Supplementary information

A framework for comparing multi-objective optimization approaches for a stormwater drainage pumping system to reduce energy consumption and maintenance costs

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This supplement contains the following:

- Table S1, Weights corresponding to different schemes and return periods

- Table S2, Optimization results with corresponding eight weight schemes

- Table S3, Objective slope under different weight schemes and return periods

- Table S4, Results of TOPSIS comparison for eight weight schemes

- Table S5, Results of E&C comparison for eight weight schemes

- Figure S1, Slope of four objectives under different weight schemes and return periods

- Figure S2, TOPSIS comparison results of eight weight schemes

- Figure S3, E&C comparison results of eight weight schemes

1. Sensitivity analysis

To test the influence of the selection of weight values in PSO-LWSM on the final optimization results, this paper adopts the perturbation method for sensitivity analysis of weight values, and the perturbation interval is $(x_n \times 0.8, \ x_n \times 1.2)$ (n=1,2,3 and 4). To simplify the analysis, when a weight of x_1-x_4 increases or decreases according to the change of disturbance value, the rest weights increase or decrease equally. The weights of eight schemes from PSO-LWSM-P1 to P8 for four objectives formed using the perturbation method under different return periods are shown in Table S1.

Table S1 Weights corresponding to different schemes and return periods.

Weighting scheme	Objective	Weight				
		Return period (years)				
		5	10	30	5	100
PSO-LWSM-P$_1$	n	0.101	0.101	0.101	0.101	0.101
	E	0.506	0.506	0.506	0.506	0.506
	Th	0.248	0.248	0.248	0.248	0.248
	Hv_{max}	0.145	0.145	0.145	0.145	0.145
PSO-LWSM-P$_2$	n	0.152	0.152	0.159	0.093	0.142
	E	0.489	0.489	0.398	0.597	0.513
	Th	0.232	0.232	0.273	0.200	0.192
	Hv_{max}	0.128	0.128	0.170	0.104	0.153
PSO-LWSM-P$_3$	n	0.159	0.159	0.159	0.093	0.142
	E	0.398	0.398	0.398	0.597	0.513
	Th	0.273	0.273	0.273	0.200	0.192
	Hv_{max}	0.170	0.170	0.170	0.104	0.153
PSO-LWSM-P$_4$	n	0.093	0.093	0.159	0.093	0.142
	E	0.597	0.597	0.398	0.597	0.513
	Th	0.200	0.200	0.273	0.200	0.192
	Hv_{max}	0.104	0.104	0.170	0.104	0.153

Weighting scheme	Objective	Weight				
		Return period (years)				
		5	10	30	5	100
PSO-LWSM-P$_5$	n	0.142	0.142	0.159	0.093	0.142
	E	0.513	0.513	0.398	0.597	0.513
	Th	0.192	0.192	0.273	0.200	0.192
	Hv_{max}	0.153	0.153	0.170	0.104	0.153
PSO-LWSM-P$_6$	n	0.110	0.110	0.110	0.110	0.110
	E	0.481	0.481	0.481	0.481	0.481
	Th	0.288	0.288	0.288	0.288	0.288
	Hv_{max}	0.121	0.121	0.121	0.121	0.121
PSO-LWSM-P$_7$	n	0.137	0.137	0.137	0.137	0.137
	E	0.504	0.504	0.504	0.504	0.504
	Th	0.249	0.249	0.249	0.249	0.249
	Hv_{max}	0.109	0.109	0.109	0.109	0.109
PSO-LWSM-P$_8$	n	0.117	0.117	0.117	0.117	0.117
	E	0.488	0.488	0.488	0.488	0.488
	Th	0.117	0.117	0.117	0.117	0.117
	Hv_{max}	0.164	0.164	0.164	0.164	0.164

Based on these weights of eight schemes, the optimization results of PSO-LWSM under return periods of 5, 10, 30, 50 and 100 years can be obtained (Table S2).

Table S2 Optimization results with corresponding eight weight schemes.

Weighting scheme	Objective	Optimization result				
		Return period (years)				
		5	10	30	50	100
PSO-LWSM-P$_1$	n	16	402	654	628	298
	E (Kw·h)	6290.25	6806.31	7777.20	8293.24	8752.30
	Th (h)	21.45	23.64	27.4	29.51	31.56
	Hv_{max} (m)	5.21	5.81	6.32	6.24	5.65
PSO-LWSM-P$_2$	n	11	340	501	474	230

Weighting scheme	Objective	Optimization result				
		Return period (years)				
		5	10	30	50	100
	E (Kw·h)	6280.26	6815.99	7792.02	8297.77	8814.42
	Th (h)	21.52	23.67	27.39	29.47	31.58
	Hv_{max} (m)	5.23	5.84	6.35	6.27	5.67
	n	11	313	477	425	213
PSO-LWSM-P_3	E (Kw·h)	6299.77	6823.15	7802.07	8310.86	8813.53
	Th (h)	21.39	23.58	27.31	29.32	31.54
	Hv_{max} (m)	5.18	5.78	6.30	6.20	5.62
	n	14	445	654	631	295
PSO-LWSM-P_4	E (Kw·h)	6276.42	6798.25	7761.59	8259.04	8777.69
	Th (h)	21.60	23.80	27.50	29.60	31.73
	Hv_{max} (m)	5.25	5.87	6.38	6.30	5.69
	n	12	381	536	531	265
PSO-LWSM-P_5	E (Kw·h)	6289.92	6809.71	7778.79	8286.08	8804.52
	Th (h)	21.61	23.80	27.51	29.68	31.82
	Hv_{max} (m)	5.20	5.80	6.32	6.24	5.64
	n	16	403	664	638	291
PSO-LWSM-P_6	E (Kw·h)	6287.73	6808.17	7784.16	8293.51	8814.31
	Th (h)	21.44	23.51	27.15	29.07	31.50
	Hv_{max} (m)	5.24	5.85	6.36	6.28	5.68
	n	13	387	574	550	273
PSO-LWSM-P_7	E (Kw·h)	6283.54	6811.87	7786.45	8281.82	8803.39
	Th (h)	21.44	23.71	27.32	29.53	31.52
	Hv_{max} (m)	5.25	5.86	6.37	6.29	5.69
	n	15	405	658	637	296
PSO-LWSM-P_8	E (Kw·h)	6281.51	6816.00	7788.90	8280.29	8800.14
	Th (h)	21.80	24.01	27.74	29.60	32.05
	Hv_{max} (m)	5.18	5.80	6.31	6.22	5.63

Based on the results in Table S2, the corresponding slope (representing variance) of

each objective under each scheme and return period is calculated as follows：

$$k = (O_n^r - O_0^r)/(x_n - x_0) \qquad \text{(S1)}$$

Where, k is the slope, O_n is the normalized value of the corresponding weight optimization result of the corresponding objective, O_0 is the normalized value of the optimization result without changing the weight, x_n is the weight corresponding to the corresponding objective, x_0 is the weight without changing. r represents the return period of the normalized value. The greater the absolute value of the slope, the higher the sensitivity of the objective. The corresponding slope of different optimization objectives under different return periods are computed and shown in Table S3 and Figure S1.

Table S3 Objective slope under different weight schemes and return periods.

Weighting scheme	Objective	Slope				
		Return period (years)				
		5	10	30	50	100
PSO-LWSM-P$_1$	n	-5.66	2.49	-1.97	-1.78	0.26
	E	-0.82	-1.05	-0.98	-0.82	-1.60
	Th	-1.81	-1.67	-1.34	-1.42	-1.70
	Hv_{max}	-0.55	-0.55	-0.49	-0.49	-0.45
PSO-LWSM-P$_2$	n	-8.48	-8.21	-7.75	-8.37	-9.24
	E	1.01	0.89	0.75	0.75	0.77
	Th	1.43	1.53	1.38	1.60	1.62
	Hv_{max}	0.05	0.05	0.05	0.06	0.05
PSO-LWSM-P$_3$	n	-6.47	-8.16	-7.07	-8.84	-8.75
	E	0.05	0.06	0.05	0.05	0.07
	Th	-0.53	-0.50	-0.43	-0.55	-0.45
	Hv_{max}	-0.31	-0.31	-0.25	-0.32	-0.27

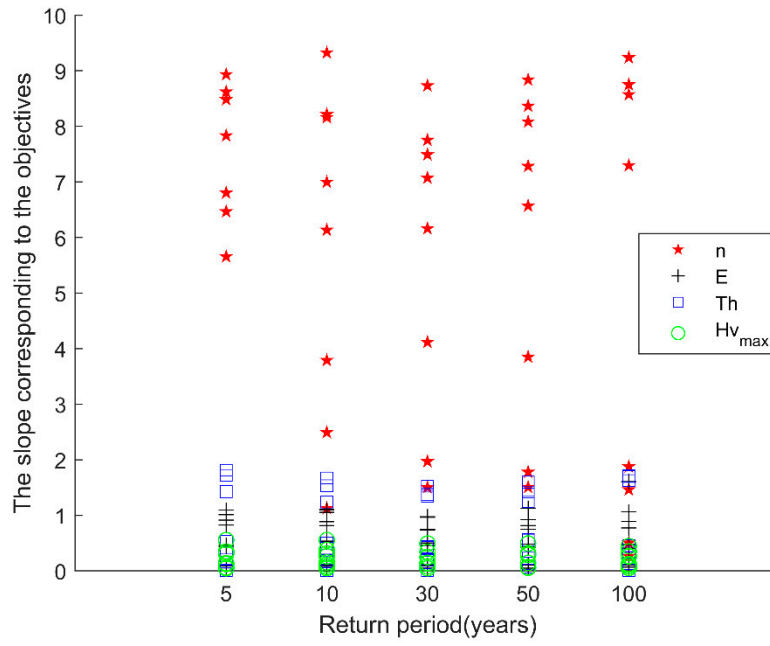| Weighting scheme	Objective	Slope Return period (years)				
		5	10	30	50	100
PSO-LWSM-P$_4$	n	-8.62	-1.13	-1.50	-1.51	0.50
	E	-0.09	-0.10	-0.10	-0.11	-0.11
	Th	0.21	0.19	0.19	0.23	0.23
	Hv_{max}	-0.12	-0.15	-0.15	-0.14	-0.12
PSO-LWSM-P$_5$	n	-8.93	-7.00	-8.73	-7.28	-7.29
	E	-0.44	-0.52	-0.50	-0.48	-0.48
	Th	0.16	0.16	0.15	0.13	0.13
	Hv_{max}	-0.35	-0.38	-0.34	-0.29	-0.35
PSO-LWSM-P$_6$	n	-8.93	3.79	-4.11	-3.85	1.88
	E	0.46	0.54	0.46	0.43	0.41
	Th	-0.33	-0.41	-0.42	-0.56	-0.34
	Hv_{max}	-0.06	-0.07	-0.08	-0.07	-0.08
PSO-LWSM-P$_7$	n	-6.80	-9.32	-7.49	-8.08	-8.57
	E	-1.10	-1.10	-0.96	-1.13	-1.06
	Th	-1.72	-1.24	-1.53	-1.25	-1.71
	Hv_{max}	-0.14	-0.11	-0.14	-0.15	-0.11
PSO-LWSM-P$_8$	n	-7.83	6.13	-6.16	-6.57	1.46
	E	0.91	0.82	0.74	0.92	0.89
	Th	-0.01	-0.01	-0.01	0.07	-0.01
	Hv_{max}	-0.34	-0.26	-0.25	-0.29	-0.26

Figure S1 Slope of four objectives under different weight schemes and return periods.

It can be seen that, the order of sensitivity of each optimization objective from high to low is $n > Th > E > Hv_{max}$, and the sensitivity of n is much higher than that of the other three optimization objectives.

The optimization results with weight schemes of PSO-LWSM compared with those of NSGA-II-TOPSIS and MOPSO-TOPSIS by the comparison module are shown in Table S4, S5, and Figure S2, S3.

Table S4 Results of TOPSIS comparison for eight weight schemes.

Weight scheme and approach	TOPSIS comprehensive evaluation index				
	Return period (years)				
	5	10	30	50	100
PSO-LWSM-P_1	0.192	0.316	0.637	0.621	0.268
PSO-LWSM-P_2	0.004	0.097	0.089	0.152	0.054
PSO-LWSM-P_3	0.003	0.007	0.017	0.019	0.007
PSO-LWSM-P_4	0.116	0.469	0.638	0.630	0.258

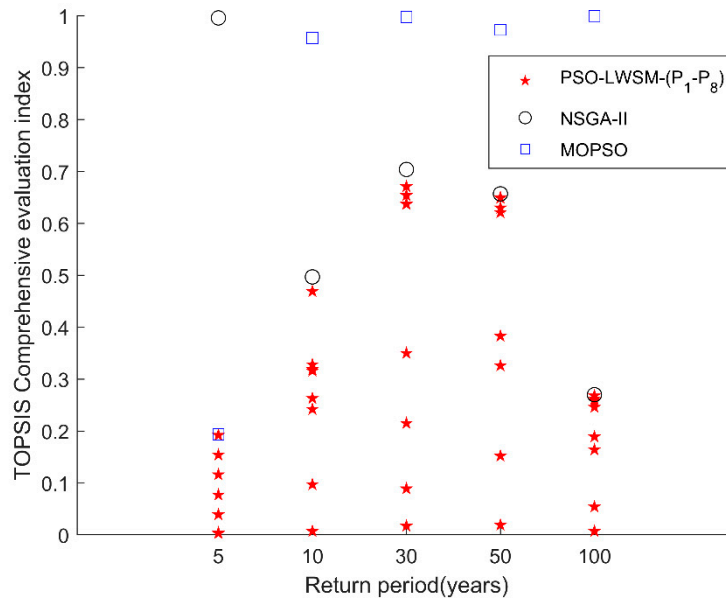| Weight scheme and approach	TOPSIS comprehensive evaluation index				
	Return period (years)				
	5	10	30	50	100
PSO-LWSM-P_5	0.039	0.242	0.215	0.326	0.164
PSO-LWSM-P_6	0.192	0.319	0.671	0.650	0.246
PSO-LWSM-P_7	0.077	0.263	0.350	0.383	0.189
PSO-LWSM-P_8	0.154	0.328	0.654	0.649	0.262
NSGA-II-TOPSIS	0.996	0.497	0.704	0.657	0.270
MOPSO-TOPSIS	0.194	0.957	0.998	0.973	1.000

Figure S2 TOPSIS comparison results of eight weight schemes.

Table S5 Results of E&C comparison for eight weight schemes.

Weight scheme and approach	E&C comprehensive evaluation index				
	Return period (years)				
	5	10	30	50	100
PSO-LWSM-P_1	0.607	0.725	0.906	0.818	0.847
PSO-LWSM-P_2	0.590	0.703	0.865	0.773	0.822
PSO-LWSM-P_3	0.587	0.690	0.857	0.755	0.813
PSO-LWSM-P_4	0.603	0.744	0.909	0.820	0.850
PSO-LWSM-P_5	0.594	0.719	0.876	0.791	0.838

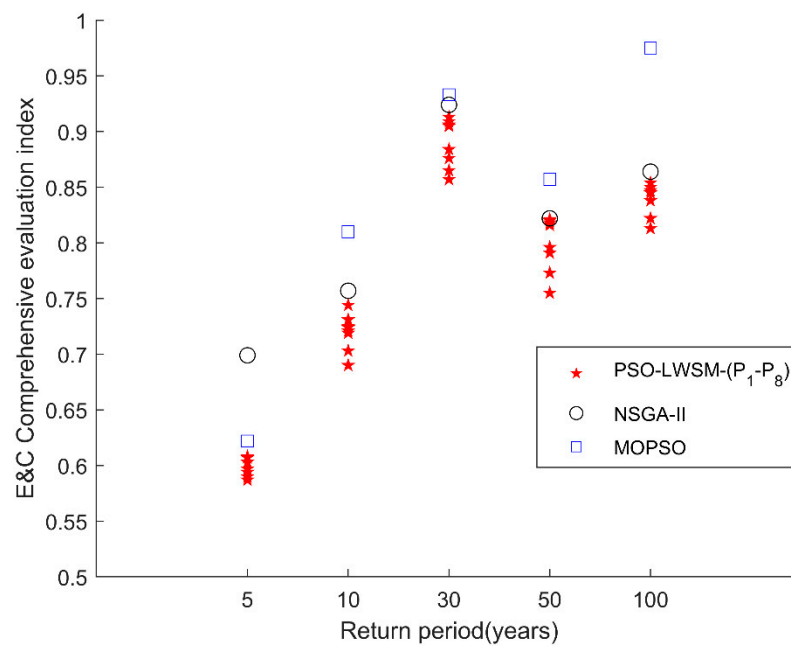| Weight scheme and approach	E&C comprehensive evaluation index				
	Return period (years)				
	5	10	30	50	100
PSO-LWSM-P_6	0.608	0.724	0.905	0.816	0.845
PSO-LWSM-P_7	0.597	0.721	0.884	0.796	0.838
PSO-LWSM-P_8	0.608	0.731	0.913	0.821	0.854
NSGA-II-TOPSIS	0.699	0.757	0.924	0.822	0.864
MOPSO-TOPSIS	0.622	0.810	0.933	0.857	0.975

Figure S3 E&C comparison results of eight weight schemes.

According to Table S4, S5, and Figure S2 and S3, the optimization result of PSO-LWSM changes as the weight alters within a certain range, but the result is still better than those of NSGA-II-TOPSIS and MOPSO-TOPSIS.