.40
14	6.02	76.0	24.0	29	4.34	72.5	27.50
15	1.49	75.9	24.1				

Table S4 Overview of catchment area in JT-S study area

Sub catchments	Area (ha)	Proportion of impermeable area (%)	Proportion of permeable area (%)
1	2.11	81.9	18.1
2	1.09	61.2	38.8
3	1.81	82.2	17.8
4	0.58	82.4	17.6
5	0.36	42.8	57.2
6	0.72	60.1	39.9
7	0.76	59.8	40.2
8	0.27	50.0	50.0
9	0.27	48.7	51.3
10	0.26	49.5	50.5
11	0.18	54.8	45.2
12	1.54	69.0	31.0
13	1.89	59.7	40.3
14	1.88	61.1	38.9
15	1.59	60.9	39.1
16	1.70	66.4	33.6
17	2.15	63.6	36.4
18	1.75	68.1	31.9
19	0.32	42.4	57.6
20	0.30	44.3	55.7
21	0.30	45.3	54.7
22	0.34	42.8	57.2
23	2.62	58.3	41.7
24	2.50	57.9	42.1
25	1.95	59.2	40.8
26	1.84	60.9	39.1
27	0.48	45.9	54.1
28	0.42	45.3	54.7
29	1.89	58.7	41.3
30	1.78	60.1	39.9
31	1.78	52.4	47.6
32	3.04	55.5	44.5
33	2.93	31.1	68.9
34	1.48	67.4	32.6
35	1.24	66.6	33.4
36	1.29	67.9	32.1
37	1.33	70.2	29.8
38	1.80	67.7	32.3
39	1.71	21.9	78.1
40	2.14	84.3	15.7
41	2.92	84.4	15.6
42	1.64	85.0	15.0
43	1.27	82.7	17.3
44	2.06	57.5	42.5
45	2.08	57.2	42.8
46	2.80	57.3	42.7
47	2.62	60.1	39.9
48	2.87	58.2	41.8
49	1.80	65.0	35.0
50	2.47	70.8	29.2
51	7.63	83.3	16.7
52	1.17	72.2	27.8
53	0.26	38.9	61.1
54	0.27	38.3	61.7
55	0.27	39.5	60.5
56	2.69	59.1	40.9
57	2.59	57.3	42.7
58	1.67	60.6	39.4
59	1.58	62.3	37.7
60	1.58	58.2	41.8
61	1.28	56.7	43.3
62	1.19	59.4	40.6
63	2.38	58.6	41.4

Table S5 Result of hydrological and hydraulic parameters Calibration using runoff coefficient

Aera	Rainfall date	rainfall (mm)	Simulated runoff coefficient	Actual runoff coefficient	Percentage Error (%)
YC-C	2023.4.11	4.7	0.6674	0.8075	14.35
	2023.7.24	5.3	0.6766		12.61
	2023.4.18	12.6	0.7802		3.38
	2023.7.18	17.3	0.7843		2.87
	2023.7.21	30.6	0.8252		2.19
JT-C	2023.5.7	1.8	0.6583	0.6717	1.98
	2023.4.3	2	0.6545		2.55
	2023.4.23	4.2	0.6702		0.21
	2023.6.17	12	0.6925		3.1
	2023.6.18	43.8	0.7686		14.43
JT-S	2023.5.7	1.8	0.6017	0.6328	4.92
	2023.4.3	2	0.6045		4.47
	2023.4.23	4.2	0.6240		1.38
	2023.6.17	12	0.6311		0.27
	2023.6.18	43.8	0.7161		13.16

Table S6 Hydrological and hydraulic parameters

Parameter	Conventional value range	Calibration value		
		YC-C	JT-C	JT-S
Impervious Area Roughness	0.005~0.05	0.011	0.009	0.008
Pervious Area Roughness	0.014~0.8	0.08	0.18	0.18
Pipe Manning roughness coefficient	0.011~0.017	0.016	0.014	0.014
Impervious Area Depression Storage(mm)	0~3.5	1.25	0.1	0.1
Pervious Area Depression Storage (mm)	2.54~7.62	4.5	5	5
percentage of Impervious Area with No Depression Storage（%）	5~85	32	40	40
Maximum infiltration rate (mm/h)	3.3~120	75	76.2	76.2
Minimum infiltration rate (mm/h)	0~10	3.5	3.8	3.8
Decay Constant (1/hours)	0~7	4	4	4
Drying Time (d)	1~7	3	3	3

Table S7 Pollutant buildup parameters and wash off parameters in YC-C area

Land uses	**Pollutant**	**Maximum buildup possible （kg/ha）**	**Half-saturation constant （d）**	**Wash off coefficient**	**Wash off exponent**
Square/ Residential roads	SS	175	7	0.006	1.85
	COD	95	6	0.007	1.3
	TN	8	5	0.005	1.85
	NH_3-N	6	5	0.004	1.85
	TP	3	8	0.003	1.65
Traffic road	SS	200	6.5	0.008	2
	COD	130	6.5	0.006	1.75
	TN	9	6	0.006	1.9
	NH_3-N	6	3.5	0.005	2.1
	TP	3.5	7	0.004	1.85
Roof	SS	165	7	0.0075	1.7
	COD	85	7.5	0.006	1.3
	TN	8	6	0.005	1.85
	NH_3-N	6	5	0.005	1.8
	TP	2	8	0.004	1.7
Green land	SS	105	5	0.007	1.65
	COD	50	7	0.004	0.8
	TN	8	6	0.005	1.6
	NH_3-N	5	3	0.004	2
	TP	2	7	0.002	1.5

Table S8 Pollutant accumulated parameters and flushing parameters in JT-C area

Land uses	Pollutant	Maximum buildup possible（kg/ha）	buildup rate constant （1/d）	Wash off coefficient	Wash off exponent
Square/ Residential roads	SS	34	0.48	0.011	1.45
	COD	35	0.49	0.007	1.95
	TN	8	0.35	0.004	1.5
	NH_3-N	1	0.42	0.02	2.7
	TP	0.2	0.4	0.004	1.9
Traffic road	SS	44	0.58	0.011	1.55
	COD	52	0.49	0.008	1.9
	TN	12	0.37	0.004	1.5
	NH_3-N	0.8	0.38	0.02	2.7
	TP	0.6	0.37	0.004	1.9
Roof	SS	20	0.47	0.008	1.25
	COD	30	0.46	0.006	1.6
	TN	14.5	0.48	0.005	1.3
	NH_3-N	0.6	0.51	0.026	2.3
	TP	0.55	0.4	0.004	1.7
Green land	SS	12	0.22	0.01	1.45
	COD	50	0.51	0.006	1.9
	TN	5.6	0.39	0.005	1.5
	NH_3-N	0.5	0.4	0.02	2.6
	TP	0.02	0.4	0.004	1.9

Table S9 Pollutant accumulated parameters and flushing parameters in JT-S area

Land uses	Pollutant	Maximum buildup possible（kg/ha）	buildup rate constant（1/d）	Wash off coefficient	Wash off exponent
Square/ Residential roads	SS	34	0.5	0.011	1.45
	COD	50	0.5	0.007	1.95
	TN	6.7	0.4	0.004	1.5
	NH_3-N	0.35	0.4	0.02	2.7
	TP	0.2	0.4	0.004	1.9
Traffic road	SS	44	0.6	0.011	1.55
	COD	68	0.5	0.008	1.9
	TN	7.1	0.4	0.004	1.5
	NH_3-N	0.28	0.4	0.02	2.7
	TP	0.6	0.37	0.004	1.9
Roof	SS	12	0.2	0.01	1.45
	COD	78	0.5	0.006	1.9
	TN	5.1	0.4	0.005	1.5
	NH_3-N	0.18	0.4	0.02	2.6
	TP	0.02	0.4	0.004	1.9
Green land	SS	13	0.5	0.008	1.25
	COD	42	0.5	0.006	1.6
	TN	7.6	0.5	0.005	1.3
	NH_3-N	0.22	0.5	0.026	2.3
	TP	0.55	0.4	0.004	1.7

Table S10 Combination scheme of source control facilities in YC-C study area

Scheme	Proportion of permeable pavement（%）	Proportion of green roof（%）	Proportion of sunken green space（%）
D1	30	-	20
D2	30	30	-
D3	-	30	30
D4	25	-	30
D5	25	25	30
D6	30	20	20
D7	25	30	25

Notes：Scheme D1 to D4 were combinations of two types of LID facilities, while scheme D5 to D7 were combinations of three types of LID facilities.

Table S11 Score table of criterion layer indexes

Indexes	Benefit performance	Economic performance	Technical performance
Benefit performance			
Economic performance			
Technical performance			

Table S12 Score table of index layer of benefit performance indexes

Indexes	SS reduction rate	COD reduction rate	TN reduction rate	NH_3-N reduction rate	TP reduction rate	Runoff volume reduction rate
SS reduction rate						
COD reduction rate						
TN reduction rate						
NH_3-N reduction rate						
TP reduction rate						
Runoff volume reduction rate						

Table S13 Score table of index layer of economic performance indexes

Indexes	Unit design cost	Unit construction cost	Operation and maintenance costs
Unit design cost			
Unit construction cost			
Operation and maintenance costs			

Table S14 Score table of index layer of technical performance indexes

Indexes	Technology maturity	Operational stability
Technology maturity		
Operational stability		

Table S15 Meaning of Scale Values

Value	**Meaning**
1	Indicates that two factors have equal importance compared to each other
3	Indicates that one factor is slightly more important than the other
5	Indicates that one factor is significantly more important than the other
7	Indicates that one factor is significantly more important than the other
9	Indicates that one factor is extremely important than the other
2，4，6，8	The intermediate value between the two adjacent judgments mentioned above

Table S16 Classification and scoring criteria for quantitative and qualitative indicators

	Index layer	**Indexes grading and scoring**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Qualitative	SS reduction rate (%)	(0，7]	(7，8]	(8，9]	(9，10]	(10，11]	(11，12]	(12，13]	(13，14]	(14，100]
	COD reduction rate (%)	(0，14]	(14，15]	(15，16]	(16，17]	(17，18]	(18，19]	(19，20]	(20，21]	(21，100]
	TN reduction rate (%)	(0，10]	(10，11]	(11，12]	(12，13]	(13，14]	(14，15]	(15，16]	(16，17]	(17，100]
	NH$_3$-N reduction rate (%)	(0，9]	(9，10]	(10，11]	(11，12]	(12，13]	(13，14]	(14，15]	(15，16]	(16，100]
	TP reduction rate (%)	(0，16]	(16，17]	(17，18]	(18，19]	(19，20]	(20，21]	(21，22]	(22，23]	(23，100]
	Runoff volume reduction rate (%)	(0，10]	(10，12]	(12，14]	(14，16]	(16，18]	(18，20]	(20，22]	(22，24]	(24，100]
	Unit design cost (yuan/m^2）	(1，∞）	(17，18]	(16，17]	(15，16]	(14，15]	(13，14]	(12，13]	(11，12]	(0，11]
	Unit construction cost (yuan/m^2）	(180，∞）	(170，180]	(160，170]	(150，160]	(140，150]	(130，140]	(120，130]	(110，120]	(0，110]
	Operation and maintenance costs (yuan/m^2）	(11.5，∞]	(11，11.5]	(10.5，11]	(10，10.5]	(9.5，10]	(9，9.5]	(8.5，9]	(8，8.5]	(0，8]
Qualitative	Technology maturity	Low maturity			General maturity			High maturity		
	Operational stability	Low stability			General stability			High stability		

Table S17 Economic costs of each scheme

Scheme	Unit design cost （yuan/m^2）	Unit construction cost （yuan/m^2）	Unit operation cost （yuan/m^2）
D1	19.29	128.89	11.17
D2	18.97	192.57	10.79
D3	12.83	180.50	7.48
D4	17.72	117.49	10.35
D5	17.06	166.72	9.83
D6	17.80	169.30	10.23
D7	17.58	165.03	10.12

Table S18 Evaluation Scores for Various indexes of each Scheme

Indexes	D1	D2	D3	D4	D5	D6	D7
Unit design cost	1	2	8	3	3	3	3
Unit construction cost	7	1	1	8	3	3	3
Unit operation cost	2	3	9	4	5	3	3
SS reduction rate	2	6	1	2	6	7	5
COD reduction rate	1	7	1	1	6	8	4
TN reduction rate	1	7	1	1	7	8	5
NH_3-N reduction rate	2	7	1	2	7	8	5
TP reduction rate	1	7	1	1	6	8	4
Runoff volume reduction rate	3	6	2	3	6	7	5
Technology maturity	6.79	6.55	6	6.67	6.45	6.51	6.51
Operational stability	5.79	5.55	5	5.67	5.45	5.51	5.51

Table S19 Simulation schemes in YC-OB study area

Number	Proportion of permeable pavement (%)	Proportion of green roof (%)	Proportion of rain garden (%)	Proportion of sunken green space (%)
1	10	10	3	25
2	10	10	6.5	25
3	10	25	6.5	10
4	10	25	10	25
5	10	25	6.5	40
6	10	40	6.5	25
7	30	10	6.5	10
8	30	10	10	25
9	30	10	6.5	40
10	30	25	3	10
11	30	25	10	10
12	30	25	3	25
13	30	25	6.5	25
14	30	25	3	40
15	30	25	10	40
16	30	40	6.5	10
17	30	40	3	25
18	30	40	10	25
19	30	40	6.5	40
20	50	10	6.5	25
21	50	25	6.5	10
22	50	25	3	25
23	50	25	10	25
24	50	25	6.5	40
25	50	40	6.5	25

Table S20 Overview of various land use in YC-OB study area

Land use	Aera (km^2)	Proportion (%)	Maximum degree of reconstruction (%)
Traffic road	2.06	11.85	0
Square/ Residential roads	4.56	26.28	30
Roof	4.69	26.98	25
Green land	5.82	33.53	35
Waterbody	0.24	1.36	0
Total	17.37	100	-

Table S21 The interception volume of the CSO storage tank when P=0.5a, P=1a and P=2a

Overflow outfall	Return period	10%	20%	30%	40%	50%
YLK1	P=0.5	401.6	803.2	**1204.8**	1606.4	2008.0
YLK2	P=0.5	451.1	**902.2**	1353.3	1804.4	2255.5
YLK1	P=1	604.2	1208.4	**1812.6**	2416.8	3021.0
YLK2	P=1	663.1	**1326.2**	1353.3	1804.4	2255.5
YLK1	P=2	785.8	1571.6	**2357.4**	3143.2	3929.0
YLK2	P=2	882.9	**1765.8**	2648.7	3531.6	4414.5

Table S22 Comprehensive cost for interceptor pipe construction with different pipe diameter

Pipe diameter	Labor cost (yuan/10 m)	Material cost (yuan/10 m)	Machinery cost (yuan/10 m)	Comprehensive cost (yuan/10 m)
400	365.41	5.29	105.13	475.83
500	454.91	6.61	123.91	585.43
600	524.27	7.97	150.47	682.71
700	723.23	9.31	180.3	912.84
800	750.83	10.39	196.92	958.14
900	930.96	11.70	205.76	1148.42
1000	1010.88	12.92	273.85	1297.65
1200	1231.44	14.40	285.95	1531.79

Table S23 Comprehensive cost of interceptor pipe construction with different interception ratio

n_0	Pipe diameter (mm)								Length (m)	Cost (yuan)
	400	500	600	700	800	900	1000	1200		
2	398.4	-	234.1	71.1	-	-	-	-	703.5	121126.8
2.5	-	398.4	234.1	-	71.1	71.1	-	-	703.5	141382.4
3	-	398.4	-	234.1	-	-	-	-	703.5	161094.1
3.5	-	247.5	38.2	-	112.6	305.2	-	-	703.5	208186.4
4	-	-	285.7	-	112.6	234.1	71.1	-	703.5	224314.6
4.5	-	-	247.5	38.2	-	112.6	234.1	71.1	703.5	261213.6
5	-	-	-	285.7	-	112.6	-	305.2	703.5	311191.4

Table S24 Comprehensive cost for wastewater pumping stations construction with different flow

Flow (L·s^{-1})	Comprehensive cost (yuan)
100~300	17624.32~22357.13
300~600	12720.30~17624.32
600~1000	10223.35~12720.30
1000~2000	7919.51~10223.35
>2000	5519.71~7919.51

Table S25 Comprehensive cost of wastewater pumping station with different interception ratio

n_0	2	2.5	3	3.5	4	4.5	5
Design flow (L/s)	503.33	653.78	775.11	883.00	999.00	1116.56	1223.00
Unit cost (yuan/(L/s))	15222.21	13518.95	12277.17	11271.91	10294.95	9414.72	8713.07
Total cost (10×10^4 yuan)	766	883	951	995	1028	1051	1065

Table S26 Comprehensive cost of wastewater treatment plant construction with different flow

Flow ($\times10^4m^3/d$)	Comprehensive cost (yuan)
1~2	1221.76~1381.74
2~5	1066.51~1221.76
5~10	916.12~1066.51
10~20	810.82~916.12
>20	718.94~810.82

Table S27 Comprehensive cost of wastewater treatment plant with different interception ratio

n_0	2	2.5	3	3.5	4	4.5	5
Design flow ($10\times10^4m^3/d$)	4.35	5.65	6.70	7.63	8.63	9.65	10.57
Unit cost (yuan/(m^3/d))	1136.4	1082.2	1041.8	1008.3	974.9	943.7	917.9
Total cost (10×10^4 yuan)	4941.9	6113.0	6976.8	7692.4	8414.4	9104.0	9698.9

Table S28 Total construction cost at different n_0

n_0 Cost (10×10^4 yuan)	2	2.5	3	3.5	4	4.5	5
Interceptor pipe	12.1	14.1	16.1	20.8	22.4	26.1	31.1
Pumping station	766	883	951	995	1028	1051	1065
WWTP	4941.9	6113.0	6976.8	7692.4	8414.4	9104.0	9698.9
Total	5720.0	7010.1	7943.9	8708.2	9464.8	10181.1	10795.0

Table S29 Volume of initial rainwater storage tank with different storage depth

Storage depth (mm)	V_1 volume (m^3)	V_2 volume (m^3)
4	712.8	976.8
5	891.0	1221.0
6	1069.2	1465.2
7	1247.4	1709.4
8	1414.3	1772.6