

Supplementary Material

Tracking performance and disturbance in decentralized wastewater treatment systems with fluorescence spectroscopy

Natalie Mladenov^{1,*}, Scott Sanfilippo¹, Laura Panduro¹, Chelsi Pascua¹, Armando Arteaga²,
Bjoern Pietruschka³

¹ Department of Civil, Construction, and Environmental Engineering, San Diego State University, San Diego, CA, 92182, USA

² Departamento de Estudios Urbanos y del Medio Ambiente, El Colegio de la Frontera Norte, Tijuana 22560, Mexico

³ WASH R&D Centre, University of KwaZulu-Natal, Durban, South Africa

* Author to whom correspondence should be addressed.

Supplementary Tables: 6

Supplementary Figures: 7

Supplementary Tables

Table S1. Formulation of synthetic wastewater used as feed for lab-scale ABR.

Ingredient	Mass (g in 40L of tap water)
Milk powder	10
Sodium acetate	10
Potassium phosphate	4
Meat extract	4
Yeast extract	4
NH ₄ Cl	2
Boric Acid	0.035
CuSO ₄	0.032
ZnCl ₂	0.01
CoCl ₂	0.0006

Table S2. Typical values (means \pm standard deviations) of COD concentration, fluorescence index (FI), freshness index (FrI), humification index (HIX), and fluorescent peaks A, B, T, C, and M in influent and effluent of lab-scale and community decentralized wastewater treatment systems.

Type of wastewater	Treatment type	N	Location	Mean values								
				COD (mg/L)	FI	FrI	HIX	Peak A (RU)	Peak B (RU)	Peak T (RU)	Peak C (RU)	Peak M (RU)
Domestic WW, South Africa	Community ABR before scum accumulated (2015)	8	Influent	488	2.38	0.69	0.85	7.92	14.98	16.53	6.30	8.75
				± 107	± 0.06	± 0.04	± 0.07	± 0.76	± 1.84	± 1.58	± 0.55	± 1.43
			Effluent	212	2.51	0.66	1.52	4.77	4.68	6.46	5.69	6.39
				± 50	± 0.02	± 0.11	± 0.16	± 0.40	± 0.57	± 0.63	± 0.35	± 1.99
“Dairy-like” synthetic wastewater	Lab ABR during normal operation w/scum (2017)	10	Influent	544	1.81	1.13	1.19	11.8	17.7	23.2	5.38	3.35
				± 106	± 0.39	± 0.14	± 0.24	± 3.05	± 2.04	± 1.45	± 1.49	± 1.25
			Effluent	178	2.61	0.87	4.51	5.26	1.49	2.28	1.97	1.19
				± 86	± 0.06	± 0.04	± 0.89	± 1.66	± 0.21	± 0.62	± 0.54	± 0.15
“Dairy-like” synthetic wastewater	Lab ABR during normal operation w/scum (2018)	6	Influent	540	2.11	0.99	1.37	11.9	16.1	23.7	4.78	2.27
				± 212	± 0.37	± 0.27	± 1.17	± 6.21	± 7.96	± 11.8	± 3.63	± 1.19
			Effluent	175	2.49	0.87	2.12	6.29	10.8	9.77	1.96	1.15
				± 79	± 0.06	± 0.18	± 2.34	± 1.90	± 8.11	± 5.71	± 0.84	± 0.22
Real, domestic wastewater, USA	Lab ABR (2018)	3	Influent	358	1.92	0.89	0.90	5.95	7.77	9.13	2.68	4.23
				± 20.8	± 0.04	± 0.02	± 0.01	± 2.46	± 2.19	± 3.07	± 0.91	± 1.68
			Effluent	135	1.90	0.96	1.71	2.61	1.89	3.16	1.84	2.22
				± 19.7	± 0.02	± 0.02	± 0.13	± 0.39	± 0.39	± 0.49	± 0.28	± 0.32
	Lab ASB (2018)	3	Influent	358	1.92	0.89	0.90	5.95	7.77	9.13	2.68	4.23
				± 20.8	± 0.04	± 0.02	± 0.01	± 2.46	± 2.19	± 3.07	± 0.91	± 1.68
			Effluent	91.1	1.98	1.03	2.72	3.17	1.85	2.94	2.47	2.69
				± 26.3	± 0.02	± 0.04	± 0.80	± 1.30	± 1.55	± 2.32	± 0.87	± 1.12
Real, domestic wastewater, Mexico*	Bio-trickling filter (2019-2020)	5	Influent	880	2.15	0.77	0.63	12.99	-	23.00	7.00	8.21
				± 13.4	± 0.13	± 0.06	± 0.10	± 4.64	-	± 7.94	± 2.16	± 2.54
			Effluent	363	2.26	0.78	1.38	4.29	-	6.44	4.99	4.19
				± 12.7	± 0.06	± 0.03	± 0.12	± 0.96	-	± 1.30	± 1.13	± 0.94

* Dash indicates that Peak B was measured but not recorded.

Table S3. Bivariate correlation of change in fluorescence metric with COD removal (R^2) for systems described in Table S1.

Correlated with:	Fluorescence metric							
	Fluorescence Index	Freshness Index	Humification Index	Peak A	Peak B	Peak T	Peak C	Peak M
% COD removal	0.02	0.34	0.35	0.64*	0.57*	0.70*	0.27	0.47
Slope of linear regression	-0.14	-0.42	-4.1	1.1	1.0	1.1	0.68	0.73

* Indicates significance ($p < 0.05$)

Table S4. Fluorescence characteristics of the 128 samples used in the PARAFAC model.

PARAFAC Sample Number	Removed (X = Yes)	Fluorescence Index	Freshness Index	Humification Index	Peak A (RU)	Peak B (RU)	Peak T (RU)	Peak C (RU)	Peak M (RU)
1		2.364157	0.587338	0.374433	5.309359	14.006796	10.584588	7.50196	6.260164
2		2.332106	0.649745	0.368787	5.216455	14.242334	10.23332	6.61263	5.659682
3		2.281156	0.67795	0.402496	4.533004	12.958853	10.613102	5.668062	4.968852
4		2.326737	0.628695	0.48268	4.925867	11.060976	10.202393	6.617527	5.843256
5		2.172866	0.621801	0.541166	5.386169	11.454912	10.686435	7.003977	6.110025
6		1.865252	0.913931	0.763105	4.035002	7.226133	9.500305	3.21641	4.260643
7		2.26865	0.605979	0.919093	3.915464	6.206565	8.874497	7.029876	6.762402
8		2.373714	0.572593	1.212909	4.147463	4.635138	7.354903	7.708642	6.962455
9		2.371558	0.591438	1.11624	4.82597	7.644718	10.805589	6.990111	5.959925
10		2.224178	0.632208	1.208612	4.795865	6.84959	9.428714	6.38558	5.712442
11		2.104202	0.655138	1.170493	4.765118	6.549198	9.490301	5.698737	5.700441
12		2.253906	0.621602	1.179891	4.10635	5.821001	8.219659	5.693942	5.14321
13		2.2163	0.646926	1.196729	4.541696	6.308493	9.17921	6.213201	5.334567
14		1.960395	0.87305	0.557357	4.532712	14.773052	17.362002	4.190106	4.916179
15		2.368902	0.599016	1.591477	5.141689	4.96269	7.378734	7.414031	6.515373
16	X	2.710987	0.613157	11.921987	13.219234	1.304901	1.988563	4.376125	1.559631
17		2.63711	0.832241	4.264304	3.549235	1.258609	1.654715	1.398982	1.02532
18		2.669887	0.850606	3.784597	7.616676	2.875893	3.837556	2.461576	1.393387
19		2.504814	0.88298	2.342458	3.542927	1.963571	2.823933	1.343258	0.994443
20		2.341815	0.632676	11.011255	13.392175	1.614563	2.497353	5.927564	1.936993
21		2.669402	0.915451	3.937162	3.917328	1.365505	1.764564	1.538683	1.123682
22		2.546334	0.99519	0.613724	6.010465	10.240261	16.747037	1.858967	1.633805
23		2.434462	0.675045	3.029043	9.845128	3.935407	6.304788	3.487216	1.374621
24		2.261285	0.613411	10.09103	14.041069	1.928079	2.830691	5.911844	1.893541
25		2.649729	0.876746	4.26853	3.938463	1.285916	1.839032	1.523092	1.022207
26		2.507671	1.097195	0.522606	4.533643	17.548402	14.427371	1.483703	1.277987
27		2.561596	0.647344	6.390759	6.742388	1.357136	2.008761	2.243327	0.813136
28	X	1.818008	0.760535	4.343565	23.405802	10.295947	10.134295	10.017119	3.35814
29		2.546739	0.879588	3.998524	5.828677	1.765893	3.097248	2.172317	1.325067
30		2.516578	0.890295	1.924416	5.429883	5.328166	5.93145	1.939217	1.350611
31		2.499348	0.871169	0.396401	5.120412	17.688376	15.011388	1.255464	1.013625
32	X	2.347529	0.976954	0.873953	5.214089	19.128324	11.387528	2.237058	1.862789
33		2.570157	0.823113	5.816329	7.351684	1.538786	2.399884	2.635369	1.305865
34		2.401462	1.028437	0.45613	6.04835	19.12711	14.936745	1.356513	1.09218
35	X	1.985935	0.706602	6.169843	9.039181	2.971083	3.506315	9.631375	3.219011
36		2.368713	1.067088	0.855241	9.247198	14.830342	23.790049	4.413213	5.146223
37		2.081997	1.118134	0.392573	6.924946	19.438937	26.405749	2.002864	2.507774
38		2.208859	0.818577	1.464974	16.370403	17.366007	24.84192	7.37129	2.066598

PARAFAC Sample Number	Removed (X = Yes)	Fluorescence Index	Freshness Index	Humification Index	Peak A (RU)	Peak B (RU)	Peak T (RU)	Peak C (RU)	Peak M (RU)
39		2.655337	0.949342	3.531216	4.073054	1.441568	2.177139	1.485321	0.741963
40		2.181284	0.909519	9.055671	20.712885	4.000695	4.367683	10.711467	5.716233
41		1.694461	1.167015	1.214192	9.038807	17.542165	23.083357	3.800083	2.915269
42		1.976779	1.228333	0.327972	10.443898	20.719786	32.300018	1.913383	2.932209
43	X	2.074522	0.671898	0.931301	13.240333	23.310365	26.194115	5.264843	1.995641
44		1.460829	1.303643	1.282322	14.50493	19.294684	24.763444	6.676075	3.128816
45		1.700482	1.043622	1.016079	15.637635	24.675149	32.651508	6.916274	2.485043
46		1.754811	1.319794	0.405506	5.658636	14.467077	18.915141	1.346606	4.084974
47	X	1.985064	1.178375	0.306159	12.121141	29.163735	32.058044	2.2214	2.746604
48	X	1.720288	0.977306	1.421218	14.325617	19.004264	21.325638	6.624618	2.228335
49		1.567602	0.889774	0.219426	5.195468	14.170812	18.370223	1.039044	1.176185
50		2.347797	0.586734	1.49802	19.421971	17.717291	31.201796	9.67023	1.326713
51		2.252893	1.314898	0.526869	12.30196	33.422581	29.193613	3.222648	4.420878
52		2.044245	0.900296	1.330642	15.012494	21.96419	22.634988	6.833625	2.368621
53		1.926524	0.938839	1.177647	14.892316	18.387112	25.944469	5.437538	1.48661
54		1.716973	0.795286	0.748291	3.21922	11.921472	6.513842	2.018343	3.340377
55	X	1.768023	0.841004	1.093991	2.493892	6.343279	4.362971	1.90975	2.659398
56		1.800487	0.78464	0.742587	2.959185	11.020577	6.108061	1.884574	3.127525
57	X	1.837185	0.827516	1.138076	2.545656	5.468768	4.293661	1.895513	2.635003
58		1.784086	0.802904	0.732137	3.131324	11.937918	6.538082	1.963257	3.332088
59	X	1.828139	0.836378	1.111265	2.678904	6.422616	4.589854	2.000277	2.786817
60		1.820251	0.766302	0.837699	3.189397	11.10262	6.180349	2.037776	3.330666
61		1.829475	0.801193	1.116511	2.642232	7.005682	4.56788	2.048232	2.941774
62		1.819632	0.787267	0.823006	2.812842	9.902221	5.630146	1.835493	2.96432
63		1.851977	0.828559	1.180753	2.609088	5.32188	4.196013	2.00162	2.804786
64		1.809508	0.775177	0.797187	2.888509	10.81713	5.862841	1.846785	3.064493
65		1.861674	0.781727	1.156916	2.643752	6.401954	4.356083	1.968351	2.829077
66	X	0.671454	4.618685	2.706073	0.029255	0	0	0.004231	0.005606
67		1.833469	0.739214	1.210559	2.578246	7.1584	4.069204	1.810763	2.87364
68		1.792108	0.78028	0.793088	3.3578	12.828563	6.701809	1.997085	3.328232
69	X	1.797324	0.787597	0.804061	3.088288	11.888393	6.251381	1.913881	3.135054
70	X	1.850376	0.73692	1.246424	2.812766	6.574629	4.309988	2.065454	3.14921
71	X	1.763691	0.792411	0.749952	3.045635	12.468874	6.240404	1.90154	3.002529
72	X	1.790158	1.911133	-	0.355996	0	0	0.388137	0.371211
73	X	1.834655	1.717667	413.001812	0.397398	0	0	0.414714	0.399459
74	X	1.798447	1.789169	114.402776	0.407668	0	0	0.427147	0.436201
75	X	1.807353	0.849704	1.0394	2.416188	6.401703	4.25823	1.823505	2.484726
76		1.587151	0.910532	0.784806	2.9416	8.354577	6.090023	1.630558	2.684885
77	X	1.822315	0.852699	1.071819	2.475524	6.127725	4.133919	1.811359	2.435533
78		1.722146	0.888542	0.813685	2.735367	8.84506	5.139707	1.648905	2.604184

PARAFAC Sample Number	Removed (X = Yes)	Fluorescence Index	Freshness Index	Humification Index	Peak A (RU)	Peak B (RU)	Peak T (RU)	Peak C (RU)	Peak M (RU)
79	X	1.76676	0.831964	1.098433	2.485575	6.454524	4.390682	1.851727	2.613126
80		2.367295	0.665792	0.562355	5.019205	9.971376	9.633949	6.691678	5.997495
81		2.52702	0.531724	1.203806	4.104255	4.513943	6.747961	7.850741	6.903158
82		2.201293	0.62771	1.147245	3.980455	4.617815	6.241832	4.86779	4.62311
83		2.193335	0.642068	0.525168	5.23611	10.40369	9.549578	5.948727	5.319659
84		2.33146	0.647593	0.864802	4.412794	7.187111	8.884295	5.707402	5.13879
85		2.155944	0.644862	0.7136	4.629425	8.143218	9.25533	5.784889	5.206915
86		2.42909	0.56161	1.088799	3.976354	4.165015	6.654151	7.181551	6.504302
87		2.322644	0.648073	0.878068	4.281607	7.002029	9.075292	5.501445	4.848514
88		2.3219	0.709441	0.29616	4.797122	15.024583	9.602996	4.965019	4.656057
89		2.075742	0.614702	0.484542	4.313104	9.775438	8.231194	5.496021	4.855949
90		2.320766	0.675441	0.475251	4.665634	11.238205	10.137838	5.401911	4.706866
91		2.309921	0.614431	0.900843	4.186282	6.181791	8.385738	6.145292	6.29465
92		2.403562	0.546249	1.046123	4.118992	5.003657	6.813583	7.002485	6.261715
93		2.0637	0.643433	1.230317	4.750816	5.423897	7.522103	6.176487	6.138966
94		2.126242	0.736414	1.10099	4.296893	4.217182	7.340211	4.100143	4.891968
95	X	2.380331	0.569265	0.977921	4.042068	5.435695	7.614388	6.756076	6.357323
96		2.022978	0.729931	0.872394	5.011777	7.370341	9.55662	5.702684	6.609958
97		2.33393	0.58149	1.076893	5.036447	5.956869	7.793557	6.617598	6.69655
98		2.326823	0.575114	1.075951	4.916754	5.596838	7.486843	7.017694	6.858455
99		2.259026	0.619131	0.423957	4.638662	11.865726	9.689994	6.501608	5.514218
100		2.288661	0.627197	0.571262	5.01014	9.4591	9.44427	6.462984	5.596782
101		2.341406	0.60025	1.041446	4.085365	5.33746	7.663466	7.009392	6.278764
102		2.232039	0.632257	1.24485	4.975684	6.591206	9.696715	6.440552	5.98147
103		2.443112	0.662284	1.170168	4.545438	7.031487	9.066235	6.420802	5.54824
104		2.286992	0.602987	1.229542	4.627819	5.797304	8.687176	6.273152	5.625429
105		2.223223	0.584184	1.037526	5.727631	7.488252	10.937186	8.088177	6.697463
106		2.351565	0.595451	1.184182	4.916688	6.814867	9.623555	6.93707	6.159395
107		2.292129	0.589051	1.349556	5.089266	6.107296	8.47733	7.312084	6.657997
108		2.692192	0.559003	1.33337	5.036022	5.600644	8.064931	8.253191	6.769981
109		2.193849	0.586304	1.211594	4.968086	6.425685	9.0418	6.239301	5.830847
110		2.247153	0.619832	1.280031	4.691468	5.589277	7.759675	5.559428	5.262286
111		2.272136	0.638694	1.103254	4.459561	6.312888	9.259632	5.984127	5.282065
112		2.137078	0.617865	1.13728	4.601185	6.391658	8.858288	5.700972	5.3185
113		2.173359	0.622332	1.065297	4.542287	7.311736	9.89254	5.372596	5.256378
114		2.110445	0.777099	1.010204	4.672782	6.048111	9.413271	4.537998	4.920255
115		2.315435	0.561721	1.306266	4.955959	6.096132	8.685061	6.874741	6.180743
116		2.255163	0.577401	1.325755	4.686281	5.207349	7.418348	6.915821	5.768599
117		2.025508	0.649964	0.959256	4.698343	8.183072	11.228523	5.493326	5.103908
118		2.08276	0.604129	1.269751	5.262822	6.159507	8.245009	5.852079	5.289355

PARAFAC Sample Number	Removed (X = Yes)	Fluorescence Index	Freshness Index	Humification Index	Peak A (RU)	Peak B (RU)	Peak T (RU)	Peak C (RU)	Peak M (RU)
119		2.244255	0.636654	0.966147	5.209248	9.412411	12.528082	6.471646	5.8243
120		2.126962	0.656847	1.003883	4.757883	8.531699	11.295941	5.412813	5.213083
121		2.323051	0.585688	1.230889	5.058701	5.969694	8.382127	6.164802	5.642687
122		2.361017	0.54153	1.410283	4.91525	5.224118	7.299608	6.903623	5.80899
123		2.291297	0.547375	1.288489	4.3487	4.734244	6.837907	6.186129	5.288832
124		1.981596	0.865518	0.81633	4.651278	7.843403	12.071523	3.788418	5.134165
125		2.382172	0.539484	1.396337	4.573362	4.504666	6.10282	5.603704	4.9918
126		2.0502	0.783243	0.92321	4.128637	5.920131	9.525229	3.903575	4.506019
127		1.997379	0.636891	0.883857	4.405681	6.790824	9.377479	4.768503	4.938404
128		2.260312	0.575125	1.227425	4.351104	5.223034	7.219252	5.094581	4.73433

Table S5. Loadings and relative amounts of each component in the 128 samples used in the PARAFAC model. (No data available for samples removed from the model).

PARAFAC Sample Number	Fmax1	Fmax2	Fmax3	sum	%C1	%C2	%C3
1	0.19	0.29	0.03	0.51	37.7%	56.4%	5.8%
2	0.17	0.28	0.03	0.48	35.4%	57.5%	7.1%
3	0.21	0.37	0.04	0.62	33.9%	59.5%	6.6%
4	0.29	0.39	0.05	0.73	39.6%	53.8%	6.6%
5	0.33	0.44	0.05	0.83	40.2%	53.2%	6.5%
6	0.46	0.80	0.10	1.36	34.1%	58.4%	7.5%
7	0.67	0.59	0.08	1.33	50.2%	44.1%	5.7%
8	0.71	0.47	0.09	1.27	55.7%	37.1%	7.1%
9	0.81	0.86	0.12	1.79	45.4%	48.1%	6.5%
10	0.86	0.85	0.14	1.84	46.4%	46.0%	7.6%
11	0.86	0.89	0.14	1.89	45.4%	47.2%	7.4%
12	0.84	0.81	0.13	1.77	47.1%	45.7%	7.3%
13	0.88	0.88	0.14	1.89	46.3%	46.5%	7.2%
14	0.32	0.87	0.07	1.27	25.6%	68.6%	5.8%
15	0.92	0.61	0.12	1.65	55.8%	37.0%	7.3%
16							
17	0.25	0.28	0.87	1.40	17.7%	20.0%	62.4%
18	0.11	0.26	0.85	1.22	9.1%	21.0%	69.9%
19	0.23	0.46	0.85	1.54	14.8%	29.7%	55.5%
20	0.13	0.08	0.93	1.14	11.3%	6.9%	81.7%
21	0.24	0.29	0.87	1.40	16.8%	20.9%	62.3%
22	0.09	0.88	0.41	1.38	6.4%	63.8%	29.7%
23	0.08	0.30	0.92	1.30	6.5%	23.1%	70.4%
24	0.09	0.08	0.95	1.13	8.2%	7.4%	84.4%
25	0.22	0.28	0.87	1.37	16.0%	20.4%	63.5%
26	0.06	0.80	0.28	1.14	5.2%	70.3%	24.5%
27	0.08	0.13	0.89	1.10	6.8%	12.2%	80.9%
28							
29	0.17	0.28	0.87	1.32	13.0%	20.9%	66.1%
30	0.17	0.61	0.85	1.63	10.3%	37.5%	52.2%
31	0.04	0.83	0.23	1.10	3.8%	75.5%	20.6%
32							
33	0.12	0.16	0.89	1.17	10.4%	14.0%	75.6%
34	0.04	0.74	0.27	1.05	3.8%	70.6%	25.6%
35							
36	0.18	0.87	0.62	1.67	10.5%	52.3%	37.2%
37	0.07	0.85	0.17	1.09	6.2%	78.1%	15.8%
38	0.05	0.60	0.94	1.58	3.0%	37.7%	59.4%
39	0.15	0.30	0.90	1.34	11.0%	22.0%	67.0%
40	0.23	0.11	1.01	1.36	17.3%	8.4%	74.3%
41	0.05	0.58	0.51	1.13	4.4%	50.8%	44.9%
42	0.06	0.90	0.14	1.10	5.8%	81.1%	13.0%
43							
44	0.00	0.60	1.00	1.60	0.0%	37.3%	62.7%
45	0.00	0.76	0.99	1.75	0.0%	43.5%	56.5%
46	0.13	0.90	0.15	1.18	11.1%	75.8%	13.1%
47							

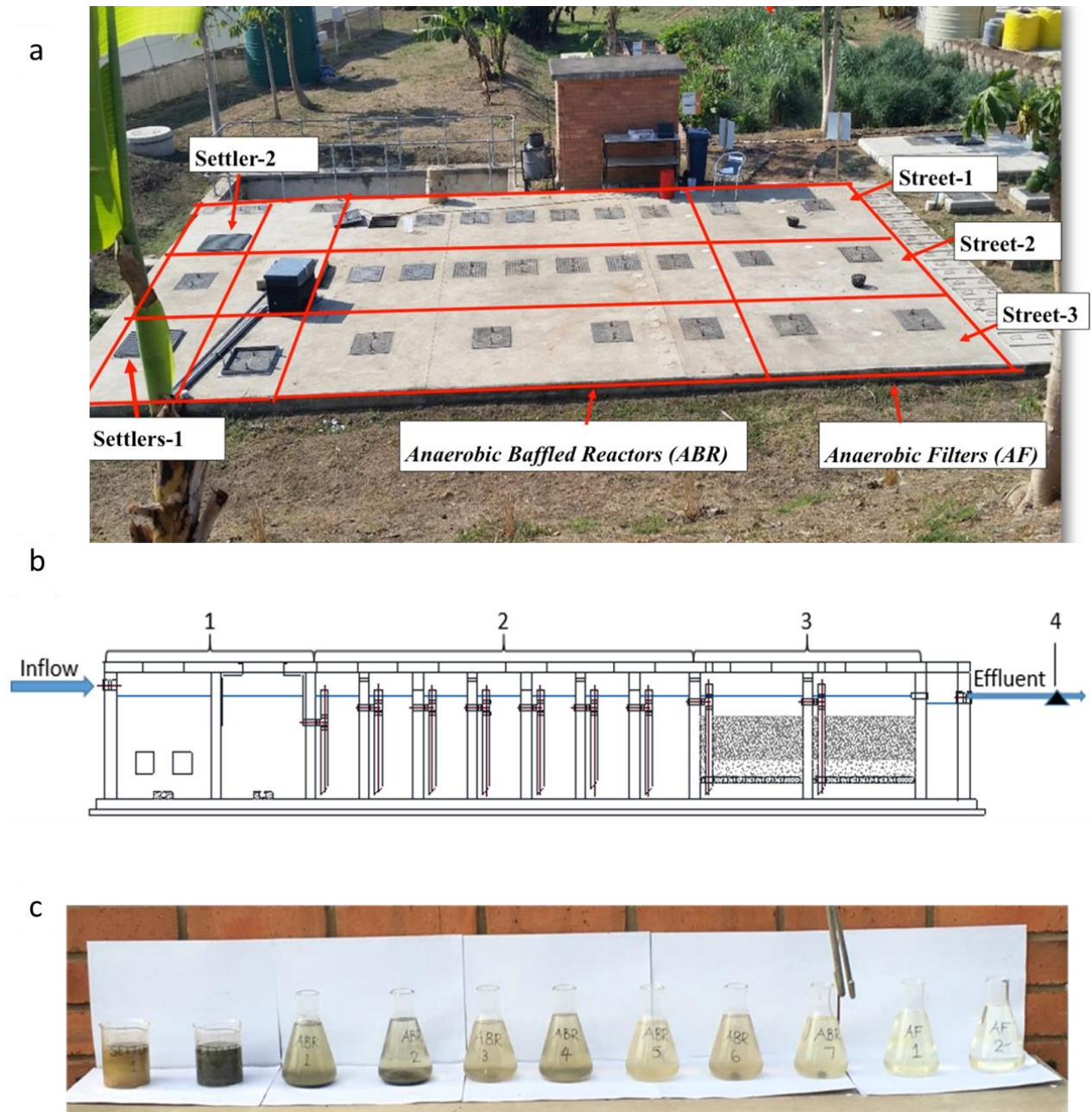
PARAFAC Sample Number	Fmax1	Fmax2	Fmax3	sum	%C1	%C2	%C3
48							
49	0.05	0.87	0.04	0.96	5.3%	90.6%	4.1%
50	0.00	0.48	0.82	1.30	0.0%	37.1%	62.9%
51	0.09	0.83	0.31	1.23	7.6%	67.1%	25.3%
52	0.05	0.64	0.97	1.65	2.9%	38.6%	58.5%
53	0.00	0.64	0.94	1.58	0.0%	40.7%	59.3%
54	0.34	0.61	0.05	1.01	34.2%	60.6%	5.3%
55							
56	0.34	0.61	0.06	1.02	33.9%	60.3%	5.8%
57							
58	0.34	0.61	0.06	1.00	33.6%	60.8%	5.6%
59							
60	0.39	0.63	0.07	1.08	35.9%	57.9%	6.1%
61	0.61	0.77	0.12	1.49	40.7%	51.6%	7.7%
62							
63	0.77	0.93	0.12	1.82	42.2%	51.0%	6.7%
64	0.35	0.60	0.05	1.00	35.0%	60.2%	4.7%
65	0.63	0.78	0.10	1.51	41.8%	51.6%	6.6%
66							
67	0.57	0.67	0.11	1.34	42.2%	49.8%	8.0%
68	0.33	0.58	0.06	0.96	34.0%	60.2%	5.8%
69							
70							
71							
72							
73							
74							
75							
76	0.43	0.81	0.08	1.31	32.5%	61.7%	5.8%
77							
78	0.37	0.64	0.06	1.07	34.6%	59.7%	5.7%
79							
80	0.38	0.47	0.06	0.91	41.4%	52.2%	6.4%
81	0.73	0.45	0.08	1.27	57.7%	35.8%	6.5%
82	0.85	0.75	0.13	1.73	49.0%	43.4%	7.5%
83	0.28	0.38	0.05	0.71	38.8%	54.0%	7.2%
84	0.78	0.88	0.11	1.76	44.3%	49.7%	6.0%
85	0.59	0.72	0.09	1.40	42.3%	51.5%	6.2%
86	0.69	0.49	0.07	1.25	55.3%	39.0%	5.6%
87	0.80	0.93	0.10	1.83	43.6%	51.0%	5.4%
88	0.12	0.25	0.02	0.39	31.0%	64.2%	4.8%
89	0.28	0.38	0.04	0.70	39.8%	53.9%	6.3%
90	0.25	0.41	0.04	0.70	35.5%	58.5%	6.0%
91	0.70	0.64	0.07	1.41	50.1%	45.1%	4.8%
92	0.71	0.54	0.07	1.32	53.7%	41.0%	5.3%
93	0.70	0.59	0.12	1.40	49.8%	41.9%	8.3%
94	0.69	0.61	0.07	1.37	50.5%	44.3%	5.1%
95	0.63	0.65	0.12	1.40	44.8%	46.6%	8.5%
96	0.65	0.72	0.10	1.48	44.3%	48.7%	7.0%
97	0.76	0.64	0.08	1.49	51.4%	43.1%	5.4%
98	0.75	0.59	0.07	1.41	53.1%	42.0%	4.9%

PARAFAC Sample Number	Fmax1	Fmax2	Fmax3	sum	%C1	%C2	%C3
99							
100	0.24	0.29	0.04	0.56	42.1%	50.9%	7.0%
101	0.67	0.56	0.09	1.31	51.1%	42.3%	6.6%
102	0.87	0.85	0.14	1.85	46.8%	45.8%	7.4%
103	0.89	0.89	0.16	1.94	46.1%	45.8%	8.1%
104	0.91	0.84	0.15	1.90	47.7%	44.3%	8.0%
105	0.87	0.86	0.13	1.86	46.9%	46.1%	7.0%
106	0.85	0.66	0.12	1.63	52.2%	40.6%	7.2%
107	0.93	0.67	0.10	1.71	54.6%	39.4%	6.1%
108	0.86	0.81	0.14	1.81	47.3%	45.0%	7.7%
109	0.84	0.80	0.14	1.78	47.2%	44.9%	7.8%
110	0.80	0.73	0.14	1.67	48.0%	43.6%	8.4%
111	0.80	0.83	0.11	1.75	45.7%	47.7%	6.5%
112	0.74	0.76	0.12	1.62	45.5%	47.1%	7.4%
113	0.79	0.91	0.14	1.85	43.0%	49.5%	7.6%
114	0.62	0.78	0.13	1.52	40.6%	51.0%	8.3%
115	0.89	0.76	0.13	1.77	50.0%	42.9%	7.1%
116	0.93	0.71	0.12	1.75	52.8%	40.5%	6.7%
117	0.67	0.90	0.13	1.70	39.4%	53.1%	7.5%
118	0.80	0.74	0.13	1.67	47.8%	44.7%	7.6%
119	0.70	0.90	0.11	1.70	40.9%	52.7%	6.4%
120	0.68	0.89	0.11	1.68	40.2%	53.2%	6.6%
121	0.84	0.74	0.12	1.71	49.1%	43.7%	7.3%
122	0.85	0.62	0.12	1.59	53.6%	39.2%	7.3%
123	0.86	0.66	0.11	1.62	52.7%	40.6%	6.7%
124	0.48	0.82	0.11	1.41	34.2%	58.3%	7.5%
125	0.78	0.57	0.10	1.46	53.7%	39.3%	7.0%
126	0.56	0.80	0.10	1.47	38.4%	54.6%	7.1%
127	0.76	0.95	0.14	1.86	41.2%	51.4%	7.5%
128	0.83	0.77	0.11	1.71	48.7%	45.0%	6.3%

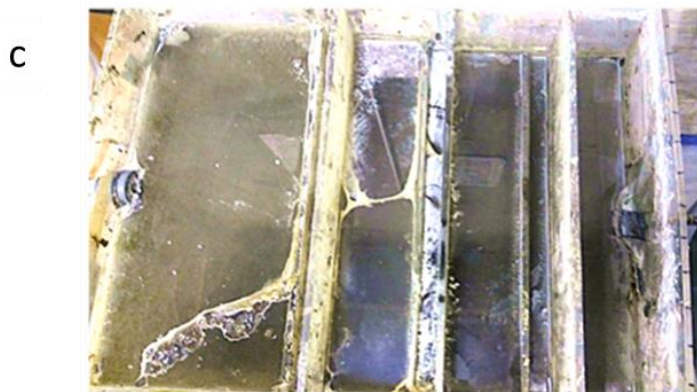
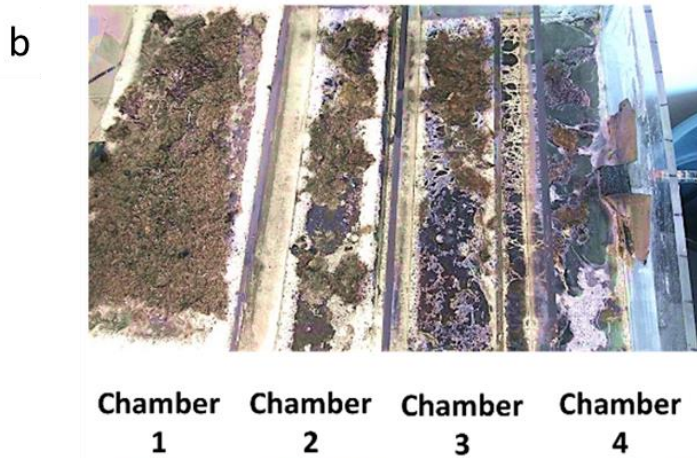
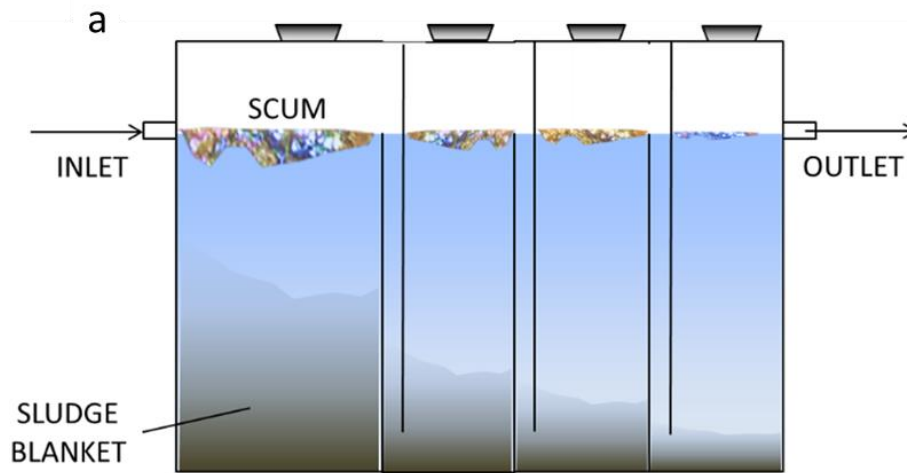
Table S6. Calculation of degradation rate coefficients (assuming first order decay) under 100% synthetic wastewater and 50% recirculated treated effluent conditions.

Parameter	Value
100% fresh synthetic wastewater	
Average COD concentration, influent	469.5
Average COD concentration, effluent	109.0
Estimated decay rate coefficient, k_{100} (h^{-1})	0.041
50% recirculated effluent	
Average COD concentration, influent	286.7
Average COD concentration, effluent	90.4
Estimated decay rate coefficient, k_{50} (h^{-1})	0.032
Reactor hydraulic residence time (HRT, h)	36

Supplementary Figures



Supplementary Figure S1. a) Photograph of decentralized wastewater treatment system in Durban, South Africa, b) cross-sectional side view of the (1) Settling Chamber (2) 7 ABR Chambers (3) 2 AF Chambers (4) Magnetic induction Flow meter (Picture courtesy of BORDA 2011), and c) photograph of flasks containing water from each chamber of the settler-ABR-AF system showing color change from inlet to outlet.



Supplementary Figure S2. Schematic showing a) side view of lab-scale ABR and photographs showing top view of scum in four chambers of the ABR under b) fresh wastewater under normal operation and c) 50% recirculated wastewater conditions. Note that scum was not physically removed; the scum dissipated due to recirculation.

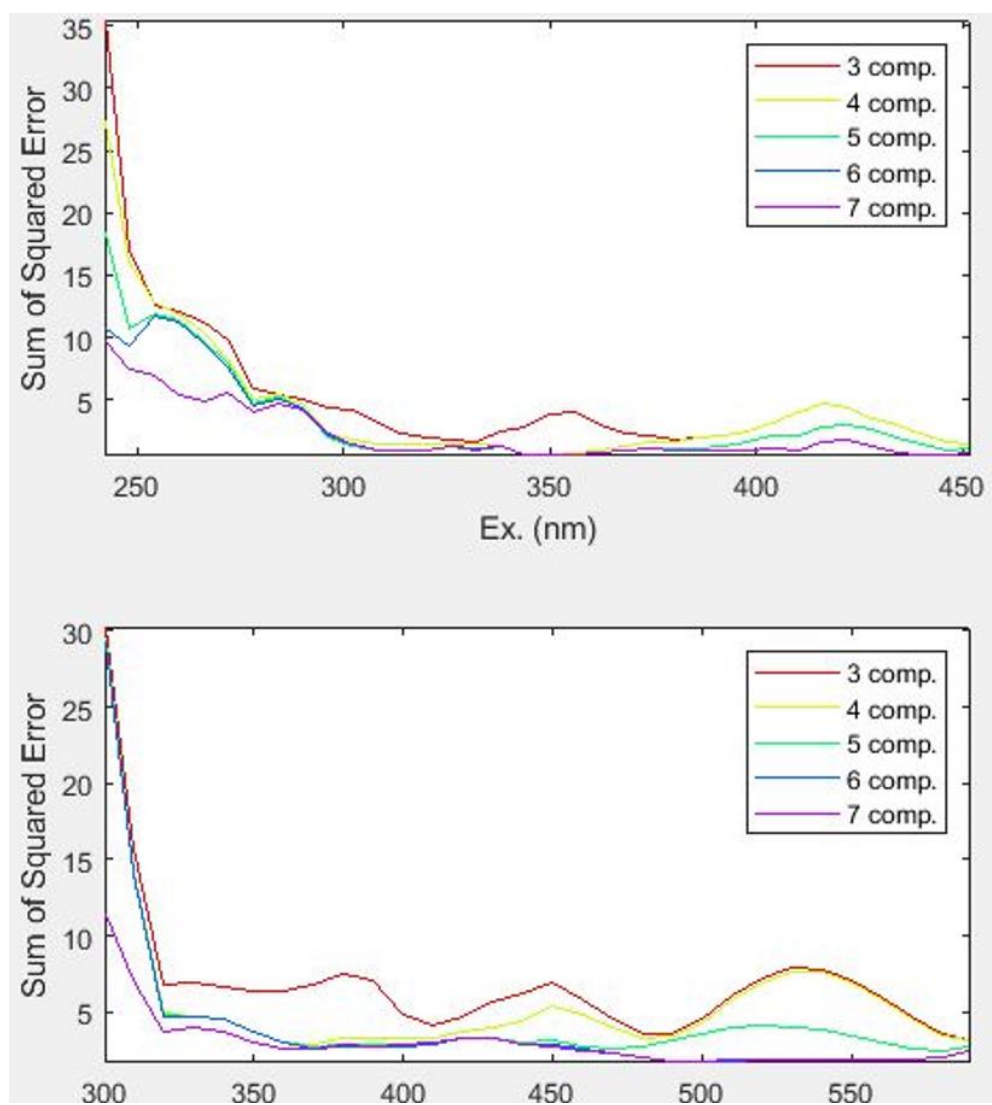


Figure S3. Sum of squared error for excitation (top) and emission (bottom) wavelengths in PARAFAC models with 3 to 7 components.

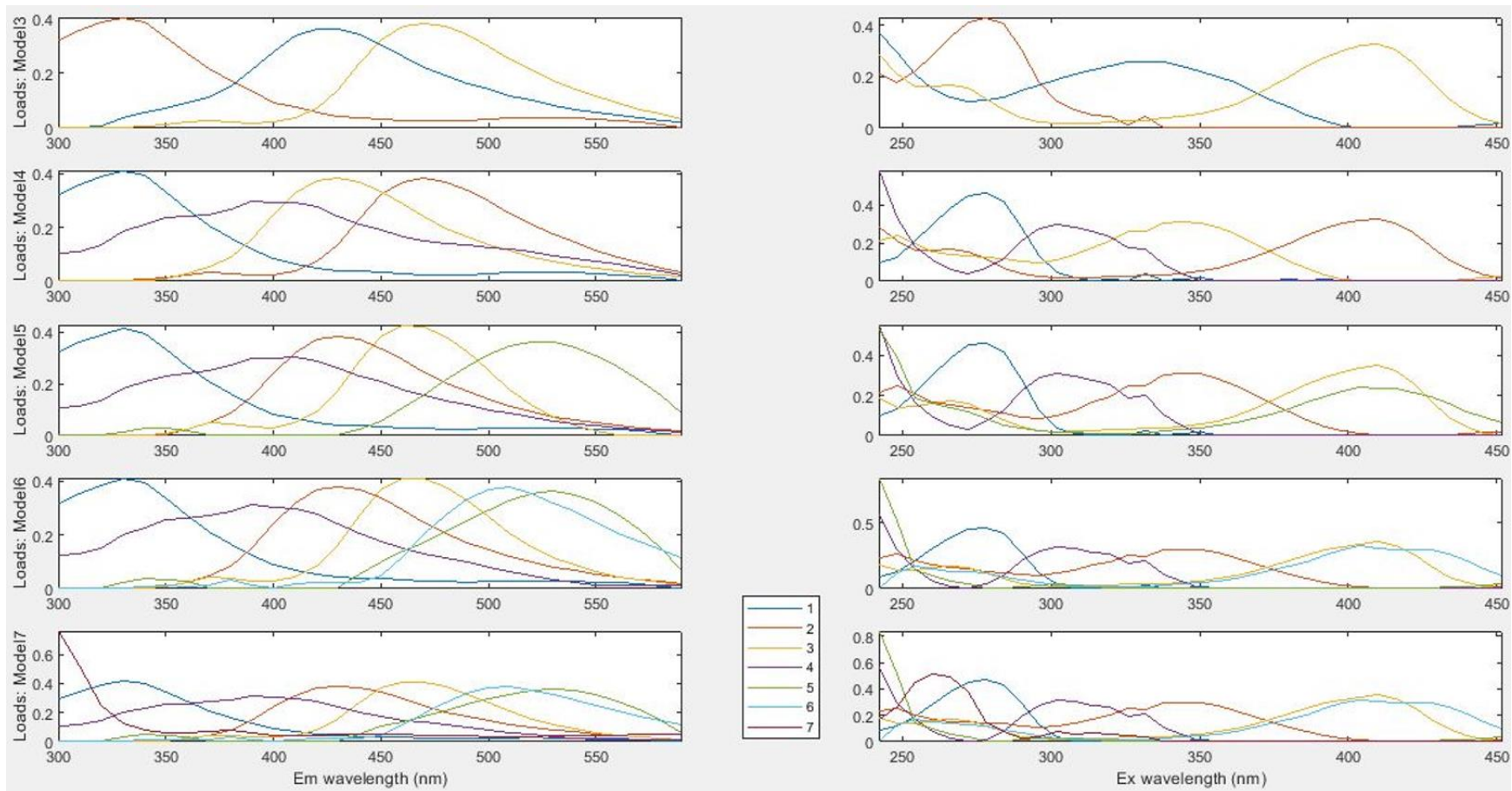
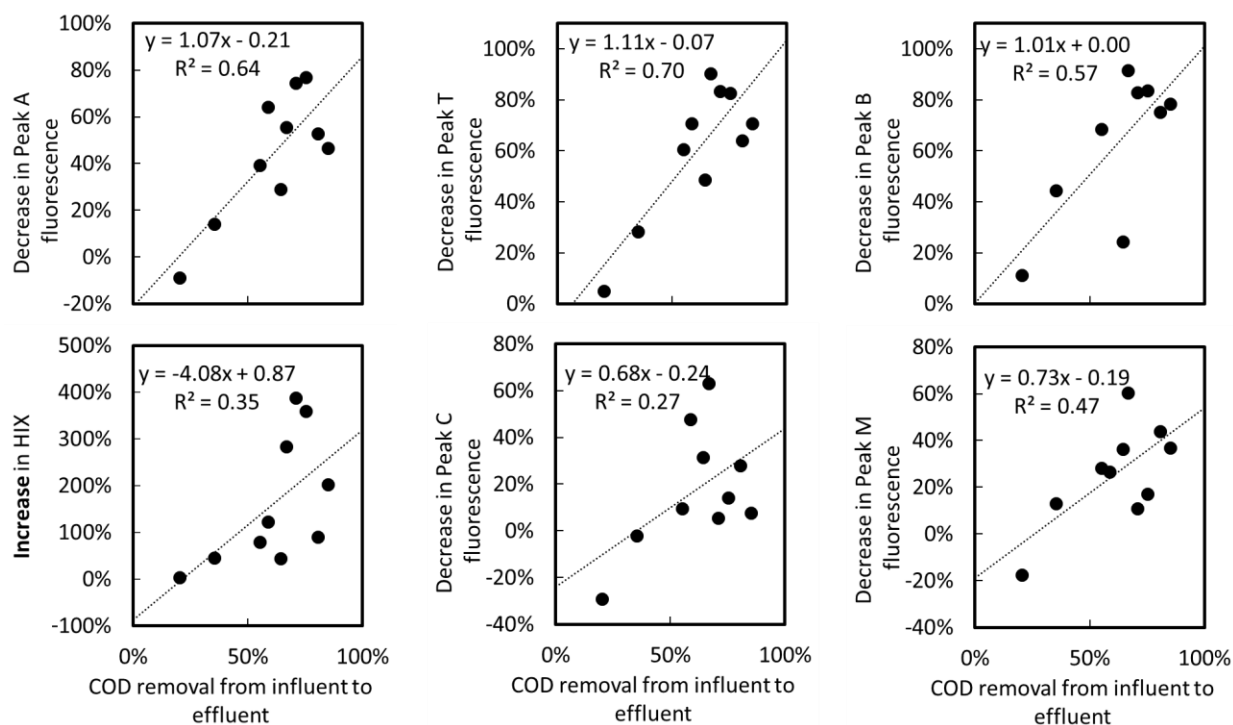


Figure S4. Loads for emission (left) and excitation (right) for 3- to 7-component models.



Figures S5. Relationships between COD removals and changes in the 5 main fluorescent peaks and HIX from influent to effluent. Each point represents the average removal or increase/decrease for each of the ten treatment scenarios given in Table 1 of the main text. Note that the HIX changes are shown as % increases in HIX from influent to effluent, whereas the peak intensity changes are shown as a % decrease from influent to effluent.

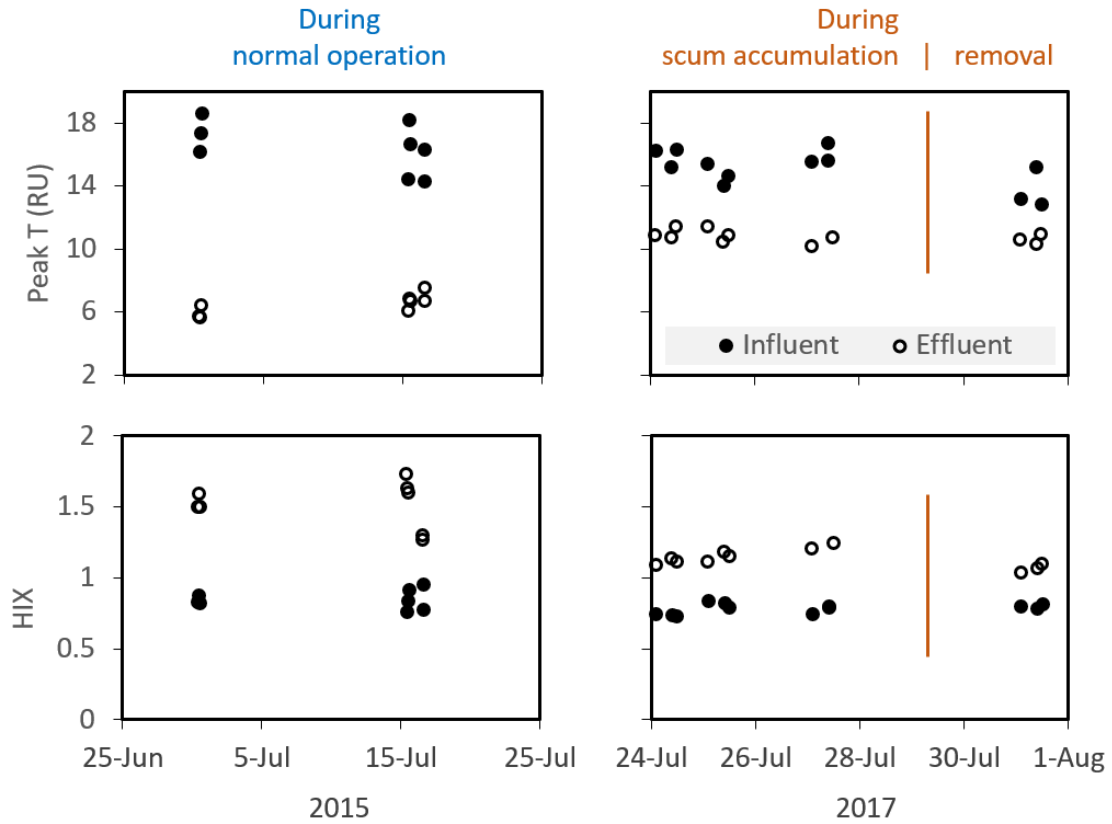


Figure S6. Changes in Peak T and HIX in influent (filled circles) and effluent (open circles) in the community-scale ABR in 2015 under normal operation (left) and in 2017 under scum accumulation and removal conditions (right). Effluent Peak T values decrease more and effluent HIX values are higher when the ABR was operating without scum accumulation issues (2015) compared to when scum accumulated to actionable levels (2017).

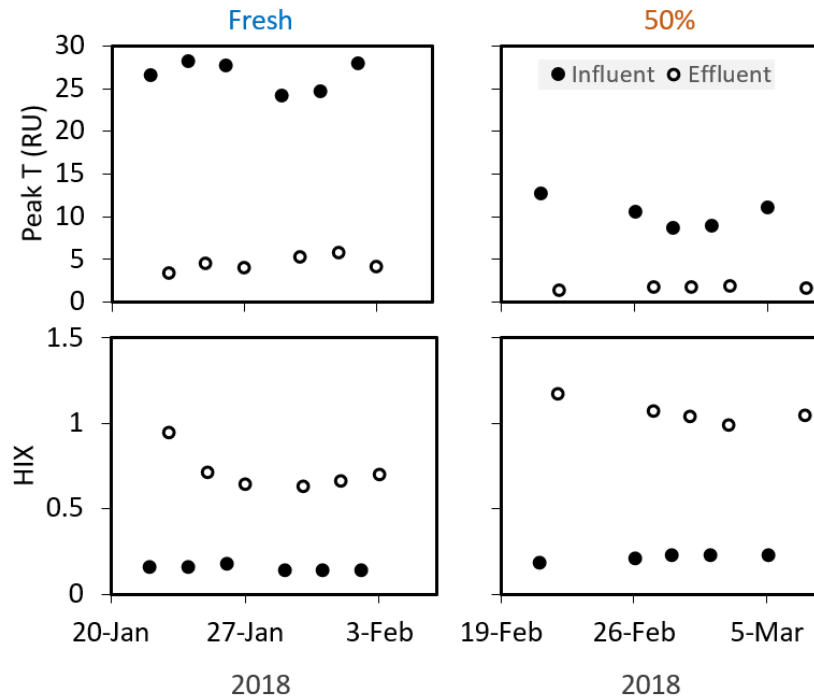


Figure S7. Changes in Peak T and HIX in influent (filled circles) and effluent (open circles) in the lab-scale ABR in 2018 under conditions with fresh 100% synthetic wastewater (left) and 50% recirculated effluent mixed with synthetic wastewater (right). Influent becomes more recalcitrant (lower Peak T) when the ABR was fed with 50% recirculated effluent compared to when the ABR was fed with fresh 100% synthetic wastewater, but effluent values are no .