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Stochastic evolutionary-based optimization for rapid diagnosis and energy-saving in pilot- and full-scale Carrousel oxidation ditches

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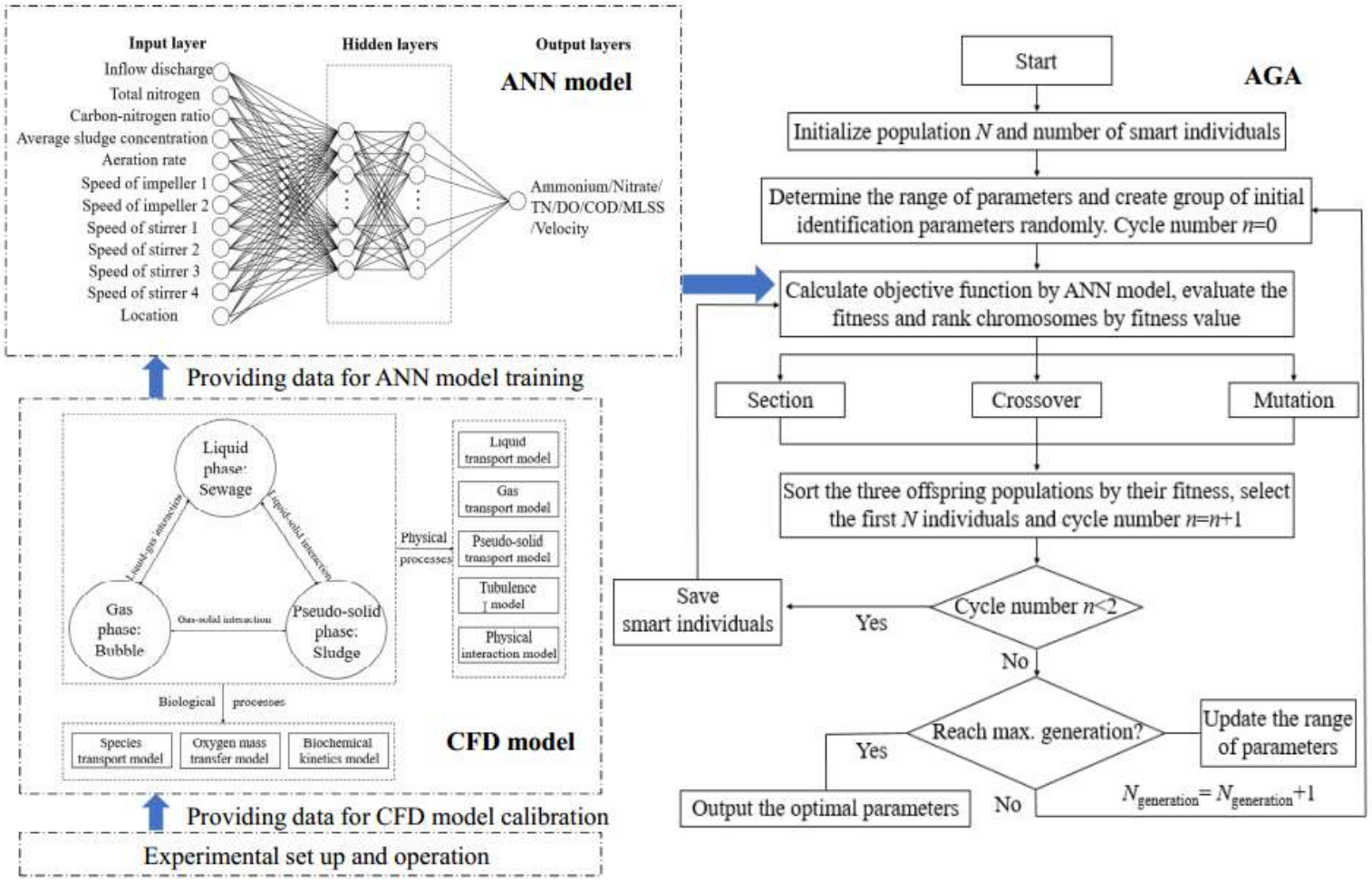

Fig. 1 Framework of hybrid model of conditions in the oxidation ditch, comprising a three-dimensional (3D) three-phase computational fluid dynamics (CFD) model, multi-site artificial neural network (ANN) model and accelerating genetic algorithm (AGA) model.

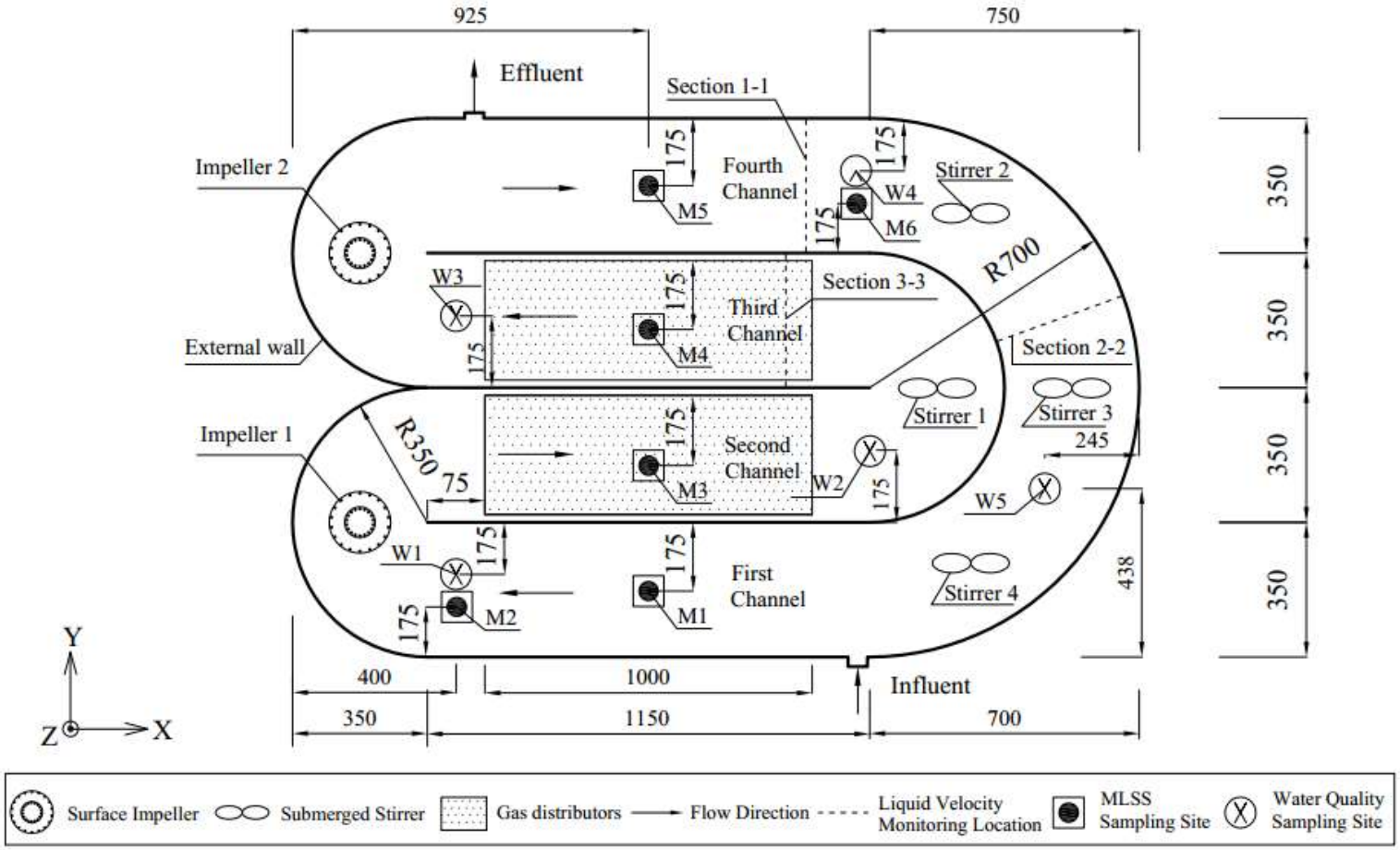

Fig. 2 Schematic of pilot-scale oxidation ditch and monitoring sites (Unit: mm).

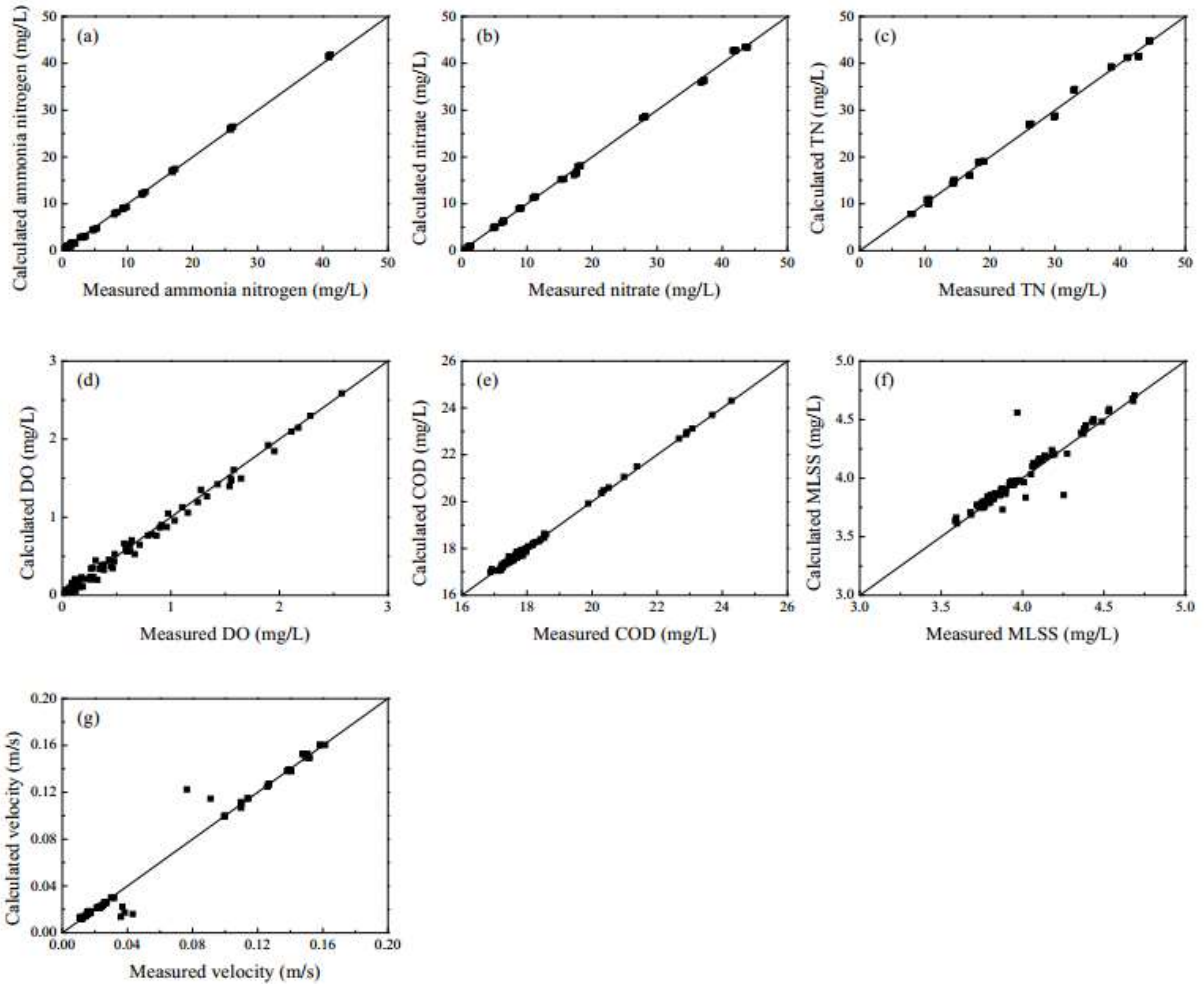

Fig. 3 Comparisons between calculated and measured values of: (a) ammonia nitrogen concentration; (b) nitrate concentration; (c) TN concentration; (d) DO concentration; (e) COD concentration; (f) MLSS concentration; and (g) liquid velocity in a pilot-scale OD.

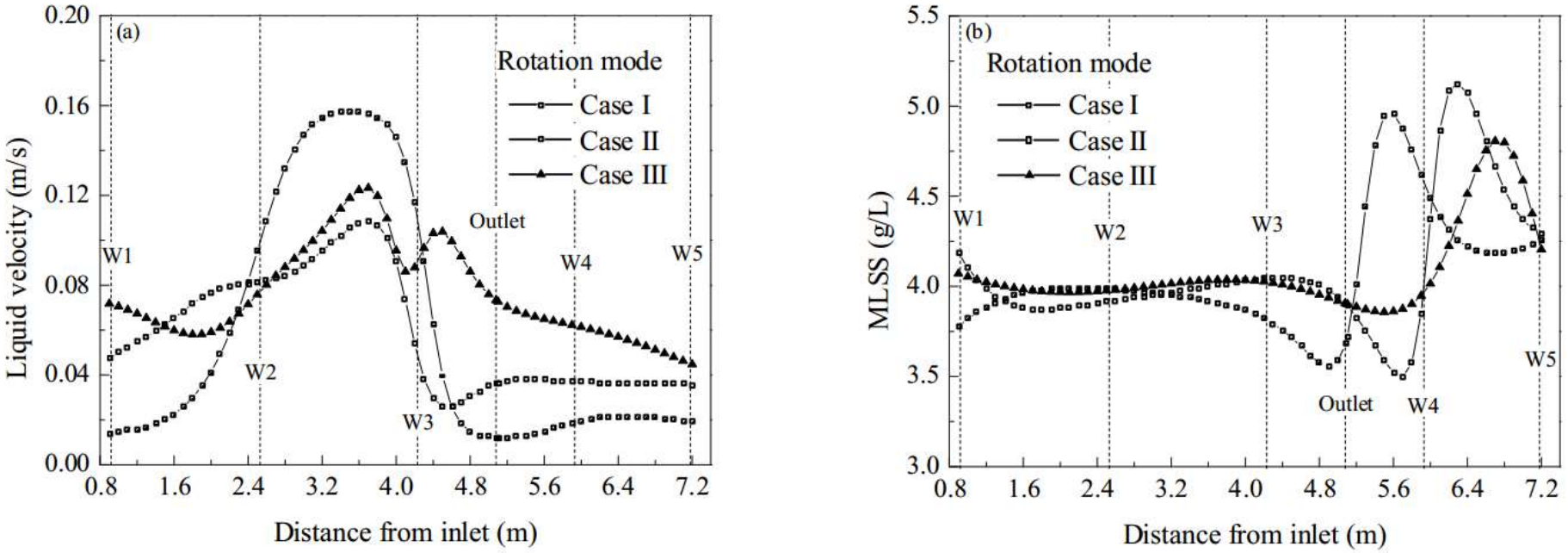

Fig. 4 Stream-wise profiles of (a) predicted liquid velocity and (b) concentration of MLSS at elevation 0.1 m above the bottom of the pilot-scale oxidation ditch, for an aeration rate of 1.4 m^3/h.

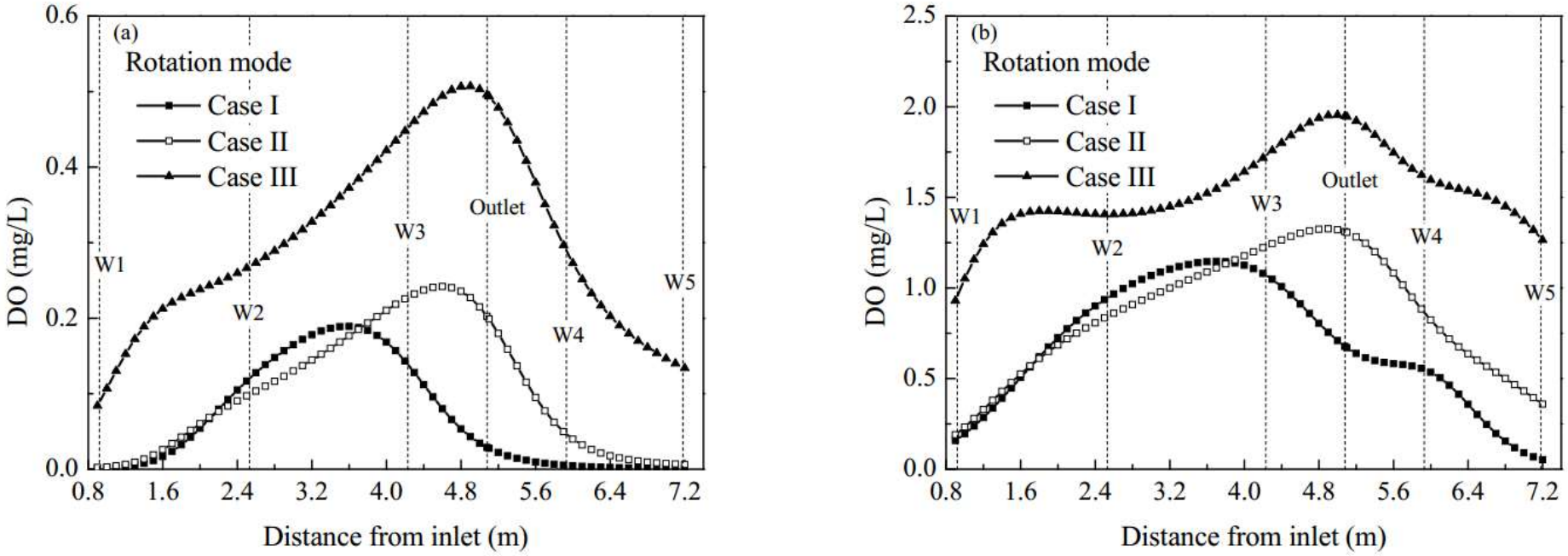

Fig. 5 Stream-wise profiles of dissolved oxygen at elevation 0.1 m above the bottom of the pilot-scale oxidation ditch, for aeration rates of (a) 1.4 m^3/h and (b) 3.0 m^3/h.

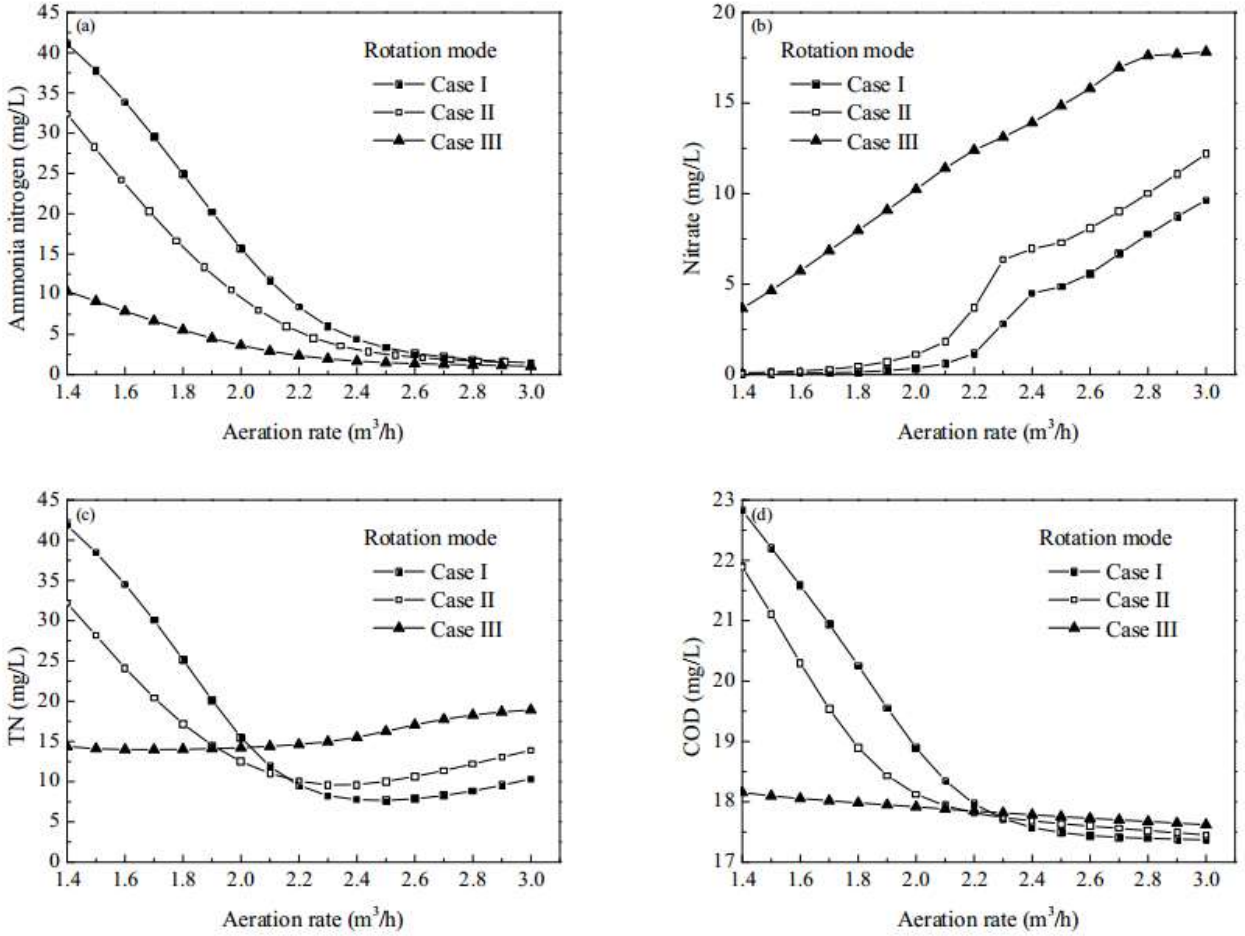

Fig. 6 Predicted effluent concentrations of (a) ammonia nitrogen, (b) nitrate, (c) TN, and (d) COD as functions of aeration rate, at an elevation 0.25 m above the bottom of the pilot-scale OD under three different operation modes.

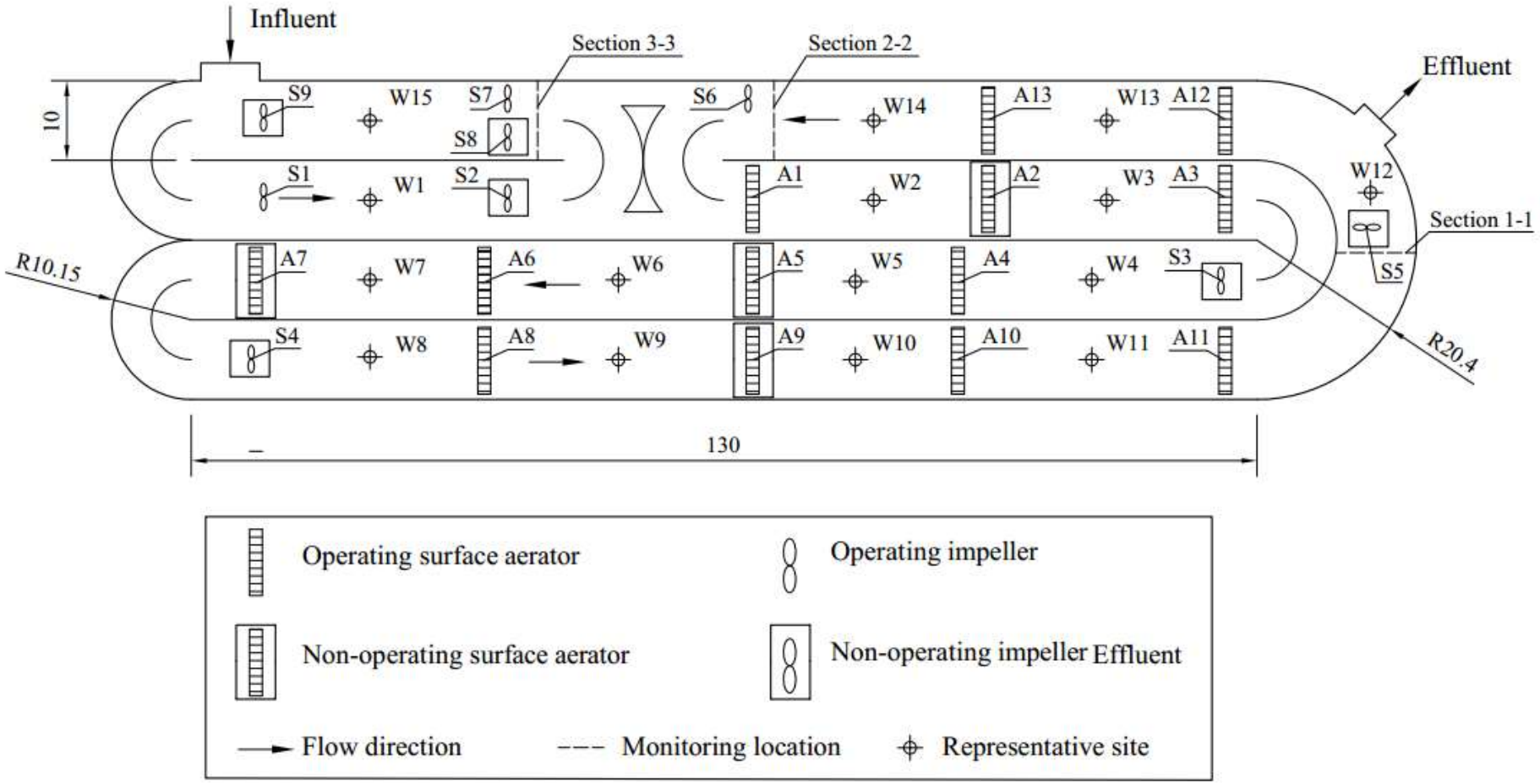

Fig. 7 Full-scale oxidation ditch and monitoring sites, Ping Dingshan, Henan Province, China (Unit: m).

Table 1 Rotational modes of impellers and stirrers.

Moving part	Case I		Case II		Case III		Case IV	
	Speed (rpm)	Direction	Speed (rpm)	Direction	Speed (rpm)	Direction	Speed (rpm)	Direction
Impeller 1	40	+[1]	80	+	180	+	40	+
Impeller 2	40	+	80	+	180	+	40	+
Stirrer 1	40	-[2]	90	-	120	-	70	-
Stirrer 2	40	+	90	+	120	+	70	+
Stirrer 3	40	+	90	+	120	+	70	+
Stirrer 4	50	+	70	+	115	+	50	+

[1] + clockwise rotation.

[2] – anticlockwise rotation.

Table 2 Experimental conditions for testing the ANN model in the pilot-scale oxidation ditch.

Inflow discharge (L/h)	TN (mg/L)	Carbon-nitrogen ratio	MLSS (g/L)	Aeration rate (m^3/h)	Speeds of impellers and stirrers
100	50	3	3.9	1.4	Case IV
100	50	3	3.9	1.8	Case IV
100	50	3	3.9	2.2	Case IV
100	50	3	3.9	2.6	Case IV
100	50	3	3.9	3	Case IV
100	50	5	3.9	1.4	Case IV
100	50	5	3.9	1.8	Case IV
100	50	5	3.9	2.2	Case IV
100	50	5	3.9	2.6	Case IV
100	50	5	3.9	3	Case IV
100	50	7	3.9	1.4	Case IV
100	50	7	3.9	1.8	Case IV
100	50	7	3.9	2.2	Case IV
100	50	7	3.9	2.6	Case IV
100	50	7	3.9	3	Case IV

Table 3 Optimum structures and test results of the ANN model in the pilot-scale oxidation ditch.

Variable	Structure	MSE	OF	R^2
Ammonia nitrogen	12−11−10−1	7.34×10^{-2}	0.33%	0.9996
Nitrate	12−8−13−1	2.21×10^{-1}	0.32%	0.9990
TN	12−14−4−1	5.69×10^{-1}	0.33%	0.9963
DO	12−7−14−1	3.34×10^{-3}	1.13%	0.9922
COD	12−12−9−1	4.87×10^{-3}	0.04%	0.9982
MLSS	12−14−13−1	7.38×10^{-3}	0.23%	0.9031
Liquid velocity	12−11−8−1	5.26×10^{-5}	1.36%	0.9822

Table 4 Optimized operating condition in the pilot-scale OD.

Operation condition							Effluent quality						
x^1	a^2_1	a_2	b^3_1	b_2	b_3	b_4	NH^4	NO^5	TN^6	DO^7	COD^8	$\bar{v}^9$	E^{10}
1.60	46.35	43.02	47.06	55.73	78.67	88.76	4.36	0.14	4.50	0.01	25.0336	0.07	216.90

x^1: aeration rate, m^3/h; a^2: rotating speed of impeller, rpm; b^3: rotating speed of stirrer, rpm; NH^4: concentration of ammonia nitrogen, mg/L; NO^5: concentration of nitrate, mg/L; TN^6: concentration of total nitrogen, mg/L; DO^7: concentration of dissolved oxygen, mg/L; COD^8: concentration of COD, mg/L; $\bar{v}^9$: averaged liquid velocity, m/s; E^{10}: energy consumption, W.

Table 5 Optimum structures and test results of the ANN model in the full-scale oxidation ditch, Ping Dingshan, Henan Province, China.

Variable	Structure	MSE	RSD	R^2	BLE
Ammonia nitrogen	23-15-13-1	0.2701	0.17%	0.9864	y=0.9973x+0.0571
Nitrate	23-14-4-1	0.1570	0.59%	0.9523	y=0.9602x+0.085
TN	23-14-9-1	0.3416	0.14%	0.9704	y=0.9952x+0.0709
COD	23-12-2-1	2.4733	0.21%	0.9886	y=0.9786x+0.5775
Liquid velocity	23-7-8-1	0.0004	0.60%	0.9216	y=0.9421x+0.0078

R^2: Correlation coefficient

BLE: Best linear fitting equation

Table 6 Optimized operating condition in full-scale OD, Ping Dingshan, Henan Province, China.

Number	Surface aeration												Submerged impeller									Effluent quality				$\bar{v}$[7]	E[8]
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	S1	S2	S3	S4	S5	S6	S7	S8	S9	NH^3	NO^4	TN^5	COD^6		
1	0[1]	1[2]	0	1	0	1	0	1	0	1	0	0	1	0	0	1	0	1	1	0	0	1	4.76	9.08	13.84	30.19	0.16	238.76
2	0	1	0	1	0	1	0	1	0	1	0	0	1	1	0	1	0	1	0	0	0	1	4.12	3.39	7.51	30.04	0.16	238.76
3	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	1	0	1	4.43	2.46	6.89	28.65	0.16	238.76
4	1	0	0	1	0	1	0	1	0	1	0	0	1	1	0	1	0	1	0	0	0	1	4.89	4.64	9.53	29.96	0.16	238.76
5	1	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	1	0	1	2.48	4.01	6.49	29.76	0.16	238.76

0^1: Non-operation; 1^2: Operation; NH^3: concentration of ammonia nitrogen, mg/L; NO^3: concentration of nitrate, mg/L; TN^5: concentration of total nitrogen, mg/L; COD^6: concentration of COD, mg/L; $\bar{v}^7$: averaged liquid velocity, m/s; E^8: energy consumption, kW.