

Summary Results of Dynamic Closedloop Simulations of the COST 624 Benchmark

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In this document the results from five different simulation platforms that have been applied to perform the COST 624 Benchmark exercise are summarised. The results are based on the so called closedloop case, i.e. active controllers, applied noise, measurement delays, etc., and include all three weather files (dry weather, rain weather and storm weather). This means that theoretically all results should not be identical but rather depend on the actual controller settings. Note that the influent and effluent quality indices are based on the new weighting values, i.e. $B_{SS} = 2$, $B_{COD} = 1$, $B_{BOD5} = 2$, $B_{NKj} = 20$, $B_{NO} = 20$. The calculations are performed as follows:

- implement the plant layout with the models described on the COST web-site;
- calculate (by simulating at least 100 days) the quasi steady states of all state variables using the defined constant input file with active controllers but no delay or noise applied;
- use this defined quasi steady state as the initial condition and simulate the plant for 14 days using the defined dry weather input file with active control, noise and delay;
- use the final values of this simulation as initial conditions and simulate the weather file of your choice (14 days) again with active control, noise and delay;
- calculate the various performance criteria exactly as defined on the web-site based on the data of the last 7 days of simulation.

In order to achieve correct results make sure of the following:

- set the numeric tolerances of your simulator to low values to ensure accurate results. You may later increase the tolerances to improve the computational speed but you should always compare these less accurate results with the ones achieved with low tolerances before you accept them;
- your simulator should read data from the input files and write data to the output files with exactly 15 minutes intervals. If your simulator makes some kind of interpolation instead then your results will not be correct;
- when calculating the different integrals that are required for the performance criteria use a simple Euler forward approximation, i.e. discrete calculation and zero-order hold between the sampling instants (sample every 15 minutes);

- the integral calculations are based on the last 7 seven days, i.e. the first sample used should be the one at time 7.0000000 days and the last sample used should be the one at time 13.989583333 d (i.e. 13 days 23 hours and 45 minutes). The sample at time 14 d should *not* be included in the integral since you are using a forward Euler approximation;
- make sure that your noise, delay and discrete nitrate measurements works properly – study a few samples in very close detail to ensure this.

The results have been collected from five different platforms – GPS-X, Fortran, Simulink, SIMBA and WEST. The Simulink and SIMBA implementations have worked without any apparent problems. After several coding errors in the Fortran implementation it also works properly. With regard to GPS-X (version 2.3.1) it should be noted that a patch from Hydromantis is required in order to solve a problem with reading and writing data at exactly the required time instants. The inclusion of noise in the GPS-X implementation is not a trivial task. The GPS-X settler model also have a problem since it only use 1 layer (i.e. the entire settler) to describe the behaviour of the soluble material (10 layers should be used according to the COST Benchmark). The first problem has been solved for the results presented in the following pages whereas the second problem remains. Similar problems were also encountered for the WEST simulator (varying time step for output data and 0 layers for the solubles in the settler) but have been corrected.

The results have been provided by several research groups and their work should be acknowledged:

- GPS-X results – John Copp and Henri Spanjers, Wageningen, The Netherlands;
- FORTRAN results – Marie-Noëlle Pons, Nancy, France;
- SIMULINK results – myself (SIMULINK_1) and Antonio Salterain, San Sebastian, Spain (SIMULINK_2);
- SIMBA results – Jens Alex, Magdeburg, Germany;
- WEST results – Peter Vanrolleghem, Henk Vanhooren and Matty Janssen, Gent, Belgium.

The results clearly indicate that we have more or less reached identical results and we can now ‘guarantee’ that they are correct. They provide a basis for comparison for those of you who are interested in setting up and performing your own benchmark simulations. If anyone has results like the ones presented here (maybe for another platform) I would appreciate if you could send them to me so that they may be incorporated.

A similar summary document have been compiled with the results of the openloop simulations for all platforms i.e. excluding active controllers, noise and delays of sensor signals.

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Performance Criteria for DRYWEATHER Dynamic Closedloop Simulations (i.e. full Dry Benchmark)

Effluent average concentrations based on load

	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
Q =	18061.332	18061	18061.2615	18061.1387	18085.6	18064.24384	m3/d	18065.76267	24.6
S_I =	30	30	30	30	30	30	g COD/m3	30	0
S_S =	0.8725696	0.888	0.8817	0.8912	0.8852	0.877920747	g COD/m3	0.882765058	0.0186304
X_I =	4.5811523	4.57	4.5718	4.5745	4.5735	4.572547704	g COD/m3	4.573916667	0.0111523
X_S =	0.2018123	0.202	0.20072	0.20125	0.201689	0.199281595	g COD/m3	0.201125483	0.002718405
X_BH =	10.231476	10.2	10.2308	10.2304	10.2303	10.2109748	g COD/m3	10.22232513	0.031476
X_BA =	0.578791	0.58	0.57825	0.5778	0.572267	0.57812071	g COD/m3	0.577538118	0.007733
X_P =	1.7569069	1.76	1.7548	1.7568	1.75555	1.754514456	g COD/m3	1.756428559	0.005485544
S_O =	1.9901785	1.987	1.9997	1.997718	1.98667	1.998866738	g (-COD)/m3	1.994626648	0.01303
S_NO =	12.412463	13.2	12.4394	12.3894	12.6486	12.33513935	g N/m3	12.57083373	0.86486065
S_NH =	2.5284975	2.45	2.5287	2.5577	2.58934	2.501994705	g N/m3	2.526038701	0.13934
S_ND =	0.7011567	0.713	0.7066	0.7084	0.708295	0.70523981	g N/m3	0.707115252	0.0118433
X_ND =	0.0144754	0.0146	0.014414	0.01443	0.0144893	0.01431048	g N/m3	0.014453197	0.00028952
S_ALK =	n/a	3.98	4.0387	4.0442	4.02869	n/a	kmol HCO3/m3	4.0228975	0.0642
TSS =	13.01263	12.98	13.0023	13.0056	13	12.98657945	g SS/m3	12.99785158	0.03263
N_TKN =	4.4892345	4.42	4.494	4.5251	4.55608	4.464296365	g N/m3	4.491451811	0.13608
N_tot =	16.901697	17.6	16.9334	16.9145	17.2047	16.79943572	g N/m3	17.05895545	0.80056428
COD_tot =	48.222708	48.24	48.2181	48.2321	48.2185	48.19336001	g COD/m3	48.22079467	0.04663999
BOD5_tot =	2.7549569	2.76	2.7567	2.759	2.75632	2.750792552	g/m3	2.756294909	0.009207448

Effluent average loads

	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
S_I =	541.83996	542	541.8378	541.8341	542.569	541.9273151	kg COD/d	542.0013625	0.7349
S_S =	15.759769	16	17.9247	16.096	16.0094	15.85897445	kg COD/d	16.27480724	2.164931
X_I =	82.741711	82.6	82.5732	82.6206	82.7148	82.59961668	kg COD/d	82.64165461	0.168511
X_S =	3.6449982	3.65	3.6252	3.6348	3.64768	3.599871326	kg COD/d	3.633758254	0.050128674
X_BH =	184.79409	185	184.7804	184.7726	185.022	184.4535385	kg COD/d	184.8037714	0.5684615
X_BA =	10.453736	10.5	10.4439	10.4357	10.3498	10.44331348	kg COD/d	10.43774158	0.1502
X_P =	31.732079	31.7	31.6946	31.7298	31.7503	31.69397694	kg COD/d	31.71679266	0.05632306
S_O =	35.945275	35.88	36.1178	36.081	35.9303	36.10801615	kg (-COD)/d	36.03647823	0.1875
S_NO =	224.18561	238	224.6717	223.7666	228.758	222.824965	kg N/d	227.0344792	15.175035
S_NH =	45.668033	44.2	45.6707	46.1949	46.83	45.19664243	kg N/d	45.62671257	2.63
S_ND =	12.663824	12.9	12.7621	12.7945	12.81	12.7396239	kg N/d	12.77834132	0.236176
X_ND =	0.2614445	0.263	0.26033	0.2606	0.262049	0.258507993	kg N/d	0.260988582	0.004492007
S_ALK =	n/a	71.9	72.9446	73.0428	72.8614	n/a	kmol HCO3/d	72.6872	1.1428
TSS =	235.02544	234.5	234.838	234.8959	235.114	234.5927377	kg N/d	234.8276796	0.614
N_TKN =	81.081555	79.83	81.1672	81.7284	82.3997	80.6441381	kg N/d	81.14183218	2.5697
N_tot =	305.26716	317.9	305.8388	305.4951	311.157	303.4691031	kg N/d	308.1878605	14.4308969
COD_tot =	870.96633	871.2	870.8798	871.1266	872.064	870.5766065	kg COD/d	871.1355561	1.4873935
BOD5_tot =	49.758191	49.85	49.7891	49.8306	49.8498	49.69098741	kg/d	49.79477974	0.15901259

Other quality variables

	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
I.Q.-index =	42042.81	42000	42042.8148	42044.7979	42042.81	42042.81572	kg poll.units/d	42036.00807	44.7979
E.Q.-index =	7545.88	7760	7556.9103	7550.6268	7665.14	7501.017593	kg poll.units/d	7596.595782	258.982407
P_sludge =	17104.3	17087	17085.4557	17116.1228	17080.74	17142.67521	kg SS	17102.71562	61.93521
P_sludge per day =	2443.5	2441	2440.7794	2445.1604	2440.11	2448.953602	kg SS/d	2443.250567	8.843602
P_sludge_eff =	1645.2	1631	1643.8657	1644.3	1645.8	1642.149164	kg SS	1642.052477	14.8
P_sludge_eff per day =	235.0	233	234.838	234.9	235.11	234.5927377	kg SS/d	234.5734563	2.11
P_total_sludge =	18749.5	18718	18729.3214	18760.4228	18726.54	18784.82437	kg SS	18744.7681	66.82437
P_total_sludge per day =	2678.5	2674	2675.6173	2680.0604	2675.22	2683.546339	kg SS/d	2677.824007	9.546339
Aeration energy =	7241	7262	7241.2745	7252.1724	7253.21	7231.502233	kWh/d	7246.859856	30.497767
Pumping energy =	1524	1328	1488.1421	1545.7928	1430.31	1521.875063	kWh/d	1473.019994	217.7928
The max effluent N_tot level (18 g N/m3) was violated during:	0.9898	2.03	1.2813	1.1875	1.4583	1.1235	d	1.345066667	1.0402
i.e.:	14.14	29	18.3036	16.99	20.83	16.05	% of the time	19.21893333	14.86
The limit was violated at:	5	9	7	7	7	7	occasions	7	4
The max effluent S_NH level (4 g N/m3) was violated during:	1.211	1.16	1.2083	1.2083	1.3021	1.197	d	1.21445	0.1421
i.e.:	17.3	16.6	17.2619	17.28	18.6	17.1	% of the time	17.35698333	2
The limit was violated at:	5	5	5	5	6	5	occasions	5.166666667	1

Controller Performance	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	average	max-min
<u>Nitrate controller for second anoxic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Proportional gain (K) =	7500	5040	15000	24027	10000	10000	m3/d/(g N/m3)	11927.83333	18987
Integral time constant (Ti) =	0.0125	0.007	0.05	0.003	0.08	0.01	d	0.027083333	0.077
Anti-windup time constant (Tt) =	not used	not used	0.03	not used	not used	not used	d	0.03	0
<u>Controlled variable, SNO2</u>									
Setpoint =	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	g N/m3	1.0000	0.0000
Integral of absolute error (IAE) =	0.1851641	4.04	1.4818	2.4945	2.57325	0.828789688	(g N/m3)*d	1.933917298	3.8548359
Integral of square error (ISE) =	0.0662959	3.35	0.59844	2.7302	1.61783	0.189228297	(g N/m3)**2*d	1.425332366	3.2837041
Max abs deviation from setpoint (max e) =	0.8827	1.59	0.88729	2.6535	0.9	0.65155339	g N/m3	1.260840565	2.00194661
Standard deviation of error (std e) =	0.1790472	0.38	0.29234	0.3595	0.480315	0.164445834	g N/m3	0.309274672	0.315869166
Variance of error (var e) =	0.0320579	0.144	0.085463	0.1292	0.230702	0.027042432	(g N/m3)**2	0.108077555	0.203659568
<u>Manipulated variable (MV), Qintrec</u>									
Max abs deviation of MV (max-min) =	49531	92232	36691.4502	n/a	30887.5	46724.644	m3/d	51213.31884	61344.5
Max abs dev of MV in one sample (delta) =	10677	12000	8077.7893	n/a	6218.02	9880.633	m3/d	9370.68846	5781.98
Standard deviation of MV (std delta) =	1622.53	285.6	1661.9725	n/a	1741.16	1554.003566	m3/d	1373.053213	1455.56
Variance of MV (var delta)=	2632603.5	81567	2762152	n/a	3031000	2414927.083	(m3/d)**2	2184449.917	2949433
<u>Oxygen controller for third aerobic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Proportional gain (K) =	20.8	16.8	500	125.8	100	5000	1/d/(g (-COD)/m3)	960.5666667	4983.2
Integral time constant (Ti) =	0.002	0.0025	0.001	0.0023	0.01	0.05	d	0.0113	0.049
Anti-windup time constant (Tt) =	not used	not used	0.0002	not used	not used	not used	d	0.0002	0
<u>Controlled variable, SO5</u>									
Setpoint =	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	g (-COD)/m3	2.0000	0.0000
Integral of absolute error (IAE) =	0.0451658	0.454	0.0075065	0.0177	0.302823	0.026609829	(g (-COD)/m3)*d	0.142300855	0.4464935
Integral of square error (ISE) =	0.0049911	0.067	1.7386e-5	0.0012	0.029381	0.000190988	(g (-COD)/m3)**2*d	0.017130079	0.066982614
Max abs deviation from setpoint (max e) =	0.3408	0.41	0.0069017	0.2251	0.259716	0.0175857	g (-COD)/m3	0.210017233	0.4030983
Standard deviation of error (std e) =	0.0543653	0.0731	0.0015756	0.01309	0.0647865	0.005226021	g (-COD)/m3	0.035357237	0.0715244
Variance of error (var e) =	0.0029556	0.0053	2.4824e-6	1.715e-4	0.004197	2.73113E-05	(g (-COD)/m3)**2	0.002108982	0.005297518
<u>Manipulated variable (MV), K1a5</u>									
Max abs deviation of MV (max-min) =	186.737	240	186.4117	228.75	186.99	182.000362	1/d	201.8148437	57.999638
Max abs dev of MV in one sample (delta) =	36.229	12	36.7723	n/a	29.7157	38.65462	1/d	30.674324	26.65462
Standard deviation of MV =	5.9096592	0.41	5.7745	4.5808	6.92972	5.964291813	1/d	4.928161836	6.51972
Variance of MV =	34.924072	168	33.3452	20.9835	48.021	35.57277683	(1/d)**2	56.80775814	147.0165

Performance Criteria for RAINWEATHER Dynamic Closedloop Simulations (i.e. full Rain Benchmark)

Effluent average concentrations based on load

	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
Q =	23808.179	23810	23808.124	23816.798	23833.1	23830.46006	m ³ /d	23817.77684	24.976
S_I =	22.832339	22.8	22.8387	22.8307	22.845	22.84560299	g COD/m ³	22.832057	0.04560299
S_S =	1.0238101	1.05	1.0296	1.033	1.03718	1.024058619	g COD/m ³	1.032941453	0.0261899
X_I =	5.6352353	5.63	5.6271	5.632	5.62768	5.62391311	g COD/m ³	5.629321402	0.01132219
X_S =	0.3127029	0.319	0.31103	0.3101	0.313841	0.308238186	g COD/m ³	0.312485348	0.010761814
X_BH =	12.876041	12.9	12.881	12.8854	12.8758	12.84971122	g COD/m ³	12.87799204	0.05028878
X_BA =	0.6854039	0.689	0.68563	0.6853	0.67765	0.685109395	g COD/m ³	0.684682216	0.01135
X_P =	2.0624052	2.06	2.061	2.0641	2.06114	2.059661251	g COD/m ³	2.061384409	0.004438749
S_O =	1.9932138	1.992	1.9998	1.9984	1.99101	1.999234002	g (-COD)/m ³	1.99633156	0.00879
S_NO =	9.1307278	9.74	9.1748	9.0932	9.31299	9.07817566	g N/m ³	9.254982243	0.66182434
S_NH =	3.2586352	3.16	3.2172	3.2388	3.2872	3.195187862	g N/m ³	3.22617051	0.1272
S_ND =	0.7842192	0.8	0.78753	0.7881	0.790726	0.786515316	g N/m ³	0.789515086	0.0157808
X_ND =	0.0216013	0.0221	0.021515	0.0214	0.0217156	0.021313945	g N/m ³	0.021607641	0.000786055
S_ALK =	n/a	4.82	4.8589	4.8668	4.85402	n/a	kmol HCO ₃ /m ³	4.84993	0.0468
TSS =	16.178817	16.20	16.1744	16.1828	16.1671	16.14497487	g SS/m ³	16.17468198	0.05502513
N_TKN =	5.6112297	5.53	5.5729	5.5959	5.64525	5.546817234	g N/m ³	5.583682822	0.11525
N_tot =	14.741958	15.27	14.7477	14.6891	14.9582	14.62499289	g N/m ³	14.83865848	0.64500711
COD_tot =	45.427938	45.44	45.4341	45.4407	45.4383	45.39629478	g COD/m ³	45.42955546	0.04440522
BOD5_tot =	3.4532607	3.465	3.4555	3.457	3.45505	3.446082944	g/m ³	3.455315607	0.018917056

Effluent average loads

	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
S_I =	543.59641	544	543.7459	543.7541	544.467	544.4212296	kg COD/d	543.9974399	0.87059
S_S =	24.375054	25	24.512	24.6027	24.7192	24.40378802	kg COD/d	24.60212367	0.624946
X_I =	134.16469	134	133.9717	134.1362	134.125	134.0204368	kg COD/d	134.0696711	0.19299
X_S =	7.4448874	7.6	7.405	7.3855	7.47982	7.345457782	kg COD/d	7.443444197	0.254542218
X_BH =	306.55509	307	306.6719	306.8889	306.87	306.2145301	kg COD/d	306.70007	0.7854699
X_BA =	16.318218	16.4	16.3236	16.3216	16.1505	16.32647208	kg COD/d	16.30673168	0.2495
X_P =	49.10211	49.2	49.0695	49.1602	49.1233	49.08267518	kg COD/d	49.1229642	0.1305
S_O =	47.454791	47.47	47.6122	47.5955	47.452	47.64266602	kg (-COD)/d	47.5514314	0.19066602
S_NO =	217.386	232	218.4344	216.5709	221.958	216.3371025	kg N/d	220.4477338	15.6628975
S_NH =	77.582168	75.3	76.5961	77.1378	78.3443	76.14279672	kg N/d	76.85052745	3.0443
S_ND =	18.670831	19.1	18.7496	18.77	18.8455	18.74302183	kg N/d	18.81315881	0.429169
X_ND =	0.5142871	0.527	0.51223	0.5096	0.517552	0.507921118	kg N/d	0.514765036	0.019078882
S_ALK =	n/a	115	118.6819	115.9115	115.687	n/a	kmol HCO ₃ /d	116.3201	3.6819
TSS =	385.18817	385.65	385.0813	385.4224	385.313	384.7421789	kg N/d	385.2328415	0.9078211
N_TKN =	133.59316	131.67	132.68	133.2734	134.544	132.1832066	kg N/d	132.9906278	2.874
N_tot =	350.97916	364.58	351.1144	349.8473	356.502	348.520309	kg N/d	353.5905282	16.059691
COD_tot =	1081.5565	1082.1	1081.6997	1082.2519	1082.94	1081.814589	kg COD/d	1082.060448	1.3835
BOD5_tot =	82.215847	82.501	82.2682	82.3346	82.3446	82.12174195	kg/d	82.29766483	0.37925805

Other quality variables

	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
I.Q.-index =	42042.81	42000	42042.8148	42044.7979	42042.81	42042.81571	kg poll.units/d	42036.00807	44.7979
E.Q.-index =	9035.95	9250	9038.6862	9014.7342	9148.28	8976.962663	kg poll.units/d	9077.435511	273.037337
P_sludge =	16518.3	16492	16504.4747	17760.2096	16499.89	16629.1722	kg SS	16734.00775	1268.2096
P_sludge per day =	2359.8	2356	2357.7821	2537.1728	2357.13	2375.596028	kg SS/d	2390.580155	181.1728
P_sludge_eff =	2696.3	2695	2695.569	2697.9575	2697.18	2693.195252	kg SS	2695.866959	4.762248
P_sludge_eff per day =	385.2	385	385.0813	385.4225	385.31	384.7421789	kg SS/d	385.1259965	0.6803211
P_total_sludge =	19214.6	19187	19200.0437	20458.1671	19197.07	19322.36745	kg SS	19429.87471	1271.1671
P_total_sludge per day =	2744.9	2741	2742.8634	2922.5953	2742.44	2760.338207	kg SS/d	2775.689485	181.5953
Aeration energy =	7168	7198	7169.7658	7172.966	7179.71	7159.81027	kWh/d	7174.708678	38.18973
Pumping energy =	2009	1647	1927.5325	2019.97	1840.03	2004.244005	kWh/d	1907.962751	372.97
The max effluent N_tot level (18 g N/m3) was violated during:	0.4165	1.16	0.79167	0.7395	0.9063	0.6825	d	0.782745	0.7435
i.e.:	5.95	16.6	11.3095	10.581	12.95	9.75	% of the time	11.19008333	10.65
The limit was violated at:	3	7	5	5	5	5	occasions	5	4
The max effluent S_NH level (4 g N/m3) was violated during:	2.002	1.86	1.8958	1.8645	1.9583	1.8375	d	1.903016667	0.1645
i.e.:	28.6	26.6	27.0833	26.67	27.98	26.25	% of the time	27.19721667	2.35
The limit was violated at:	8	8	8	8	8	8	occasions	8	0

Controller Performance	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	average	max-min
<u>Nitrate controller for second anoxic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Proportional gain (K) =	7500	5040	15000	24027	10000	10000	m3/d/(g N/m3)	11927.83333	18987
Integral time constant (Ti) =	0.0125	0.007	0.05	0.003	0.08	0.01	d	0.027083333	0.077
Anti-windup time constant (Tt) =	not used	not used	0.03	not used	not used	not used	d	0.03	0
<u>Controlled variable, SNO2</u>									
Setpoint =	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	g N/m3	1.0000	0.0000
Integral of absolute error (IAE) =	0.21702	4.375	1.8182	2.1352	2.57325	0.987478863	(g N/m3)*d	2.017691477	4.15798
Integral of square error (ISE) =	0.0903118	4.14	0.84205	2.0863	1.61783	0.278570956	(g N/m3)**2*d	1.509177126	4.0496882
Max abs deviation from setpoint (max e) =	0.920014	2.51	0.9092	2.6536	0.9	0.732948	g N/m3	1.437627	1.920652
Standard deviation of error (std e) =	0.2080349	0.445	0.3468	0.53021	0.480315	0.19954995	g N/m3	0.368318308	0.33066005
Variance of error (var e) =	0.0432785	0.198	0.12027	0.28113	0.230702	0.039820182	(g N/m3)**2	0.152200114	0.241309818
<u>Manipulated variable (MV), Qintrec</u>									
Max abs deviation of MV (max-min) =	92232	46845	77424.58	n/a	70176.3	92232	m3/d	75781.976	45387
Max abs dev of MV in one sample (delta) =	10135	12000	8897.2944	n/a	6157.58	9998.969	m3/d	9437.76868	5842.42
Standard deviation of MV (std delta) =	1769.7859	288	1641.798	n/a	1754.69	1764.968821	m3/d	1443.848544	1481.7859
Variance of MV (var delta)=	3132142.1	82944	2695501	n/a	3078930	3115114.94	(m3/d)**2	2420926.408	3049198.1
<u>Oxygen controller for third aerobic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Proportional gain (K) =	20.8	16.8	500	125.8	100	5000	1/d/(g (-COD)/m3)	960.5666667	4983.2
Integral time constant (Ti) =	0.002	0.0025	0.001	0.0023	0.01	0.05	d	0.0113	0.049
Anti-windup time constant (Tt) =	not used	not used	0.0002	not used	not used	not used	d	0.0002	0
<u>Controlled variable, SO5</u>									
Setpoint =	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	g (-COD)/m3	2.0000	0.0000
Integral of absolute error (IAE) =	0.0389263	0.395	0.0069977	0.01257	0.262958	0.023169863	(g (-COD)/m3)*d	0.123270311	0.3880023
Integral of square error (ISE) =	0.0037126	0.052	5.8307e-5	7.3292e-4	0.0225193	0.0001474	(g (-COD)/m3)**2*d	0.013195088	0.051941693
Max abs deviation from setpoint (max e) =	0.3068	0.386	0.065537	0.2251	0.249905	0.0173045	g (-COD)/m3	0.208441083	0.3686955
Standard deviation of error (std e) =	0.0469105	0.0654	0.0028853	0.01023	0.0567189	0.004591101	g (-COD)/m3	0.031122634	0.0625147
Variance of error (var e) =	0.0022006	0.00428	8.3252e-6	1.47e-4	0.00321	2.10782E-05	(g (-COD)/m3)**2	0.001644501	0.004271675
<u>Manipulated variable (MV), K1a5</u>									
Max abs deviation of MV (max-min) =	189.993	240	220.2254	228.75	189.837	182.447648	1/d	208.5421747	57.552352
Max abs dev of MV in one sample (delta) =	31.43	12	35.7611	n/a	28.5663	35.78925	1/d	28.70933	23.78925
Standard deviation of MV =	5.0835676	0.365	5.2715	3.9255	6.06096	5.12467932	1/d	4.305201153	5.69596
Variance of MV =	25.84266	0.133	27.7882	15.4095	36.7353	26.26233813	(1/d)**2	22.02849969	36.6023

Performance Criteria for STORMWEATHER Dynamic Closedloop Simulations (i.e. full Storm Benchmark)

Effluent average concentrations based on load

	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
Q =	20658.1	20658	20658.0636	20662.025	20685.7	20655.21858	m ³ /d	20662.8512	30.48142
S_I =	26.276135	26.3	26.2992	26.2948	26.297	26.29839548	g COD/m ³	26.29425508	0.023865
S_S =	0.9883815	1.01	0.99954	1.0091	1.00276	0.996289003	g COD/m ³	1.001011751	0.0216185
X_I =	5.635894	5.64	5.632	5.6367	5.63126	5.625275255	g COD/m ³	5.633521543	0.014724745
X_S =	0.2911464	0.289	0.28741	0.2895	0.287287	0.285748547	g COD/m ³	0.288348658	0.005397853
X_BH =	11.881283	11.9	11.9024	11.9045	11.8936	11.86434217	g COD/m ³	11.89102086	0.04015783
X_BA =	0.6299315	0.633	0.63109	0.6304	0.624101	0.630154636	g COD/m ³	0.629779523	0.008899
X_P =	1.9045318	1.91	1.9066	1.9084	1.90578	1.904030422	g COD/m ³	1.906557037	0.005969578
S_O =	1.9895274	1.988	1.9975	1.9953	1.98967	1.998351338	g (-COD)/m ³	1.994069748	0.008823938
S_NO =	10.540929	11.2	10.5639	10.5035	10.7358	10.45710651	g N/m ³	10.66687259	0.74289349
S_NH =	3.091531	3	3.0529	3.0935	3.12301	3.030287975	g N/m ³	3.065204829	0.12301
S_ND =	0.7688992	0.785	0.77672	0.7788	0.77868	0.775628963	g N/m ³	0.777288027	0.0161008
X_ND =	0.0206647	0.0206	0.020422	0.0205	0.0204212	0.020301113	g N/m ³	0.020484836	0.000363587
S_ALK =	n/a	4.44	4.4881	4.4955	4.48152	n/a	kmol HCO ₃ /m ³	4.47628	0.0555
TSS =	15.257111	15.279	15.2696	15.2775	15.2565	15.23216327	g SS/m ³	15.26197905	0.04683673
N_TKN =	5.3344175	5.261	5.3051	5.3485	5.37576	5.277536136	g N/m ³	5.317052273	0.11476
N_tot =	15.875347	16.47	15.8689	15.852	16.1115	15.73464265	g N/m ³	15.98539828	0.73535735
COD_tot =	47.607303	47.67	47.6583	47.674	47.6418	47.60423551	g COD/m ³	47.64260642	0.06976449
BOD5_tot =	3.1974613	3.21	3.2044	3.2077	3.20159	3.194243652	g/m ³	3.202565825	0.015756348

Effluent average loads

	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
S_I =	542.81501	543	543.2904	543.303	543.97	543.199107	kg COD/d	543.2629195	1.15499
S_S =	20.418083	20.8	20.6486	20.85	20.7427	20.57856714	kg COD/d	20.67299169	0.431917
X_I =	116.42686	117	116.3466	116.4656	116.486	116.19129	kg COD/d	116.4860583	0.80871
X_S =	6.0145323	5.98	5.9374	5.9816	5.94272	5.902198706	kg COD/d	5.959741834	0.112333594
X_BH =	245.44473	246	245.8812	245.971	246.028	245.0605808	kg COD/d	245.7309185	0.9674192
X_BA =	13.013189	13.1	13.0371	13.0253	12.91	13.01598174	kg COD/d	13.01692846	0.19
X_P =	39.344009	39.4	39.386	39.4314	39.4223	39.32816457	kg COD/d	39.38531226	0.10323543
S_O =	41.099855	41.09	41.2644	41.2269	41.1577	41.27638369	kg (-COD)/d	41.20504774	0.17652869
S_NO =	217.75556	232	218.2292	217.0235	222.077	215.9938208	kg N/d	220.5131801	16.0061792
S_NH =	63.865155	62	63.0676	63.9179	64.6016	62.5912605	kg N/d	63.34058592	2.6016
S_ND =	15.883995	16.2	16.0454	16.0915	16.1075	16.02078577	kg N/d	16.0581968	0.316005
X_ND =	0.4268931	0.426	0.42187	0.4235	0.422427	0.419323933	kg N/d	0.423335672	0.007569167
S_ALK =	n/a	91.8	92.716	92.8861	92.7032	n/a	kmol HCO ₃ /d	92.526325	1.0861
TSS =	315.18291	316.11	315.4412	315.664	315.592	314.6236619	kg N/d	315.4356287	1.4863381
N_TKN =	110.19893	108.68	109.5924	110.5108	111.201	109.0086625	kg N/d	109.8652988	2.521
N_tot =	327.95449	340.24	327.8216	327.5344	333.278	325.0024833	kg N/d	330.3051622	15.2375167
COD_tot =	983.47641	984.64	984.5272	985.0413	985.502	983.27589	kg COD/d	984.4104667	2.22611
BOD5_tot =	66.053475	66.31	66.1977	66.2775	66.227	65.97780085	kg/d	66.17391264	0.33219915

Other quality variables

	GPS-X	FORTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	Average	max-min
I.Q.-index =	43758.11	43800	43758.1149	43762.6545	43758.11	43758.11618	kg poll.units/d	43765.85093	41.89
E.Q.-index =	8305.04	8520	8304.2364	8299.6743	8414.7	8236.283952	kg poll.units/d	8346.655775	283.716048
P_sludge =	18260.0	18242	18239.7257	17933.16	18233.98	18279.49815	kg SS	18198.06064	346.33815
P_sludge per day =	2608.6	2606	2605.6751	2562.88	2604.85	2611.356878	kg SS/d	2599.893663	48.476878
P_sludge_eff =	2206.3	2198	2208.0883	2209.6557	2209.14	2202.365633	kg SS	2205.591606	11.6557
P_sludge_eff per day =	315.2	314	315.4412	315.6651	315.59	314.6236619	kg SS/d	315.0866603	1.6651
P_total_sludge =	20466.2	20440	20447.8141	20142.8157	20443.12	20481.86378	kg SS	20403.6356	339.04808
P_total_sludge per day =	2923.7	2920	2921.1163	2878.5451	2920.45	2925.98054	kg SS/d	2914.965323	47.43544
Aeration energy =	7284	7309	7286.0561	7291.71	7298.36	7276.881102	kWh/d	7291.0012	32.118898
Pumping energy =	1818	1498	1727.3132	1808.825	1645.26	1795.618912	kWh/d	1715.502852	320
The max effluent N_tot level (18 g N/m3) was violated during:	0.8855	1.64	1.1042	1.0104	1.3021	0.9555	d	1.149616667	0.7545
i.e.:	12.65	23.4	15.7738	14.45	18.6	13.65	% of the time	16.42063333	10.75
The limit was violated at:	6	8	7	6	8	6	occasions	6.833333333	2
The max effluent S_NH level (4 g N/m3) was violated during:	1.925	1.86	1.875	1.8675	1.9062	1.8585	d	1.882033333	0.0665
i.e.:	27.5	26.5	26.7857	26.67	27.23	26.55	% of the time	26.87261667	1
The limit was violated at:	7	7	7	7	7	7	occasions	7	0
The max effluent TSS level (30 g SS/m3) was violated during:	0.0000	0.0209	0.020833	0.01041	0.0208	0.0105	d	0.013907167	0.0209
i.e.:	0.0000	0.299	0.29762	0.149	0.3	0.15	% of the time	0.19927	0.3
The limit was violated at:	0	2	2	1	2	1	occasions	1.333333333	2

Controller Performance	GPS-X	FORTTRAN	SIMULINK_1	SIMULINK_2	SIMBA	WEST	unit	average	max-min
<u>Nitrate controller for second anoxic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Gain (K) =	7500	5040	15000	24027	10000	10000	m3/d/(g N/m3)	11927.83333	18987
Integral time constant (Ti) =	0.0125	0.007	0.05	0.003	0.08	0.01	d	0.027083333	0.077
Anti-windup time constant (Tt) =	not used	not used	0.03	not used	not used	not used	d	0.03	0
<u>Controlled variable, SNO2</u>									
Setpoint =	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	g N/m3	1.0000	0.0000
Integral of absolute error (IAE) =	0.1851641	4.21	1.761	2.3134	2.57322	1.027497715	(g N/m3)*d	2.011713636	4.0248359
Integral of square error (ISE) =	0.0662959	3.84	0.83314	2.344	1.61778	0.293552484	(g N/m3)**2*d	1.499128064	3.7737041
Max abs deviation from setpoint (max e) =	0.8827	2.09	1.068	2.6535	0.9	0.70860989	g N/m3	1.383801648	1.94489011
Standard deviation of error (std e) =	0.1790472	0.435	0.34494	0.562	0.480308	0.204845748	g N/m3	0.367690158	0.3829528
Variance of error (var e) =	0.0320579	0.189	0.11899	0.3159	0.230695	0.204845748	(g N/m3)**2	0.181914775	0.2838421
<u>Manipulated variable (MV), Qintrec</u>									
Max abs deviation of MV (max-min) =	49531	39120	73298.4899	n/a	57782.9	92232	m3/d	62392.87798	53112
Max abs dev of MV in one sample (delta) =	10677	12000	8139.0546	n/a	5861.37	9382.8445	m3/d	9212.05382	6138.63
Standard deviation of MV (std delta) =	1622.53	290	1683.6845	n/a	1768.08	1811.847205	m3/d	1435.228341	1521.847205
Variance of MV (var delta)=	2632603.5	84100	2834793	n/a	3126120	3282790.294	(m3/d)**2	2392081.359	3198690.294
<u>Oxygen controller for third aerobic reactor</u>									
Controller type	velocity PI	disc PI with aw	cont PI with aw	disc PI with aw	cont PI	PI			
Gain (K) =	20.8	16.8	500	125.8	100	5000	1/d/(g (-COD)/m3)	960.5666667	4983.2
Integral time constant (Ti) =	0.002	0.0025	0.001	0.0023	0.01	0.05	d	0.0113	0.049
Anti-windup time constant (Tt) =	not used	not used	0.0002	not used	not used	not used	d	0.0002	0
<u>Controlled variable, SO5</u>									
Setpoint =	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	g (-COD)/m3	2.0000	0.0000
Integral of absolute error (IAE) =	0.0451658	0.454	0.024638	0.01682	0.320457	0.060102363	(g (-COD)/m3)*d	0.153530527	0.43718
Integral of square error (ISE) =	0.0049911	0.065	0.003239	0.001355	0.0336601	0.005850015	(g (-COD)/m3)**2*d	0.019015869	0.063645
Max abs deviation from setpoint (max e) =	0.3408	0.411	0.22993	0.2616	0.259643	0.2252782	g (-COD)/m3	0.288041867	0.1857218
Standard deviation of error (std e) =	0.0543653	0.713	0.021358	0.0139	0.0693439	0.028923226	g (-COD)/m3	0.150148404	0.6991
Variance of error (var e) =	0.0029556	0.508	0.00045614	1.934e-4	0.00480858	0.000836553	(g (-COD)/m3)**2	0.086208379	0.5078066
<u>Manipulated variable (MV), K1a5</u>									
Max abs deviation of MV (max-min) =	186.737	240	193.166	n/a	193.19	193.373209	1/d	201.2932418	53.263
Max abs dev of MV in one sample (delta) =	36.229	12	36.7754	n/a	29.7863	39.85488	1/d	30.929116	27.85488
Standard deviation of MV =	5.9096592	0.396	5.5011	n/a	6.69429	5.684237013	1/d	4.837057243	6.29829
Variance of MV =	34.924072	0.157	30.2624	n/a	44.8135	32.31055042	(1/d)**2	28.49350448	44.6565